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Kawasaki et al.

(54) VACUUM EVACUATION APPARATUS

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USPC **417/201**

(57) **ABSTRACT**

The present invention relates to a vacuum evacuation apparatus which can be mounted in a posture that can freely be selected a vacuum evacuation apparatus for evacuating a container from an atmospheric pressure to a high vacuum or less includes a first vacuum pump for evacuating the container to a high vacuum or less, and a second vacuum pump for evacuating the container from an atmospheric pressure to a medium or low vacuum the first vacuum pump and the second vacuum pump are integrally connected to each other into an integral unit.

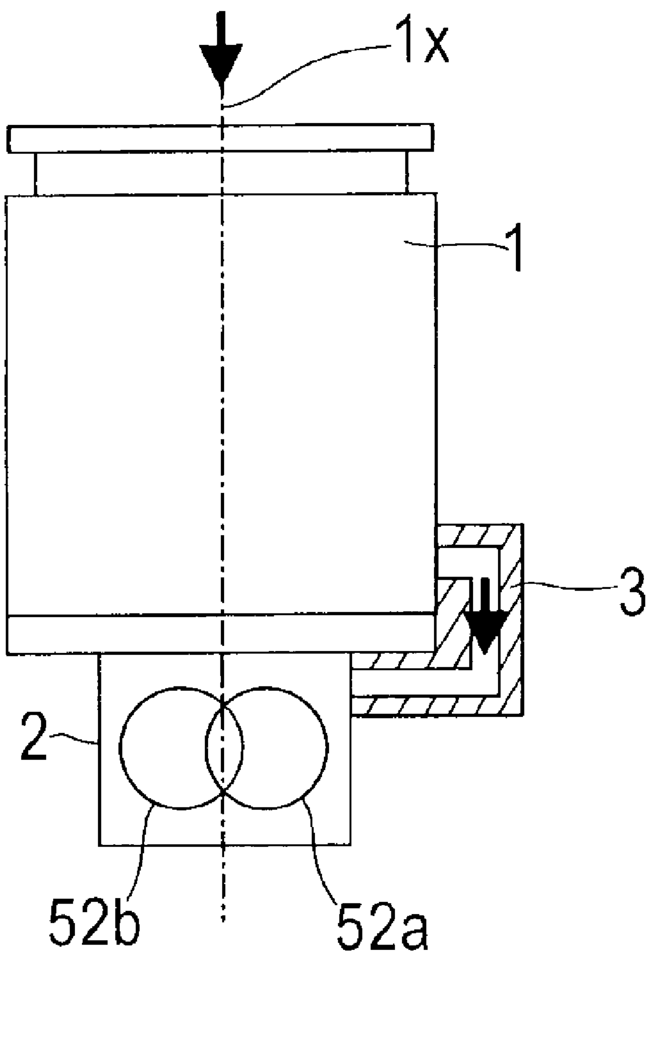


FIG. 1B

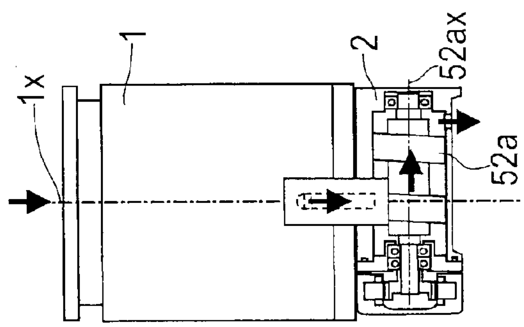


FIG. 1A

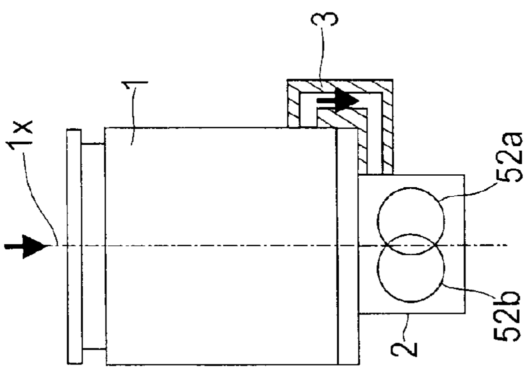


FIG. 1C

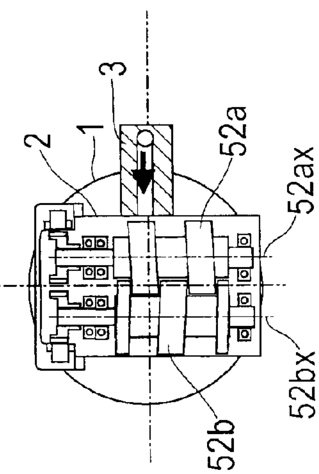
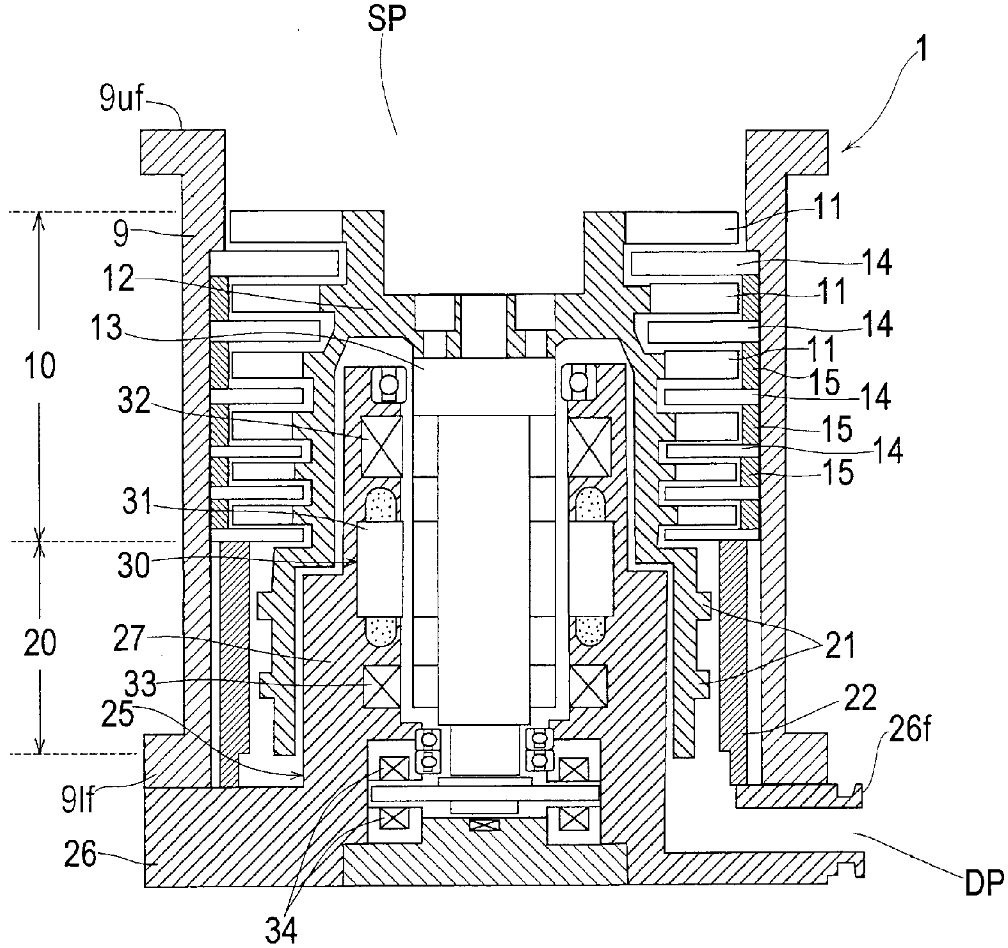


FIG. 2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15
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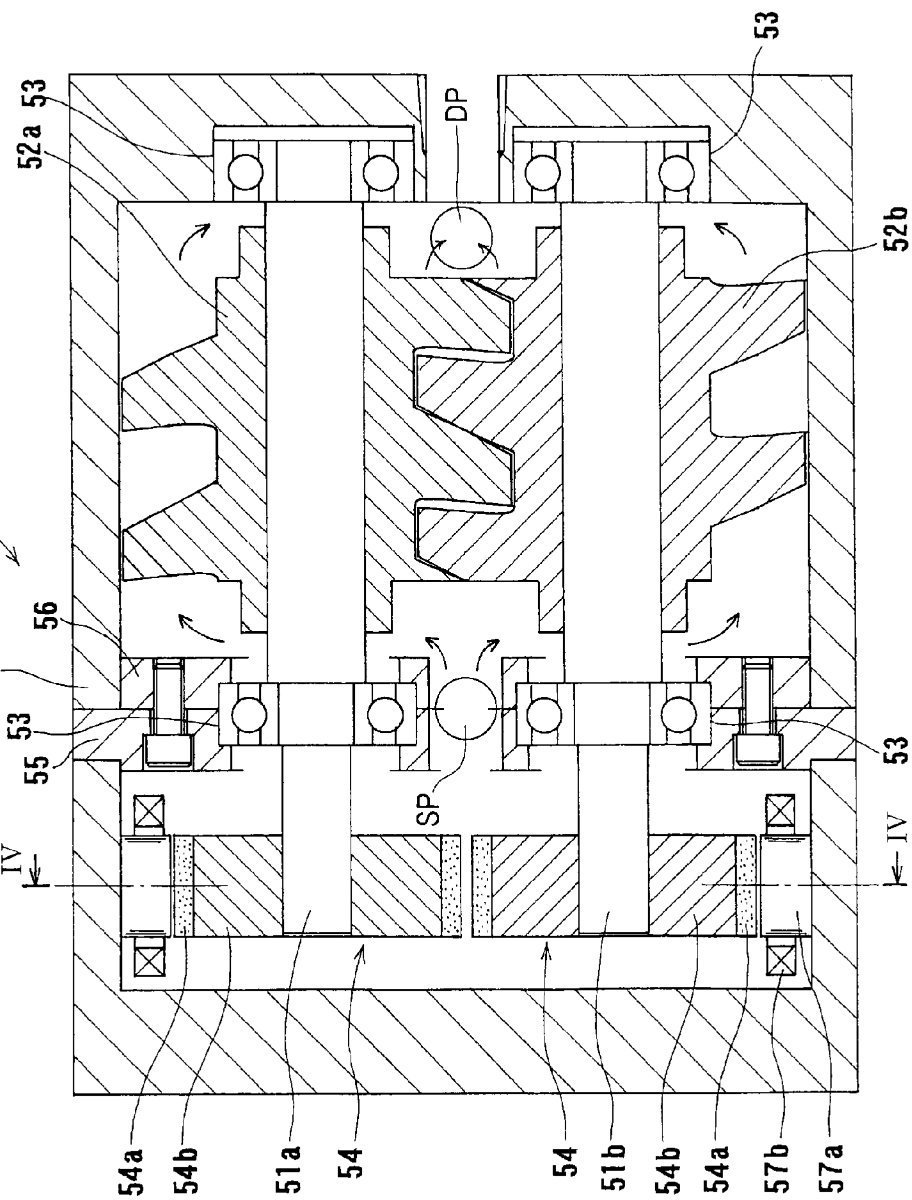
22
26f
DP


2
52a
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DP
53
52b
56
50
53
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SP
53
IV
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54b
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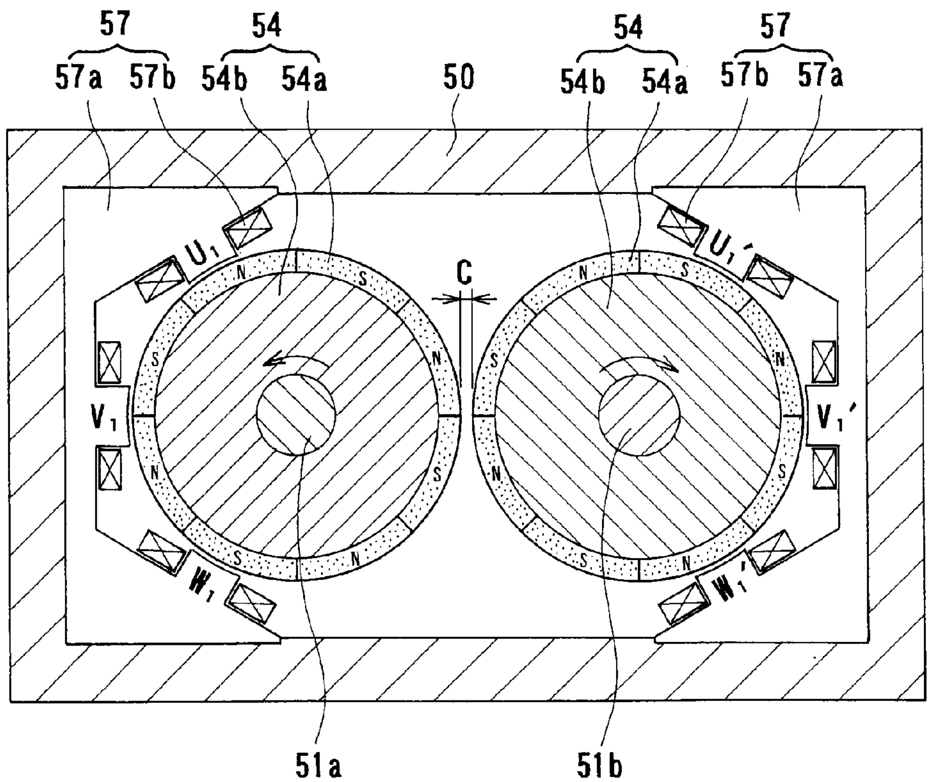
57a

FIG. 3

FIG. 4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54
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57a
57b
54b
54a
50
54b
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57b
57a
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U1'
V1
V1'
W1
W1'
N
S
51a
51b

FIG. 5B

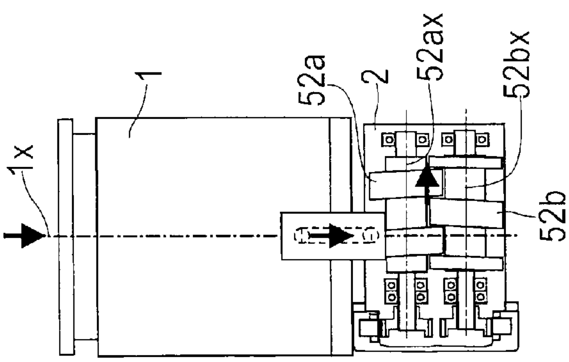


FIG. 5A

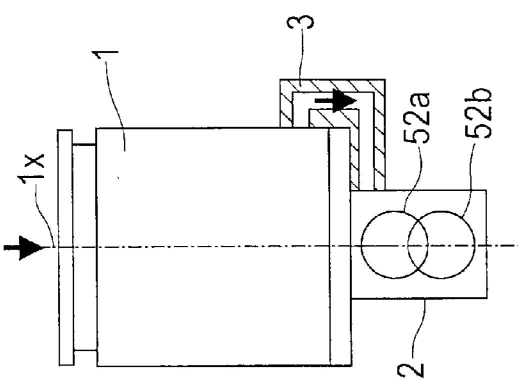


FIG. 5C

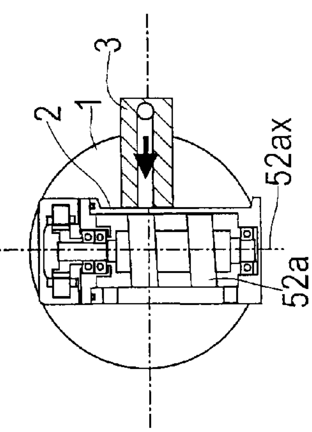


FIG. 6A

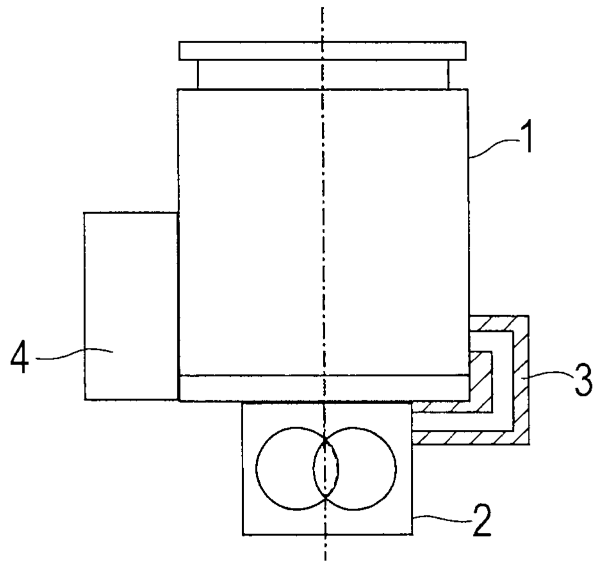


FIG. 6B

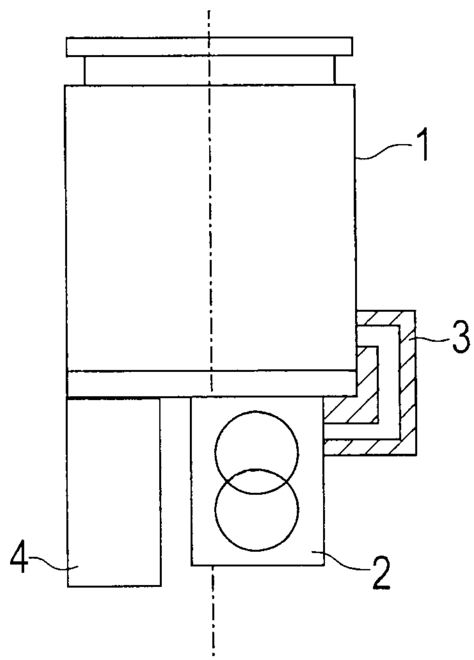


FIG. 7A

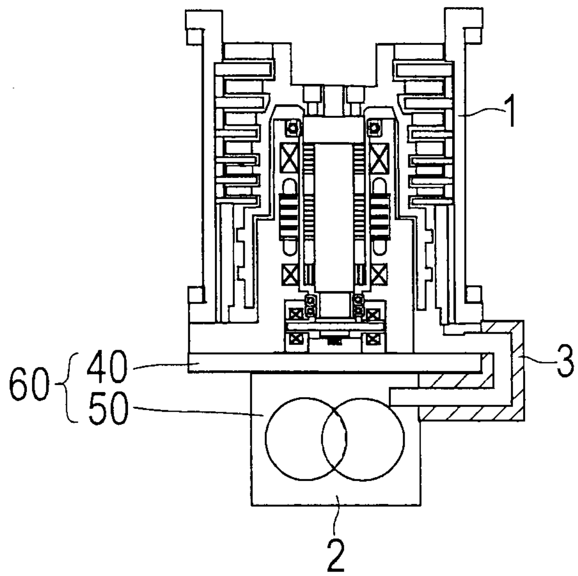


FIG. 7B

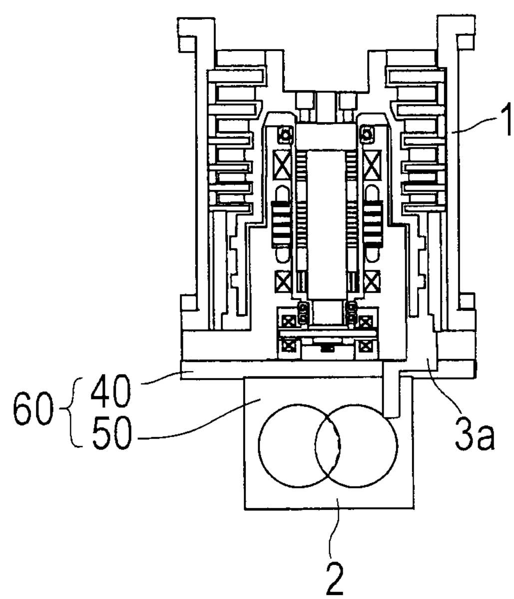


FIG. 8

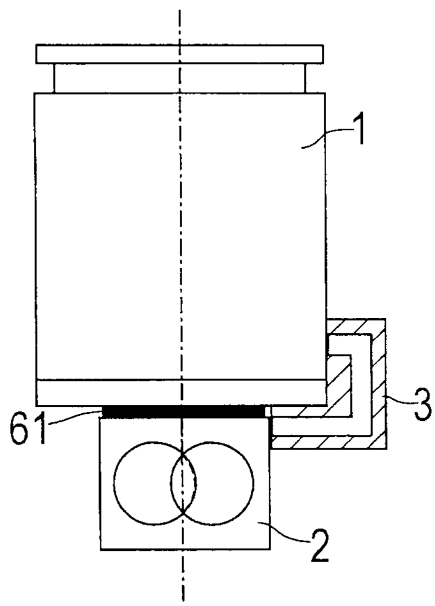


FIG. 9

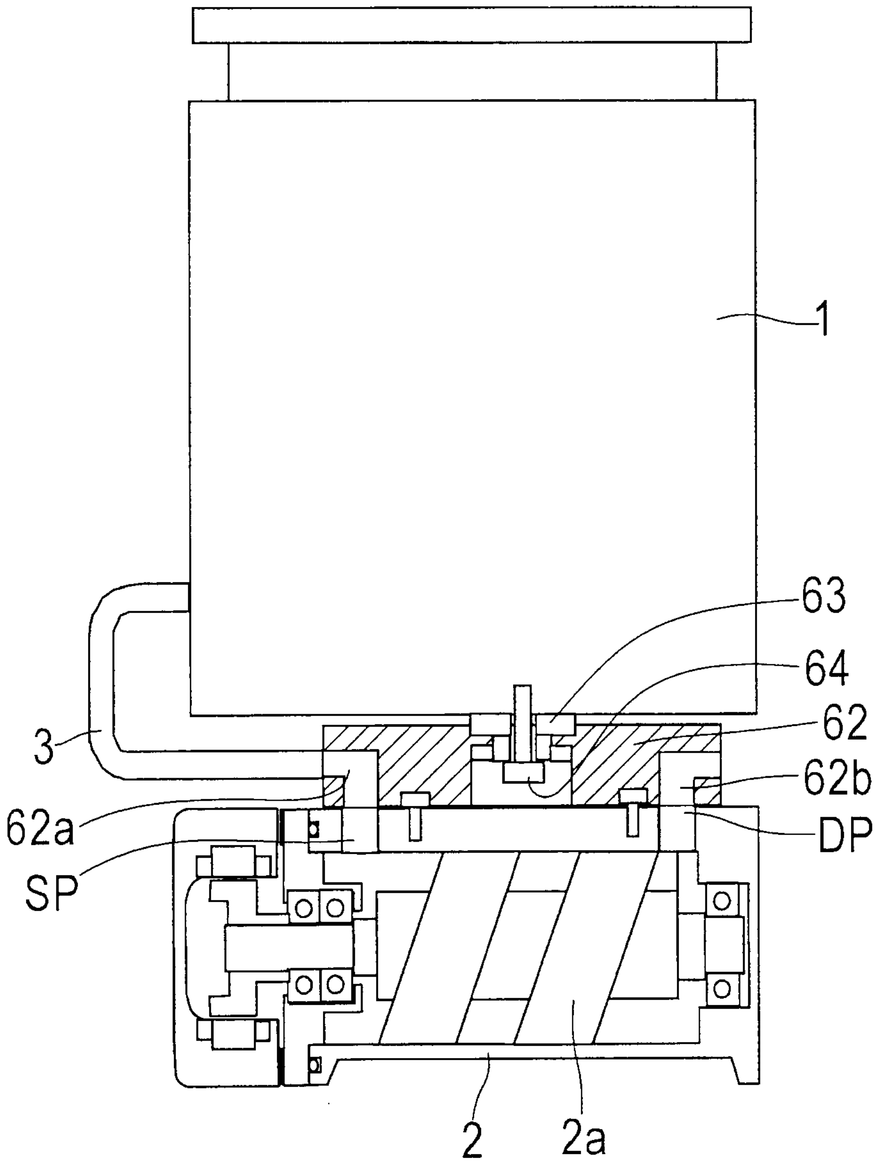


FIG. 10A

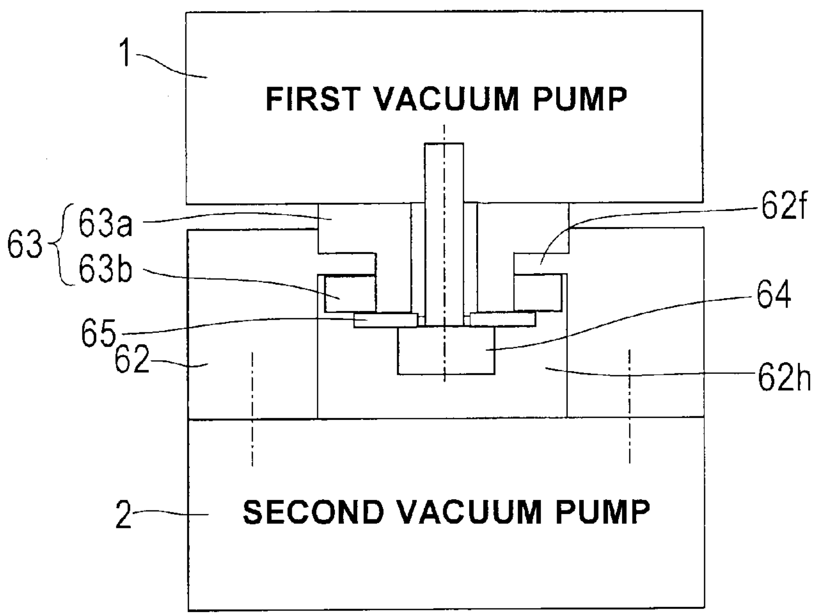


FIG. 10B

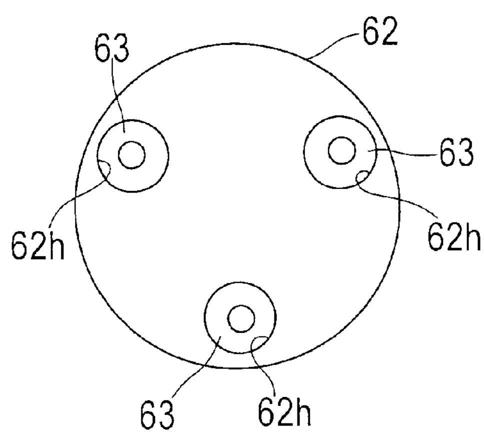


FIG. 10C

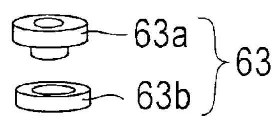


FIG. 11B

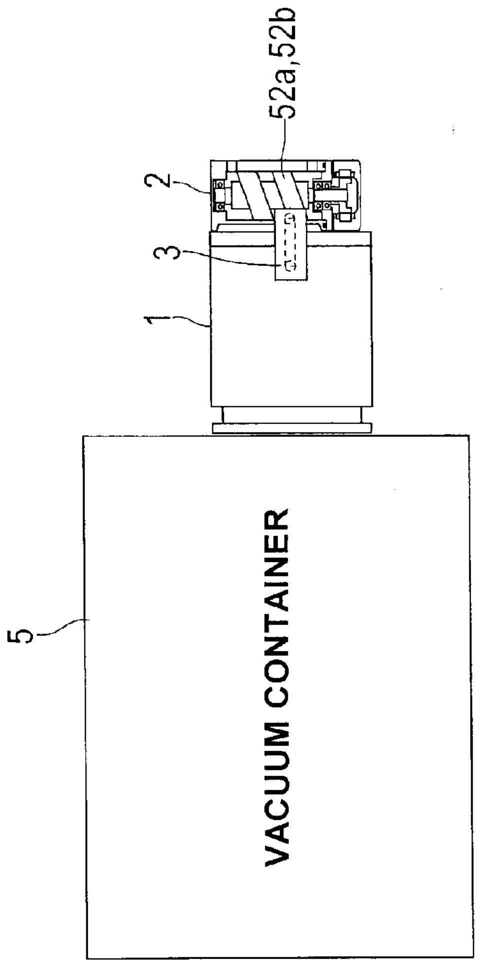


FIG. 11A

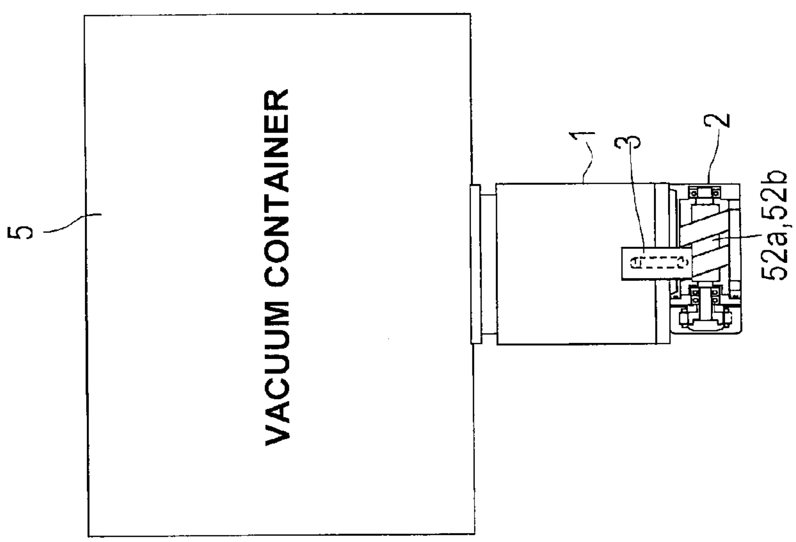


FIG. 12A

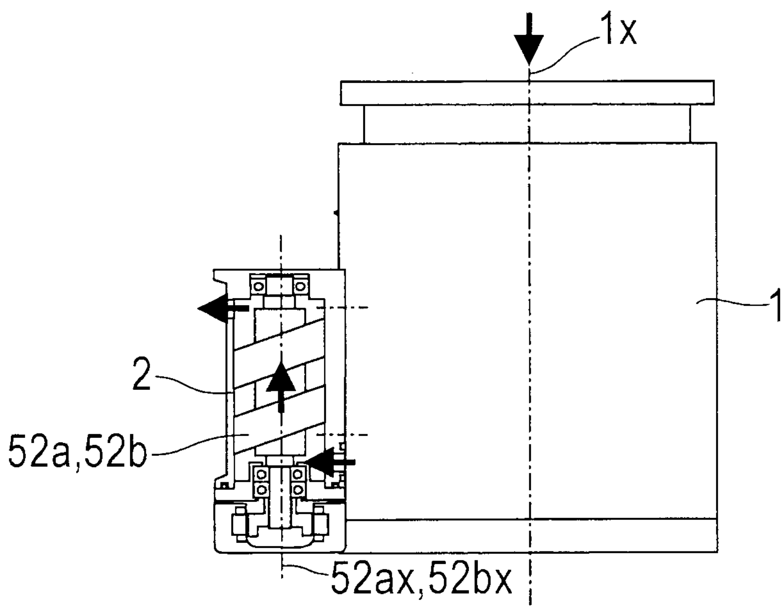


FIG. 12B

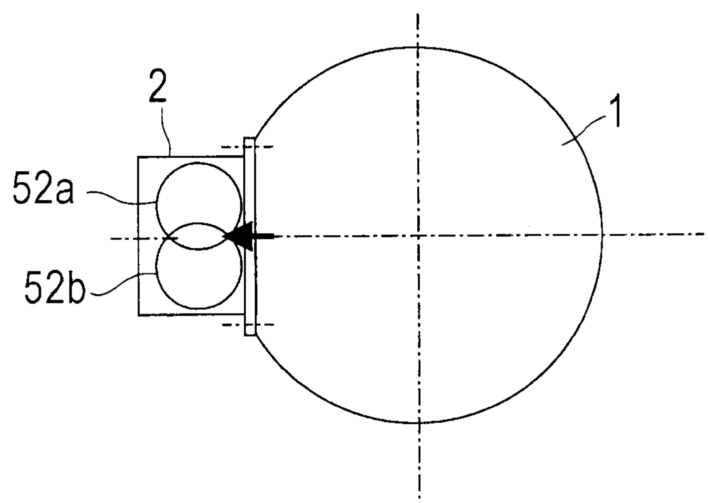


FIG. 13C

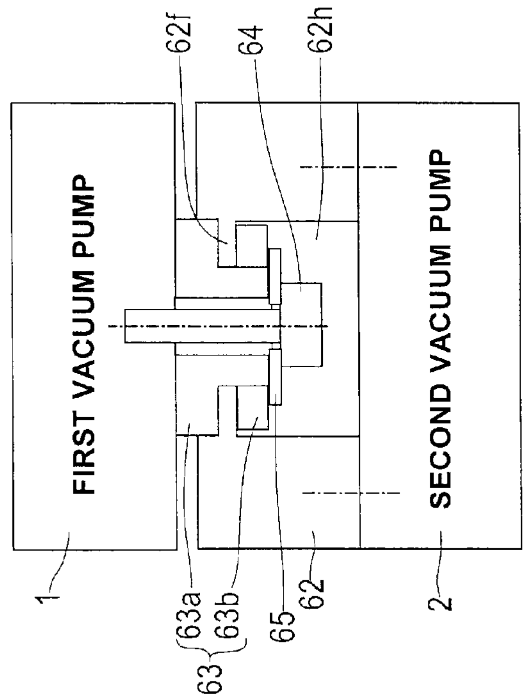


FIG. 13A

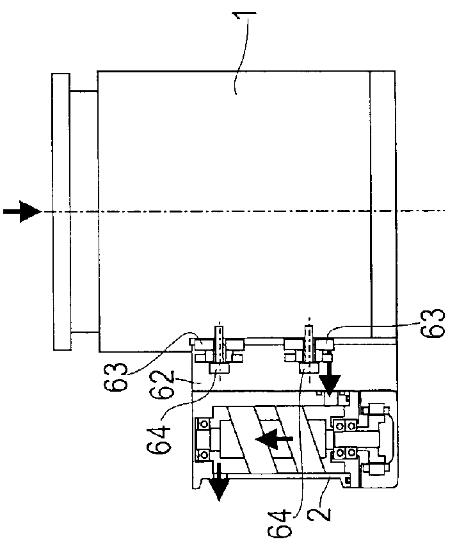


FIG. 13B

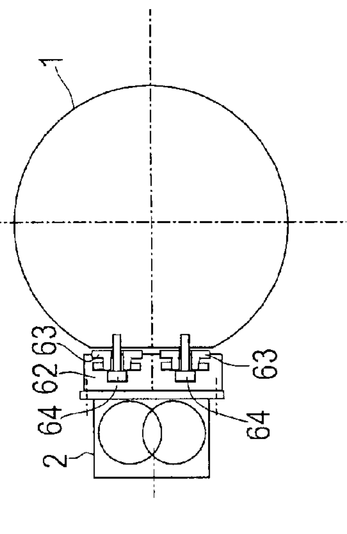


FIG. 14

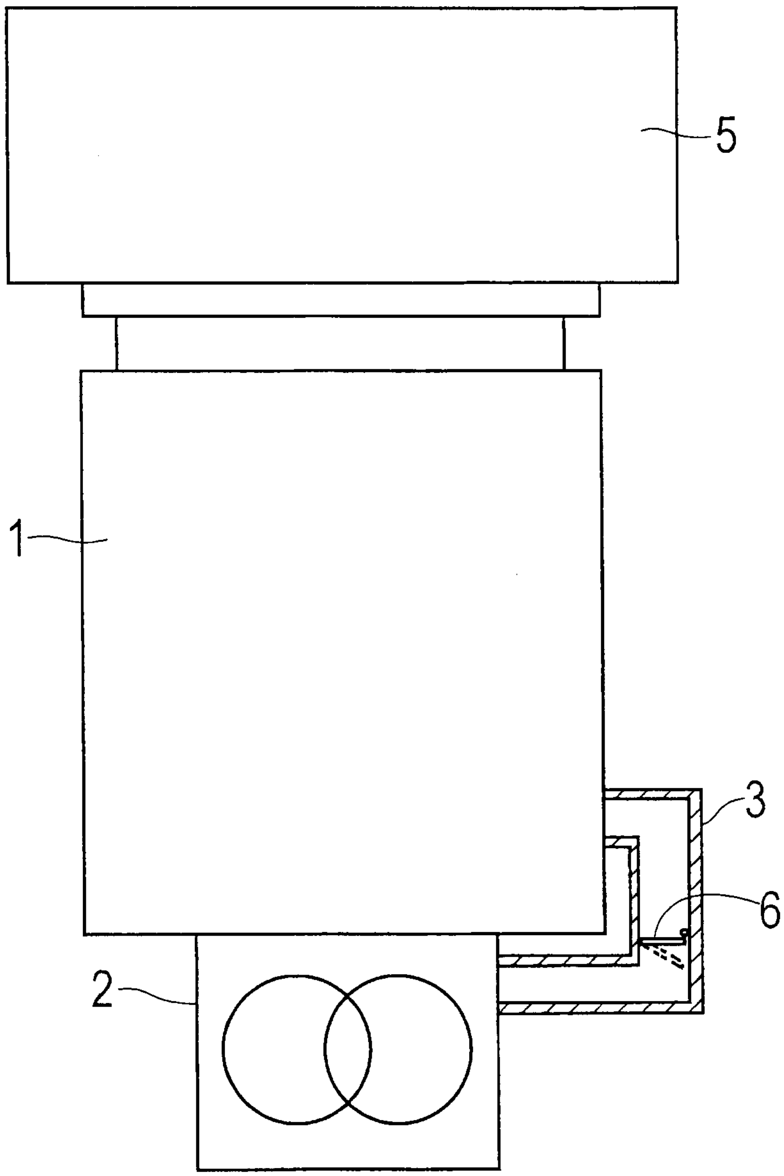


FIG. 15

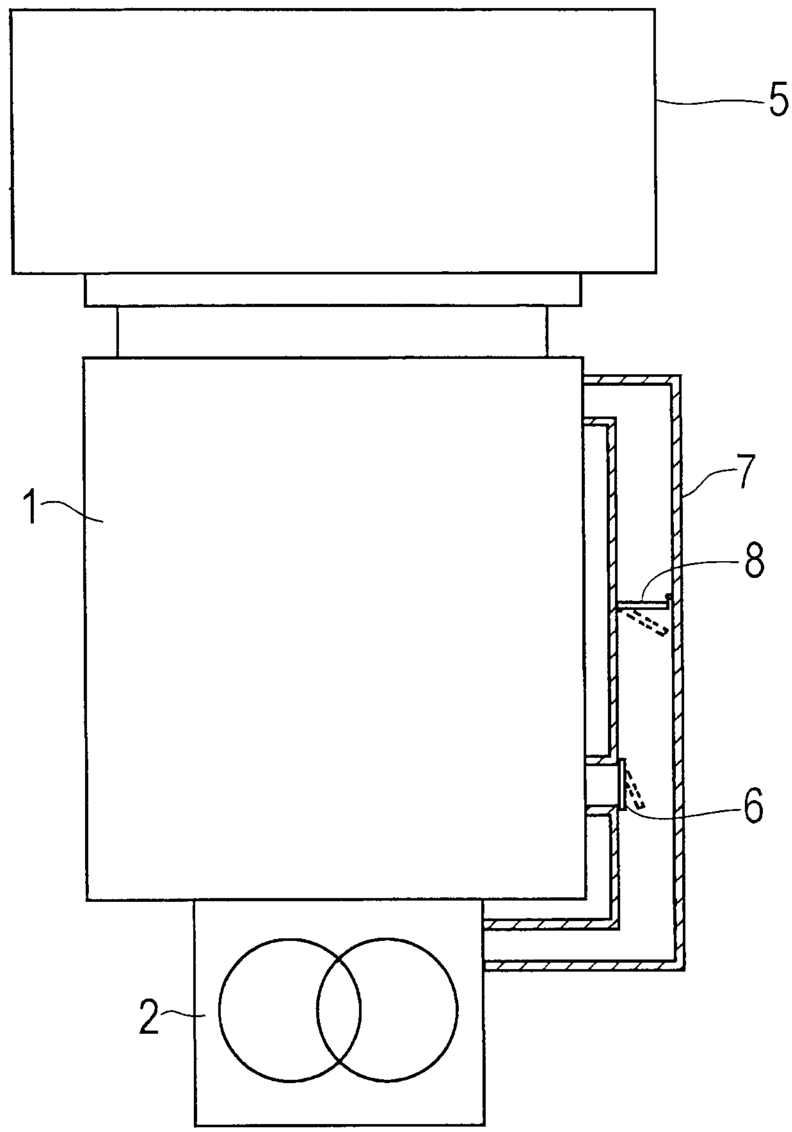


FIG. 16

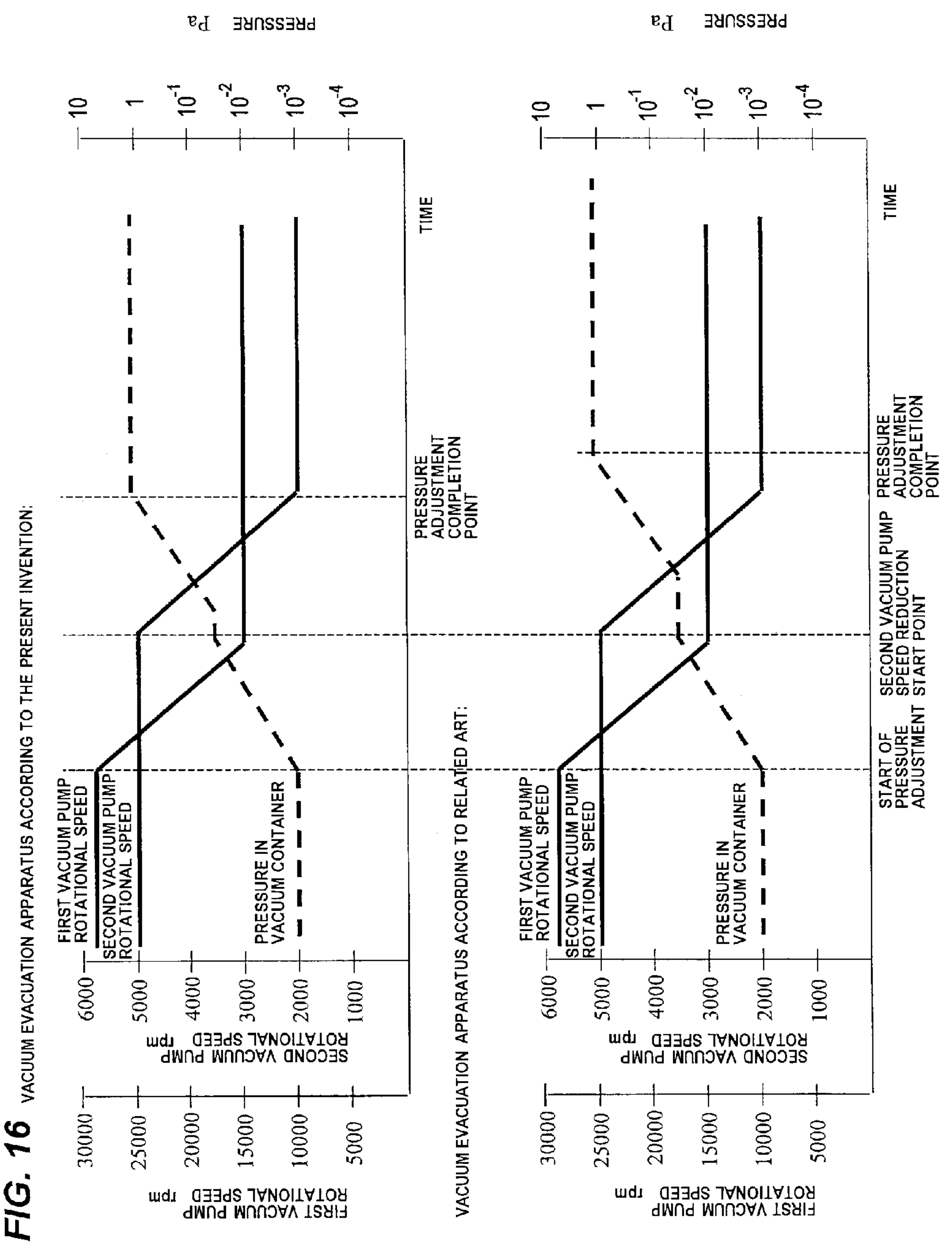

VACUUM EVACUATION APPARATUS ACCORDING TO THE PRESENT INVENTION:
FIRST VACUUM PUMP ROTATIONAL SPEED rpm
30000
25000
20000
15000
10000
5000
SECOND VACUUM PUMP ROTATIONAL SPEED rpm
6000
5000
4000
3000
2000
1000
FIRST VACUUM PUMP ROTATIONAL SPEED
SECOND VACUUM PUMP ROTATIONAL SPEED
PRESSURE IN VACUUM CONTAINER
PRESSURE ADJUSTMENT COMPLETION POINT
TIME
PRESSURE Pa
10
1
10-1
10-2
10-3
10-4
VACUUM EVACUATION APPARATUS ACCORDING TO RELATED ART:
FIRST VACUUM PUMP ROTATIONAL SPEED rpm
SECOND VACUUM PUMP ROTATIONAL SPEED rpm
FIRST VACUUM PUMP ROTATIONAL SPEED
SECOND VACUUM PUMP ROTATIONAL SPEED
PRESSURE IN VACUUM CONTAINER
START OF PRESSURE ADJUSTMENT
SECOND VACUUM PUMP SPEED REDUCTION START POINT
PRESSURE ADJUSTMENT COMPLETION POINT
TIME
PRESSURE Pa

FIG. 17

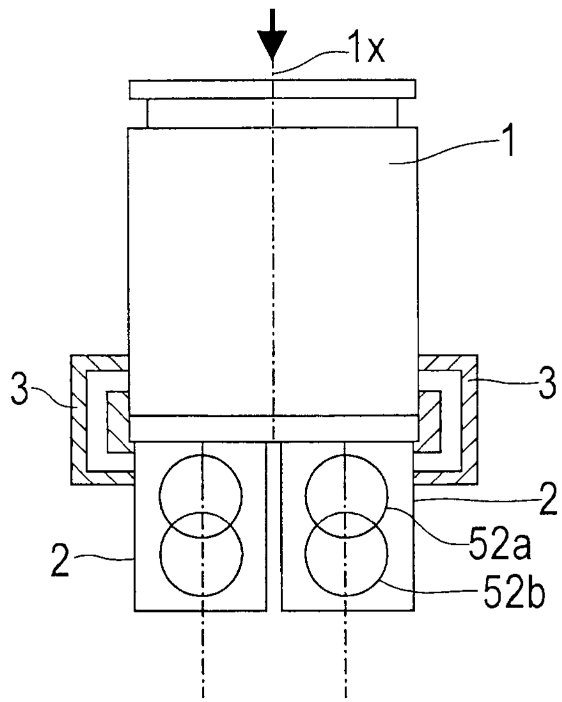


FIG. 18

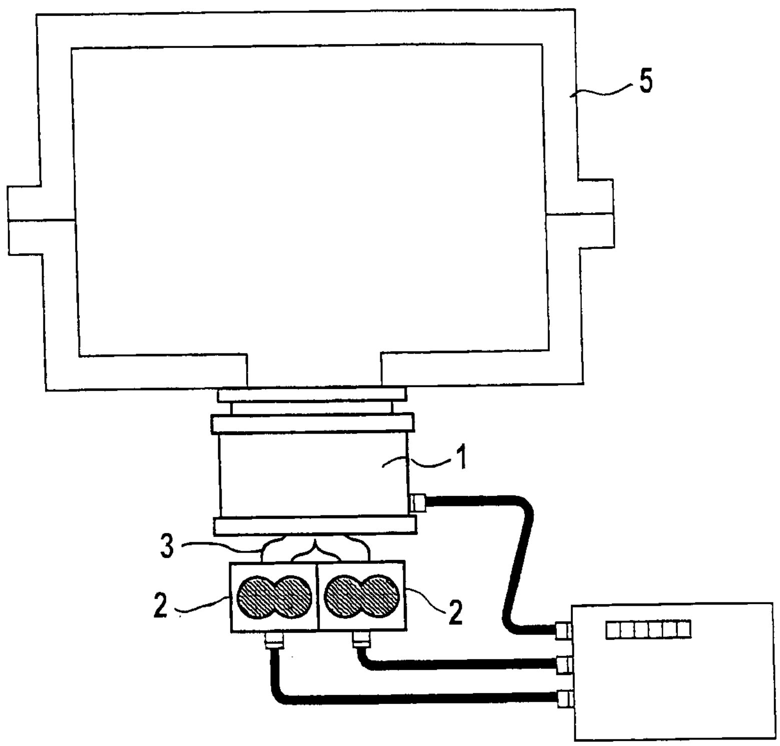


FIG. 19

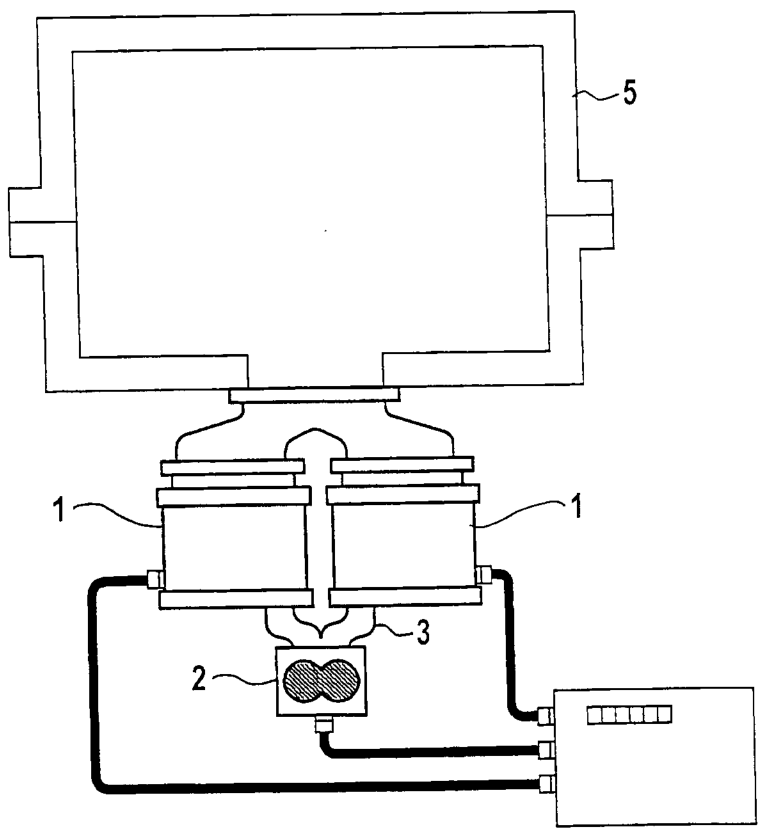


FIG. 20

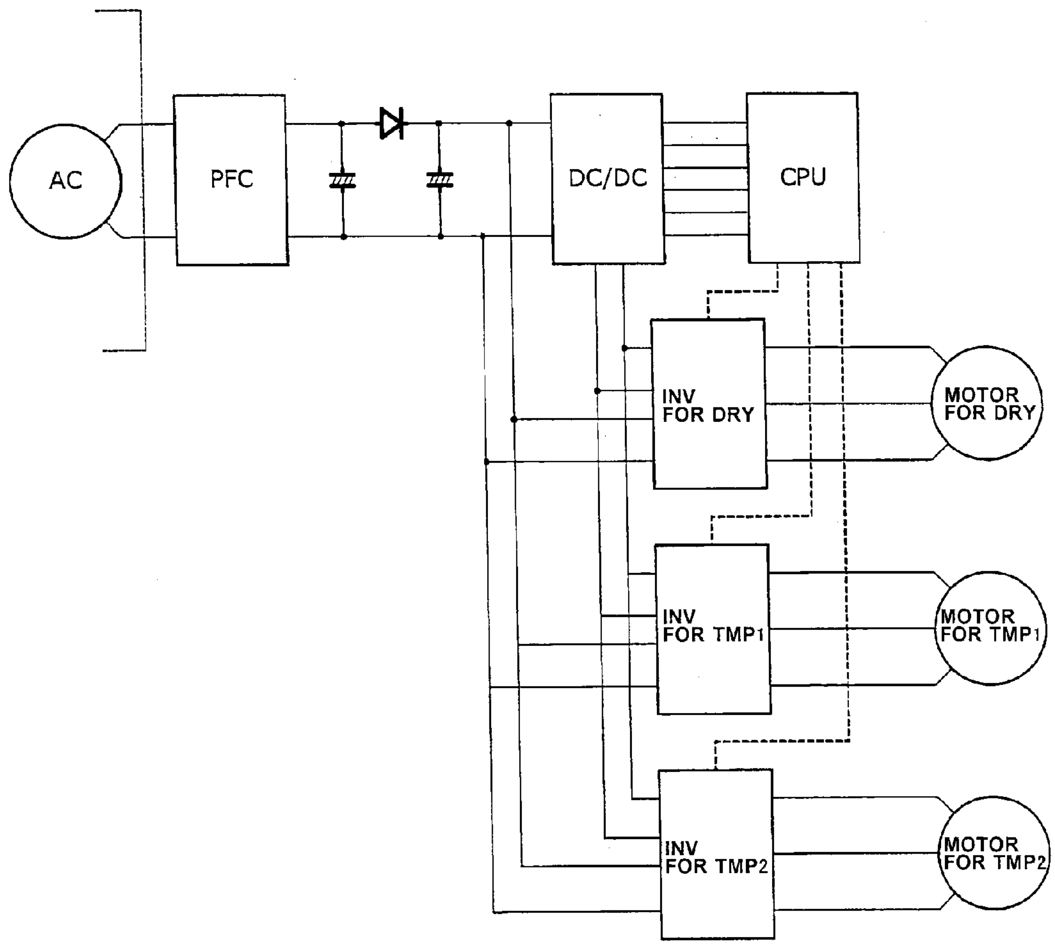

AC
PFC
DC/DC
CPU
INV
FOR DRY
MOTOR
FOR DRY
INV
FOR TMP1
MOTOR
FOR TMP1
INV
FOR TMP2
MOTOR
FOR TMP2

FIG. 21

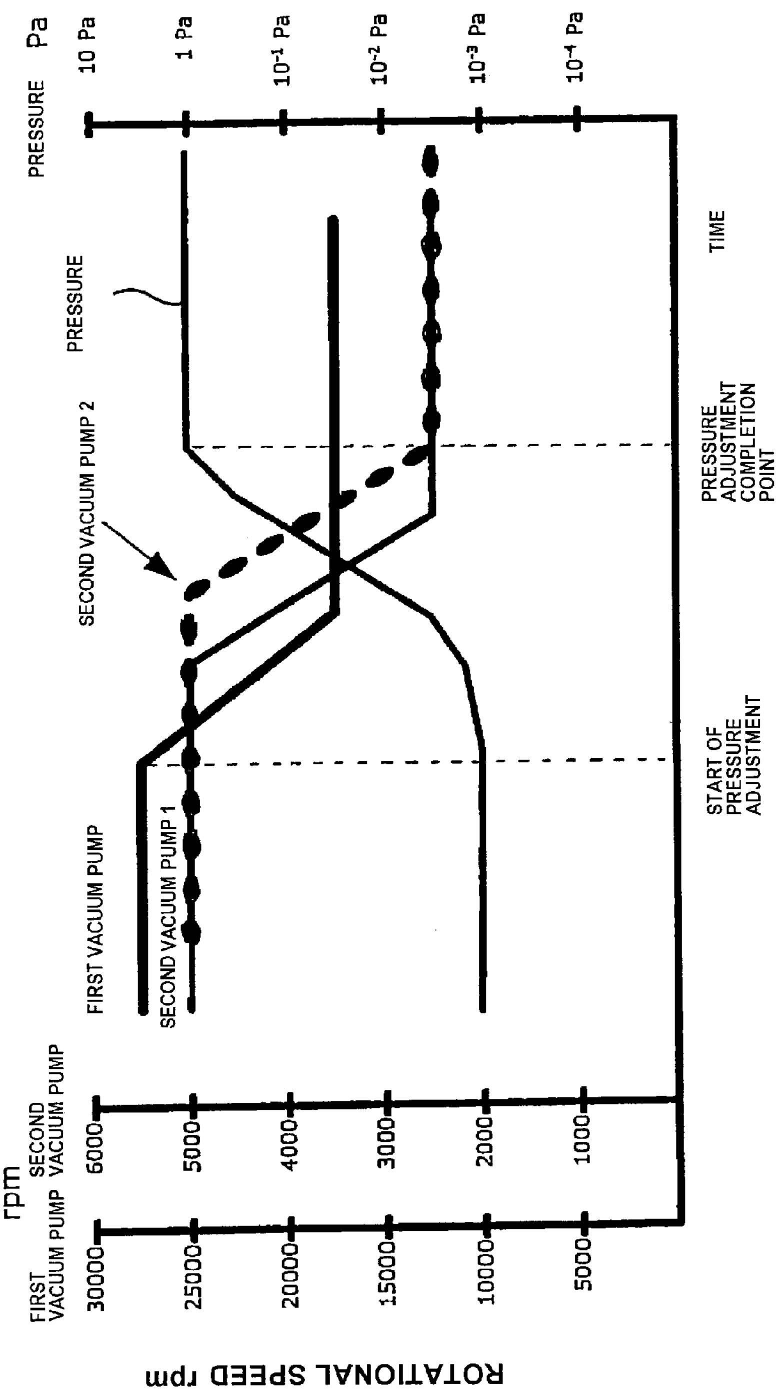

PRESSURE
Pa
10 Pa
1 Pa
10^{-1} Pa
10^{-2} Pa
10^{-3} Pa
10^{-4} Pa
PRESSURE
SECOND VACUUM PUMP 2
FIRST VACUUM PUMP
SECOND VACUUM PUMP 1
TIME
PRESSURE ADJUSTMENT COMPLETION POINT
START OF PRESSURE ADJUSTMENT
rpm
FIRST VACUUM PUMP
SECOND VACUUM PUMP
30000
25000
20000
15000
10000
5000
6000
5000
4000
3000
2000
1000
ROTATIONAL SPEED rpm

FIG. 22

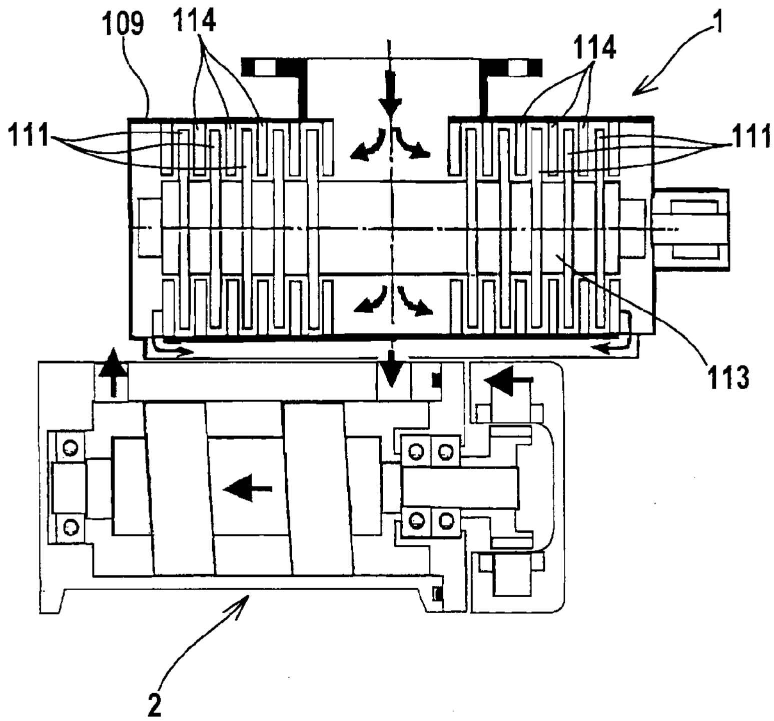


FIG. 23

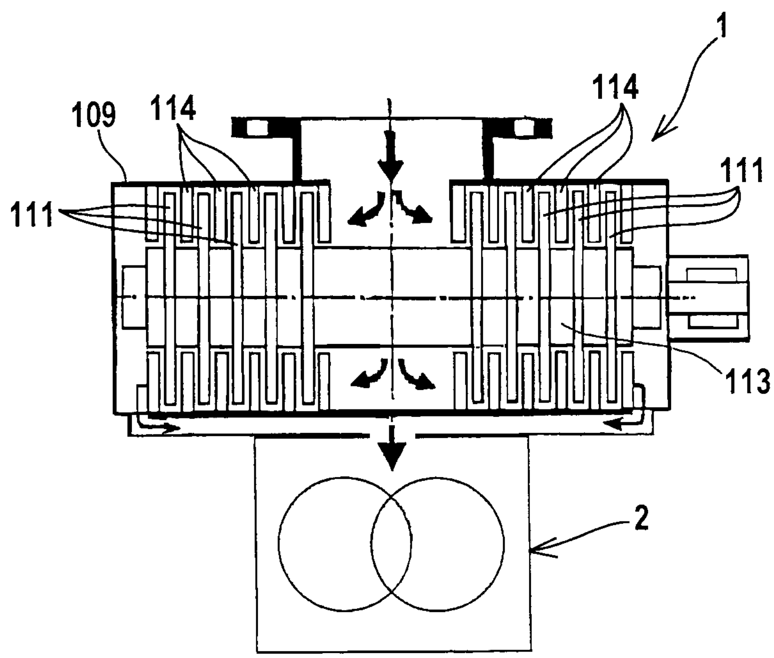


FIG. 24

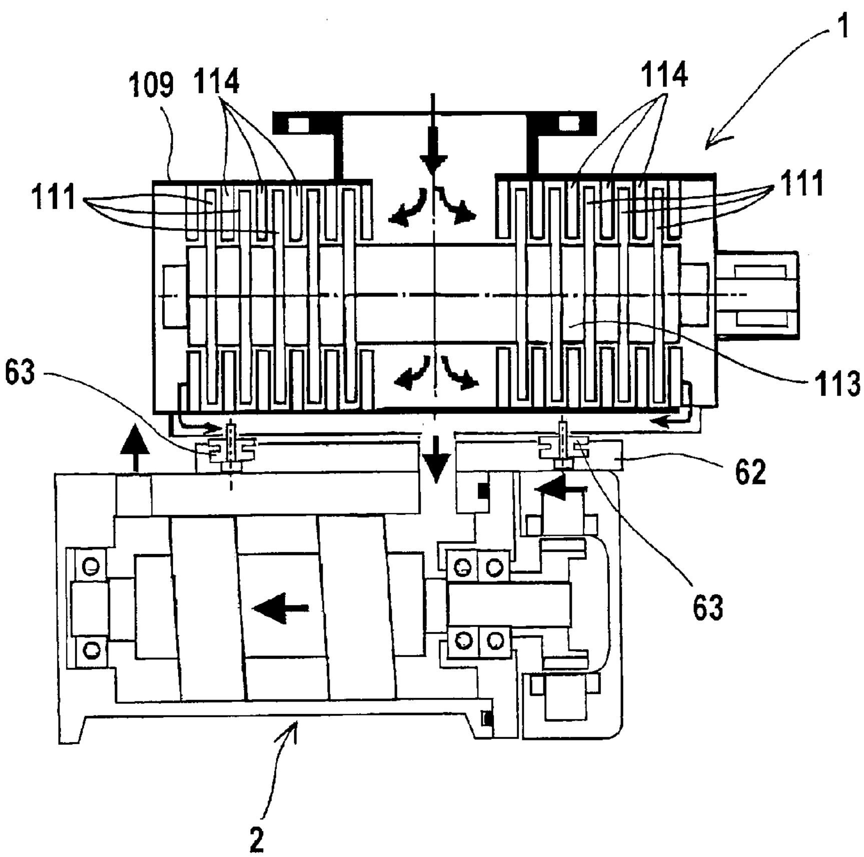
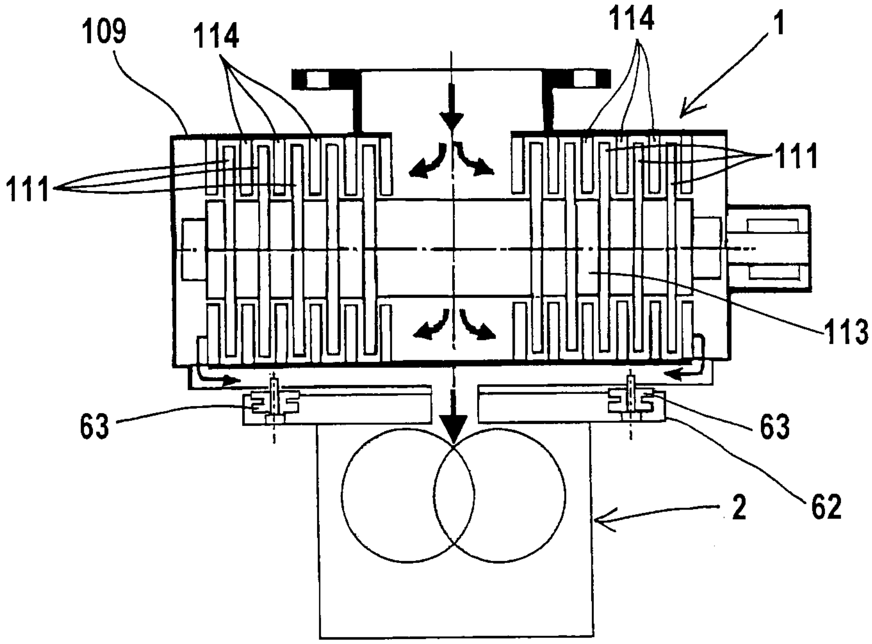


FIG. 25



VACUUM EVACUATION APPARATUS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This document claims priority to Japanese Patent Application No. 2012-080559, filed on Mar. 30, 2012, the entire contents of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a vacuum evacuation apparatus which is capable of compressing a gas from an ultrahigh vacuum to an atmospheric pressure, and more particularly to a vacuum evacuation apparatus which can be mounted in a posture that can freely be selected.

[0004] 2. Description of the Related Art

[0005] Conventionally, in a semiconductor fabrication apparatus or the like, a combination of a turbomolecular pump and a dry vacuum pump has been used for evacuating a gas in a chamber to create a clean ultrahigh vacuum in the chamber. The turbomolecular pump serves to evacuate the chamber to an ultrahigh vacuum range, and the dry vacuum pump serves to evacuate the chamber in a range from an atmospheric pressure to a medium vacuum. The turbomolecular pump and the dry vacuum pump are driven by respective power supplies and individually controlled in operation.

[0006] The turbomolecular pump and the dry vacuum pump are thus used as vacuum pumps in different vacuum ranges. When a turbomolecular pump is used, it is necessary to initially use a dry vacuum pump to evacuate the chamber to a rough vacuum range, i.e., a medium vacuum range, in which the turbomolecular pump can be used to further evacuate the chamber. Therefore, it is essential to install the dry vacuum pump as a roughing vacuum pump in order to use the turbomolecular pump.

[0007] As one advanced concept of the turbomolecular pump, an atmospheric pressure-evacuation-type turbomolecular pump which can evacuate the chamber from an atmospheric pressure range has been proposed. However, such turbomolecular pump has not yet been fully developed into a practically feasible product on account of various problems about requirements for mechanical strength of a rotor that needs to rotate at ultrahigh speeds, radiation of the heat of a compressed gas produced at the time of evacuation from an atmospheric pressure range to an ultrahigh vacuum range, the structure of a motor that needs large torques and ultrahigh-speed rotation, and a driving power supply source.

[0008] Heretofore, in order to create an ultrahigh vacuum, it has been the general practice to use a positive displacement vacuum pump such as an oil rotary pump, a roots dry pump, or a screw dry pump which is capable of creating a vacuum in the range from several Torr to 10^{-2} Torr, and a kinetic vacuum pump (turbomolecular pump) or an entrapment vacuum pump (cryopump), disposed upstream of the positive displacement vacuum pump, for creating an ultrahigh vacuum (see Japanese laid-open patent publication Nos. 11-40094, 2000-131476 and 2002-147386). Specifically, two vacuum pumps are connected in series with each other for creating an ultrahigh vacuum. The positive displacement vacuum pump is mostly installed or placed on an installation surface such as a ground surface, and the kinetic vacuum pump or the entrapment vacuum pump is installed in the vicinity of a vacuum container (vacuum chamber) to be evaluated to an ultrahigh vacuum or is directly connected to the vacuum container (vacuum chamber). The vacuum pump that is installed in the vicinity of the vacuum container or is directly connected to the vacuum container is referred to as a first vacuum pump, and the vacuum pump that is installed or placed on the installation surface such as a ground surface is referred to as a second vacuum pump. The second vacuum pump is not installed in the vicinity of the vacuum container because of its vibrations or noise or because it uses oil, but is installed at a remote location, e.g., at a downstairs installation site. Therefore, the second vacuum pump is connected to the first vacuum pump by a long vacuum piping. As a result, the second vacuum pump needs to have evacuation capacity in view of the conductance of the vacuum piping, i.e., to have larger capacity as required by the conductance of the vacuum piping.

[0009] Vacuum pumps having a single rotational shaft which can compress a gas from an ultrahigh vacuum to an atmospheric pressure are disclosed in the following documents:

[0010] 1) Japanese laid-open patent publication No. 60-204997:

[0011] The disclosed vacuum pump is a kinetic vacuum pump, which includes a helical screw pump section and a centrifugal pump section, for compressing a gas from an ultrahigh vacuum to an atmospheric pressure. Since turbine blades and centrifugal blades are mounted in series on one rotational shaft, the centrifugal blades which are located at an atmospheric pressure side have a poor evacuation efficiency in the atmospheric pressure range, and thus the vacuum pump requires large driving power.

[0012] 2) Japanese patent No. 2680156:

[0013] The disclosed vacuum pump is a kinetic vacuum pump, which includes a centrifugal compression pump stage and a circumferential flow compression pump stage, for compressing a gas from an ultrahigh vacuum to an atmospheric pressure. Since centrifugal blades and vortex flow blades are mounted in series on one rotational shaft, the vortex flow blades which are located at an atmospheric pressure side have a poor evacuation efficiency in the atmospheric pressure range, and thus the vacuum pump requires large driving power.

[0014] The problems of the related art in which a single vacuum pump can compress a gas from an ultrahigh vacuum to an atmospheric pressure are summarized as follows: The use of blades having different evacuation principles provided on the same rotational shaft causes a problem of limitations of evacuation performance, and the use of kinetic vacuum pump section having a poor evacuation efficiency in an atmospheric pressure range causes a problem of increased driving power.

SUMMARY OF THE INVENTION

[0015] As described above, in a vacuum evacuation apparatus having two vacuum pumps connected in series, i.e., a positive displacement vacuum pump and a kinetic vacuum pump which can compress a gas from an ultrahigh vacuum to an atmospheric pressure, because the positive displacement vacuum pump has a good evacuation efficiency in an atmospheric pressure range, a highly efficient evacuation system can be realized. However, the displacement vacuum pump cannot be installed in the vicinity of a vacuum container (vacuum chamber) because of its vibrations, heat generated when a gas is compressed to an atmospheric pressure, and the like.

[0016] Further, a single vacuum pump which is capable of compressing a gas from an ultrahigh vacuum to an atmospheric pressure has a problem of limitations of evacuation performance and a problem of increased driving power.

[0017] The present invention has been made in view of the above drawbacks. It is therefore an object of the present invention to provide a vacuum evacuation apparatus which is capable of compressing a gas from an ultrahigh vacuum to an atmospheric pressure, simplifying an evacuation system and reducing a driving power for higher efficiency, and can be installed in any desired directions in the vicinity of a vacuum container or directly on the vacuum container.

[0018] In order to achieve the above object, according to a first aspect of the present invention, there is provided a vacuum evacuation apparatus for evacuating a container from an atmospheric pressure to a high vacuum or less, comprising: a first vacuum pump for evacuating the container to a high vacuum or less; and a second vacuum pump for evacuating the container from an atmospheric pressure to a medium or low vacuum; wherein the first vacuum pump and the second vacuum pump are integrally connected to each other into an integral unit.

[0019] Here, the high vacuum means a pressure range from 0.1 to 10^{-5} Pa. The medium vacuum means a pressure range from 100 to 0.1 Pa. The low vacuum means a pressure range from a pressure lower than the atmospheric pressure to 100 Pa. Further, an ultrahigh vacuum means a pressure range from 10^{-5} to 10^{-8} Pa. An extrahigh vacuum means a pressure lower than 10^{-8} Pa. A vacuum that can be created on the earth is about 10^{-10} Pa at present.

[0020] According to the present invention, the first vacuum pump and the second vacuum pump are integrally connected to each other, and hence it is possible for the user to evacuate a gas in a container to an ultrahigh vacuum by a single pump system. Since the first vacuum pump for evacuating a gas in the container to a high vacuum or less and the second vacuum pump for evacuating the gas in the container from an atmospheric pressure to a medium or low vacuum are combined with each other, it is possible for the respective pumps to consume appropriate amounts of power respectively in the medium vacuum range and the ultrahigh vacuum range. Therefore, there is provided a pump system that does not essentially operate in a low evacuation efficiency state, i.e., a state where evacuation in the ultrahigh vacuum range is performed by a single pump comprising a positive vacuum pump or a state where evacuation in the atmospheric pressure range is performed by a single pump comprising a kinetic vacuum pump.

[0021] The expression "the first vacuum pump and the second vacuum pump are integrally connected to each other into an integral unit" means that the first vacuum pump and the second vacuum pump are coupled and integrated into a physically single pump unit. In this case, a controller for controlling the whole pumps in the vacuum evacuation apparatus may be mounted on the pump unit or may be installed in the vicinity of the pump unit. In the case where the first vacuum pump and the second vacuum pump are coupled and integrated, the first vacuum pump and the second vacuum pump may be directly coupled or a coupling member may be provided between the first vacuum pump and the second vacuum pump.

[0022] In a preferred aspect of the present invention, the first vacuum pump has a rotational shaft and the second vacuum pump has a rotational shaft, and the rotational shaft of the first vacuum pump and the rotational shaft of the second vacuum pump have respective axes which are perpendicular to each other.

[0023] When the first vacuum pump and the second vacuum pump are in operation, they produce vibrations in substantially the same directions, i.e., their vibrational energies are intensive in substantially the same directions. Specifically, the first vacuum pump and the second vacuum pump produce vibrations due to unbalanced rotating bodies in the radial directions of their rotational shafts. If the rotational shaft of the second vacuum pump and the rotational shafts of the first vacuum pump in the unitized vacuum evacuation apparatus according to the present invention are disposed parallel to each other, then it is possible for the second vacuum pump and the first vacuum pump to simultaneously produce rotary vibrations in the radial directions perpendicular to the axes of the rotational shafts, causing resonant vibrations and causing impairment of pump mechanical components. If such radial vibrations are generated, they tend to be added to each other and the added vibrations are transmitted as excessive vibrations to the vacuum container side. According to the present invention, the axes of the rotational shafts of the first vacuum pump and the axis of the rotational shaft of the second vacuum pump extend perpendicularly to each other, thereby minimizing radial vibrations generated by the rotational shaft of the first vacuum pump that is attached to the vacuum container.

[0024] In a preferred aspect of the present invention, the first vacuum pump has a rotational shaft and the second vacuum pump has a rotational shaft, and the rotational shaft of the first vacuum pump and the rotational shaft of the second vacuum pump are rotatably supported by one of self-lubricating bearings, bearings having a semi-solid lubricant or a solid lubricant therein, gas bearings, and magnetic bearings; and wherein the rotational shaft of the first vacuum pump and the rotational shaft of the second vacuum pump are rotatable regardless of directions in which the first vacuum pump and the vacuum pump are installed.

[0025] According to the present invention, the bearings that support the rotational shaft of the first vacuum pump and the bearings that support the rotational shafts of the second vacuum pump may comprise rolling bearings made of a self-lubricating material or including grease in roller races, self-lubricating journal bearings, or non-contact bearings such as gas bearings or magnetic bearings. These bearings allow the rotational shafts to rotate in stable conditions regardless of mounting directions of the vacuum evacuation apparatus. Since the vacuum evacuation apparatus according to the present invention has an appearance as a single pump unit, the user does not usually think that it contains the first vacuum pump and the second vacuum pump combined together. The dry vacuum pumps used generally for a second vacuum pump uses low-viscosity lubricating oil such as mineral oil to lubricate the bearings, and hence has certain limitations on the mounting directions thereof. On the other hand, the turbomolecular pump has its rotational shaft rotatably supported by ball bearings that are lubricated mainly by grease, or non-contact bearings, so that the turbomolecular pump is free of limitations with respect to directions in which it is mounted. The dry vacuum pump according to the present invention uses the bearings which can support the rotational shafts without using low-viscosity lubricating oil such as mineral oil, and thus does not pose limitations on the mounting directions of the pump unit.

[0026] In a preferred aspect of the present invention, the first vacuum pump has a bottom component and the second vacuum pump has a casing, and the bottom component and the casing are integrally connected to each other, thereby integrally connecting the first vacuum pump and the second vacuum pump.

[0027] According to the present invention, the bottom component of the first vacuum pump and the pump casing of the second vacuum pump are integrated into a common part, and an evacuation passage is provided in the common part to allow the first vacuum pump and the second vacuum pump to communicate with each other. Thus, the number of parts used is reduced and hence the cost thereof is reduced, and the overall unit takes up a reduced volume. By incorporating the evacuation path of the two pumps into the common part, the evacuation path of the two pumps can be shortened to increase the conductance of the pump unit, and the volume of the second vacuum pump can be reduced. Then, the cost of the entire pump unit can be further reduced and the volume taken up by the entire pump unit can be reduced. Furthermore, since the bottom component and the pump casing are integrated, thermal conductivity of the two pumps can be improved. The second vacuum pump which compresses a gas up to the atmospheric pressure consumes more electric power and generates more heat than the first vacuum pump at the ultrahigh vacuum side. If the second vacuum pump is cooled by cooling water, the increased thermal conductivity between the two pumps allows only a cooling mechanism incorporated in the first vacuum pump to cool the two pumps efficiently (to radiate heat from the two pumps efficiently).

[0028] In a preferred aspect of the present invention, the first vacuum pump and the second vacuum pump are integrally connected to each other through a heat insulation member or a small area of contact.

[0029] If the second vacuum pump is not cooled by cooling water, then in order to lower the thermal conductivity between the fastening surfaces of the first vacuum pump and the second vacuum pump, it is effective to combine a thermal insulation with the fastening portion or to reduce the cross-sectional area of a contacting region of the fastening portion, or both to combine a thermal insulation with the fastening portion and to reduce the cross-sectional area of a contacting region of the fastening portion. If the second vacuum pump is not cooled by cooling water, then it is forcedly air-cooled. The second vacuum pump which compresses a gas up to the atmospheric pressure consumes more electric power and generates more heat than the first vacuum pump. If the second vacuum pump is forcedly air-cooled, its exhaust heat performance is much lower than the cooling water. If the thermal conductivity between the two pumps is high, the heat may be transferred from the second vacuum pump to the first vacuum pump, possibly impairing the normal operation of the first vacuum pump. Therefore, by providing the heat insulation member at the connecting portion of the two pumps or making the contact area of the connecting portion small, the thermal conductivity between the two pumps is lowered to minimize the heat transfer from the second vacuum pump to the first vacuum pump.

[0030] In a preferred aspect of the present invention, the first vacuum pump and the second vacuum pump are integrally connected to each other through a vibro-isolating mechanism.

[0031] The second vacuum pump which compresses a gas up to the atmospheric pressure vibrates to an extent greater than the first vacuum pump. If vibrations of the vacuum evacuation apparatus of the present invention which integrates the first vacuum pump and the second vacuum pump are large, the vacuum evacuation apparatus cannot be installed in the vicinity of the vacuum container. Therefore, the vibro-isolating mechanism for isolating vibrations from the second vacuum pump is provided at the connecting portion of the first vacuum pump and the second vacuum pump, and thus any vibrations that are transmitted from the second vacuum pump to the first vacuum pump can be reduced. The vibro-isolating mechanism may comprise a vibro-isolating rubber (natural rubber, nitrile rubber, silicone rubber, fluoro rubber, etc.) which has a Young's modulus equal to or smaller than 1000 KPa (1000 to 10 KPa) and an Asker C hardness level equal to or smaller than 50 (50 to 4), or may comprise a spring.

[0032] In a preferred aspect of the present invention, the first vacuum pump has an outlet port and the second vacuum pump has an inlet port, and the outlet port and the inlet port are interconnected by an evacuation passage component comprising a vibro-isolating material.

[0033] If the evacuation passage component is made of a highly rigid material or has a highly rigid structure, then it may transmit vibrations from the second vacuum pump to the first vacuum pump. Since the evacuation passage component is made of a vibro-isolating material, it can minimize vibrations transmitted from the second vacuum pump to the first vacuum pump. The vibro-isolating material may be a rubber material (natural rubber, nitrile rubber, silicone rubber, fluoro rubber, etc.) which has a Young's modulus equal to or smaller than 1000 KPa (1000 to 10 KPa) and an Asker C hardness level equal to or smaller than 50 (50 to 4), and may be in the shape of a tube or a block.

[0034] In a preferred aspect of the present invention, the first vacuum pump has an inlet port and the second vacuum pump has an inlet port, and the inlet port of the first vacuum pump and the inlet port of the second vacuum pump are interconnected by a bypass passage for bypassing the first vacuum pump.

[0035] According to the present invention, the bypass pipe which interconnects the inlet port of the first vacuum pump and the inlet of the second vacuum pump is provided. The bypass pipe serves to directly discharge a gas from the inlet port of the first vacuum pump into the inlet of the second vacuum pump, thereby bypassing the first vacuum pump. Consequently, even when the vacuum in the vacuum container breaks, a sudden load buildup can be prevented from being exerted on the first vacuum pump, and hence the rotating body of the first vacuum pump can be protected against damage.

[0036] In a preferred aspect of the present invention, the first vacuum pump has an outlet port and the second vacuum pump has an inlet port, and the outlet port and the inlet port are interconnected by an evacuation passage component incorporating therein a check valve for preventing a fluid from flowing back from the second vacuum pump to the first vacuum pump while the first vacuum pump is in operation.

[0037] According to the present invention, the first vacuum pump and the second vacuum pump are integrally connected together into an integral pump unit including the evacuation passage component therein. Therefore, the pressure conditions for the evacuation passage component are known. When one of the first and second vacuum pumps fails to operate, e.g., when the second vacuum pump becomes faulty in operation, the back pressure of the first vacuum pump increases suddenly. By providing the check valve which automatically closes under the differential pressure in the evacuation passage component, the pressure at the exhaust side of the first vacuum pump can be prevented from abruptly rising.

[0038] In a preferred aspect of the present invention, further comprising a controller for controlling the first vacuum pump and the second vacuum pump wherein the controller is integrally connected to the first vacuum pump or is installed separately from the first vacuum pump.

[0039] In a preferred aspect of the present invention, when each of the first vacuum pump and the second vacuum pump reaches a rated rotational speed and no gas is introduced into the container, the controller lowers a voltage applied to a motor of at least one of the first vacuum pump and the second vacuum pump and continuously operates the motor at a motor maximum efficient point.

[0040] In a preferred aspect of the present invention, the controller is capable of controlling the pressure in the container at a target pressure level by individually controlling respective rotational speeds of the first vacuum pump and the second vacuum pump depending on flow rates of the gas evacuated therefrom.

[0041] With the first vacuum pump and the second vacuum pump that are integrally connected into an integral unit, passage pipes combined with the integral unit and having given diameters and lengths remain unchanged or constant. In the event of changes in the rotational speeds of the first vacuum pump and the second vacuum pump, the flow rate and the pressure change with regularity.

[0042] Usually, the evacuation rate of a pump is controlled by adjusting the opening area of the suction side with a control valve or the like. According to the present invention, however, the pressure in the vacuum container to be evacuated is controlled by controlling at least one of the rotational speed of the first vacuum pump and the rotational speed of the second vacuum pump, rather than by adjusting the opening (opening area) of a valve disposed between the vacuum container and the pump. In this manner, the evacuation rate of each of the vacuum pumps is adjusted to adjust the overall evacuation rate of the pump system as the vacuum evacuation apparatus. In other words, the pressure in the vacuum container can be controlled by the single pump system without the need for a control valve other than the vacuum pumps.

[0043] In a preferred aspect of the present invention, wherein the first vacuum pump comprises a turbomolecular pump, and the second vacuum pump comprises a dry vacuum pump.

[0044] In a preferred aspect of the present invention, the second vacuum pump comprises a dry vacuum pump having a pair of pump rotors with respective magnet rotors mounted thereon, the magnet rotors have equal numbers of magnetic poles and are disposed so that their different magnetic poles are magnetically attracted to each other, and currents supplied to a multiphase armature including an iron core and a plurality of windings disposed radially outwardly of at least one of the magnet rotors are switched to actuate the at least one of the magnet rotors for thereby rotating the pump rotors in opposite directions in synchronism with each other.

[0045] According to the present invention, the dual-shaft pump rotors can be rotated synchronously in the opposite directions by a simple structural motor having permanent magnets and windings for rotating the permanent magnets. Therefore, any timing gears for synchronizing the dual-shaft pump rotors are not required, and oil-free, low vibrations and low noise can be realized. If lubricating oil is used to lubricate the bearings and timing gears, the lubricating oil leaks out when the pump is tilted, and hence mounting posture of the pump is limited. However, the oil-free pump according to the present invention can be mounted in a posture that can freely be selected, and does not produce significant vibrations and noise caused by contact of the timing gears.

[0046] Since the dry vacuum pump having the above structure is used as the second vacuum pump, any vibrations that are transmitted from the second vacuum pump to the first vacuum pump can be suppressed, and thus the second vacuum pump can be integrally coupled to the first vacuum pump. When the first vacuum pump and the second vacuum pump are integrally coupled to each other, the second vacuum pump can be mounted at a freely selectable posture. Furthermore, when the integral unit of the first vacuum pump and the second vacuum pump is attached to an object to be evacuated, e.g., a vacuum container (vacuum chamber), the integral unit can be mounted at a freely selectable posture.

[0047] In a preferred aspect of the present invention, one of the first vacuum pump and the second vacuum pump comprises a single vacuum pump and the other of the first vacuum pump and the second vacuum pump comprises either a single vacuum pump or a plurality of vacuum pumps.

[0048] In a preferred aspect of the present invention, the first vacuum pump and the second vacuum pump are integrally connected to each other by at least one evacuation passage.

[0049] According to the present invention, since the plural second vacuum pumps are integrally connected to the single first vacuum pump, it is possible to construct a roughening pump system having an evacuation capacity which matches the evacuation capacity of the first vacuum pump. Since the plural second vacuum pumps can be controlled in parallel for controlling the pressure in the vacuum container, the pressure in the vacuum container can be controlled more appropriately. Further, even if one of the second vacuum pumps fails to operate, the other second vacuum pump can back up the first vacuum pump. Therefore, even if one of the second vacuum pumps shuts down, a situation where the first vacuum pump shuts down to cause a quick pressure buildup in the vacuum container can be avoided.

[0050] A plurality of the first vacuum pumps may be integrally connected to a single second vacuum pump. With this arrangement, the rotor of each of the first vacuum pumps can be reduced in size. Two or three vacuum pumps that are integrally connected to each other can be controlled by a single controller.

[0051] In a preferred aspect of the present invention, the ratio of an axial dimension of the second vacuum pump and an axial dimension, which is assumed to be 1, of the first vacuum pump is in a range from 1 to 0.6, and the ratio of a volume of the second vacuum pump and a volume, which is assumed to be 1, of the first vacuum pump is in a range from 0.3 to 0.5.

[0052] Since the second vacuum pump can be smaller in size than the first vacuum pump, there is no limitation on the mounting posture when the second vacuum pump is mounted on the first vacuum pump.

[0053] By using the combination of the above dimension and volume ratios for the first vacuum pump and the second vacuum pump, it is possible to integrally connect a plurality of second vacuum pumps to the first vacuum pump which has an evacuation capacity that is several times greater than each of the second vacuum pumps.

[0054] The present invention offers the following advantages:

[0055] (1) By integrating a first vacuum pump for evacuating the container to a high vacuum or less and a second vacuum pump for evacuating the container from an atmospheric pressure to a medium or low vacuum, ultrahigh vacuum evacuation can be performed by a single pump system. Further, by a combination of the first vacuum pump for evacuating the container to a high vacuum or less and the second vacuum pump for evacuating the container from an atmospheric pressure to a medium or low vacuum, the pumps can evacuate the container respectively to the medium vacuum range and the ultrahigh vacuum range by appropriate respective consumed power, and the consumed power of the whole system can be reduced.

[0056] (2) Since the second vacuum pump as an auxiliary pump can be integrally coupled to the first vacuum pump, the installation space (footprint) of the auxiliary pump can be reduced.

[0057] (3) When the first vacuum pump and the second vacuum pump are integrally coupled to each other, the second vacuum pump can be mounted at a freely selectable posture. Furthermore, when the integral unit of the first vacuum pump and the second vacuum pump is attached to an object to be evacuated, e.g., a vacuum container (vacuum chamber), the integral unit can be mounted at a freely selectable posture.

[0058] (4) The pressure in the vacuum container to be evacuated is controlled by controlling at least one of the rotational speed of the first vacuum pump and the rotational speed of the second vacuum pump, rather than by adjusting the opening (opening area) of a valve disposed between the vacuum container and the pump. Therefore, the evacuation rate of each of the vacuum pumps is adjusted to adjust the overall evacuation rate of the pump system. In other words, the pressure in the vacuum container can be controlled by the single pump system without the need for a control valve or the like.

[0059] The above and other objects, features, and advantages of the present invention will become more apparent from the following description when taken in conjunction with the accompanying drawings in which preferred embodiments of the present invention are shown by way of illustrative example.

BRIEF DESCRIPTION OF THE DRAWINGS

[0060] FIG. **1**A is a front elevational view, partly in cross section, of a vacuum evacuation apparatus according to a first aspect of the present invention;

[0061] FIG. **1**B is a side elevational view, partly in cross section, of the vacuum evacuation apparatus shown in FIG. **1**A;

[0062] FIG. **1**C is a bottom view, partly in cross section, of the vacuum evacuation apparatus shown in FIG. **1**A;

[0063] FIG. **2** is a schematic cross-sectional view showing structural details of a first vacuum pump of the vacuum evacuation apparatus shown in FIG. **1**A;

[0064] FIG. **3** is a schematic cross-sectional view showing structural details of a second vacuum pump of the vacuum evacuation apparatus shown in FIG. **1**A;

[0065] FIG. **4** is a cross-sectional view taken along line IV-IV of FIG. **3**;

[0066] FIG. **5**A is a front elevational view, partly in cross section, of the vacuum evacuation apparatus with the second vacuum pump being installed at another posture;

[0067] FIG. **5**B is a side elevational view, partly in cross section, of the vacuum evacuation apparatus shown in FIG. **5**A;

[0068] FIG. **5**C is a bottom view, partly in cross section, of the vacuum evacuation apparatus shown in FIG. **5**A;

[0069] FIGS. **6**A and **6**B are front elevational views of the vacuum evacuation apparatus with a controller mounted on the first vacuum pump in different positions;

[0070] FIGS. **7**A and **7**B are schematic cross-sectional views showing a vacuum evacuation apparatus in which a bottom component of the first vacuum pump and a pump casing of the second vacuum pump are integrally joined to each other;

[0071] FIG. **8** is a schematic front elevational view, partly in cross section, of a vacuum evacuation apparatus in which a vibro-isolating mechanism is provided between the first vacuum pump and the second vacuum pump

[0072] FIG. **9** is a schematic front elevational view, partly in cross section, of a vacuum evacuation apparatus in which a fastening component for fastening the first vacuum pump and the second vacuum pump is combined with a vibro-isolating mechanism;

[0073] FIG. **10**A is a cross-sectional view of the structure of a fastening assembly comprising the fastening component and vibro-isolating bushings shown in FIG. **9**;

[0074] FIG. **10**B is a bottom view of the fastening assembly shown in FIG. **10**A;

[0075] FIG. **10**C is an exploded perspective view of one of the vibro-isolating bushings shown in FIG. **10**A;

[0076] FIGS. **11**A and **11**B are front elevational views of a pump unit (vacuum evacuation apparatus) having a first vacuum pump and a second vacuum pump that are integrally mounted on a vacuum container (vacuum chamber);

[0077] FIG. **12**A is a front elevational view, partly in cross section, of a vacuum evacuation apparatus with a second vacuum pump mounted on a side surface of a first vacuum pump;

[0078] FIG. **12**B is a bottom view of the vacuum evacuation apparatus with the second vacuum pump mounted on the side surface of the first vacuum pump;

[0079] FIGS. **13**A and **13**B are a front elevational view, partly in cross section, and a bottom view of a vacuum evacuation apparatus with a second vacuum pump mounted on a side surface of a first vacuum pump, the first vacuum pump and the second vacuum pump being fastened to each other by a fastening component combined with a vibro-isolating mechanism;

[0080] FIG. **13**C is a cross-sectional view showing structural details of a fastening assembly of the vacuum evacuation apparatus shown in FIGS. **13**A and **13**B;

[0081] FIG. **14** is a schematic front elevational view of a vacuum evacuation apparatus including a first vacuum pump, a second vacuum pump, and a check valve disposed in a evacuation passage component which interconnects an outlet port of the first vacuum pump and an inlet port of the second vacuum pump;

[0082] FIG. **15** is a schematic front elevational view of a vacuum evacuation apparatus including a first vacuum pump, a second vacuum pump, and a bypass pipe interconnecting an inlet port of the first vacuum pump and an inlet port of the second vacuum pump for bypassing the first vacuum pump;

[0083] FIG. **16** is a set of graphs showing comparison results in which the rotational speeds of first and second vacuum pumps were changed to adjust the pressure in a vacuum container in a pump rotational speed control process which was performed on a vacuum evacuation apparatus according to the present invention and a vacuum evacuation apparatus according to the related art, in the case of the first vacuum pump comprising a turbomolecular pump and the second vacuum pump comprising a dry pump;

[0084] FIG. **17** is a schematic front elevational view, partly in cross section, of a vacuum evacuation apparatus according to an embodiment of the present invention which includes a single first vacuum pump and a plurality of second vacuum pumps integrally connected to the first vacuum pump;

[0085] FIG. **18** is a schematic front elevational view, partly in cross section, of a vacuum evacuation apparatus according to an embodiment of the present invention which includes a single first vacuum pump and a plurality of second vacuum pumps integrally connected to the first vacuum pump by inlet and outlet passages;

[0086] FIG. **19** is a schematic front elevational view, partly in cross section, of a vacuum evacuation apparatus according to an embodiment of the present invention which includes a plurality of first vacuum pumps and a single second vacuum pump integrally connected to the first vacuum pumps by inlet and outlet passages;

[0087] FIG. **20** is a block diagram of a control circuit for controlling a vacuum evacuation apparatus including two first vacuum pumps and a single second vacuum pump which are integrally connected;

[0088] FIG. **21** is a graph showing how the rotational speeds of a single first vacuum pump and two second vacuum pumps were changed to adjust the pressure in a vacuum container in a pump rotational speed control process which was performed on a vacuum evacuation apparatus according to the present invention, in the case of the first vacuum pump comprising a turbomolecular pump and the two second vacuum pumps comprising a dry pump;

[0089] FIG. **22** is a cross-sectional view of a turbomolecular pump for use in a vacuum evacuation apparatus according to the present invention;

[0090] FIG. **23** is a cross-sectional view of another turbomolecular pump for use in a vacuum evacuation apparatus according to the present invention;

[0091] FIG. **24** is a cross-sectional view of still another turbomolecular pump for use in a vacuum evacuation apparatus according to the present invention; and

[0092] FIG. **25** is a cross-sectional view of yet another turbomolecular pump for use in a vacuum evacuation apparatus according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0093] A vacuum evacuation apparatus according to preferred embodiments of the present invention will be described in detail below with reference to FIGS. **1**A through **25**. Identical or corresponding parts are denoted by identical or corresponding reference characters throughout views.

[0094] FIGS. **1**A, **1**B and **1**C are views showing a vacuum evacuation apparatus according to a first aspect of the present invention, FIG. **1**A is a front elevation view, partly in cross section, FIG. **1**B is a side elevational view, partly in cross section, and FIG. **1**C is a bottom view, partly in cross section.

[0095] As shown in FIGS. **1**A, **1**B and **1**C, according to an embodiment of the present invention, a vacuum evacuation apparatus is configured to evacuate a vacuum container (vacuum chamber) from an atmospheric pressure to an ultrahigh vacuum range. The vacuum evacuation apparatus comprises a first vacuum pump **1** capable of evacuating the container to a high vacuum or less and a second vacuum pump **2** capable of evacuating the container to a pressure ranging from an atmospheric pressure to a medium or low vacuum. The first vacuum pump **1** and the second vacuum pump **2** are unitized as an integral apparatus. Specifically, the first vacuum pump **1** and the second vacuum pump **2** are coupled together into an integral unit. The first vacuum pump **1** comprises a turbomolecular pump, and the second vacuum pump **2** comprises a dry vacuum pump. An outlet port of the first vacuum pump **1** and an inlet port of the second vacuum pump **2** are interconnected by an evacuation passage component **3**.

[0096] For evacuating a gas in a certain container from an atmospheric pressure range to an ultrahigh vacuum range, normally, a positive displacement pump (e.g., dry pump) as a second vacuum pump is initially used to evacuate the container to a medium vacuum range, and then a turbomolecular pump as a first vacuum pump is activated to evacuate the container to an ultrahigh vacuum range, thus performing evacuation operation. According to the conventional method, the second vacuum pump (e.g., dry pump) for evacuating the container to a medium vacuum and the first vacuum pump (e.g., turbomolecular pump) for evacuating the container to an ultrahigh vacuum range are separately prepared, and connected together by a piping, thus constructing an evacuating system which is capable of performing a series of evacuation. However, in this method, depending on the length and diameter of the piping used to interconnect the dry pump and the turbomolecular pump, even though the container to be evacuated remains unchanged, the evacuation time and power required for evacuation tend to vary, and even the pumps themselves may need to be changed. Consequently, special engineering expertise is often required in evacuating equipment planning.

[0097] According to the present invention, the first vacuum pump **1** comprising a turbomolecular pump and the second vacuum pump **2** comprising a dry vacuum pump are integrated and unitized. Thus, the user can construct and perform ultrahigh vacuum evacuation in a container by a single pump system. By a combination of the turbomolecular pump and the dry vacuum pump, the pumps can evacuate the container respectively to the medium vacuum range and the ultrahigh vacuum range by appropriate respective consumed power. Therefore, according to the present invention, there is provided a pump system that does not essentially operate in a low evacuation efficiency state, i.e., a state where evacuation in the ultrahigh vacuum range is performed by a single pump comprising a positive vacuum pump or a state where evacuation in the atmospheric pressure range is performed by a single pump comprising a kinetic vacuum pump.

[0098] The expression “the first vacuum pump **1** and the second vacuum pump **2** are coupled together into an integral unit" means that the first vacuum pump **1** and the second vacuum pump **2** are coupled and integrated into a physically single pump unit, as shown in FIG. **1**A. In this case, a controller for controlling the whole pumps in the vacuum evacuation apparatus may be mounted on the pump unit or may be installed in the vicinity of the pump unit.

[0099] As shown in FIGS. **1**A, **1**B and **1**C, the second vacuum pump **2** comprises a screw-type dry vacuum pump having a pair of screw rotors **52***a*, **52***b* rotatably disposed in a pump casing (described below).

[0100] FIG. **2** is a schematic cross-sectional view showing structural details of the first vacuum pump **1** of the vacuum evacuation apparatus shown in FIGS. **1**A through **1**C.

[0101] As shown in FIG. **2**, the turbomolecular pump as the first vacuum pump **1** comprises a pump casing **9**, and a turbine blade pumping assembly **10** and a thread groove pumping assembly **20** which are disposed in the pump casing **9** and successively arranged from an inlet port side to an outlet port side of the turbomolecular pump. The turbine blade pumping assembly **10** comprises a plurality of turbine blades **11** as an array of multistage rotor blades and multistage stator blades **14** disposed immediately downstream of the corresponding turbine blades **11**. The multistage turbine blades **11** are integrally formed on a substantially cylindrical rotor **12** fixedly mounted on a rotational shaft **13** that is rotatably disposed centrally in the pump casing **9**. The multistage stator blades **14** are held between spacers **15** stacked in the pump casing **9** and are fixed in the pump casing **9**. The turbine blades **11** as rotor blades and the stator blades **14** are alternately disposed in the turbine blade pumping assembly **10**.

[0102] The thread groove pumping assembly **20** comprises cylindrical thread grooves **21** disposed on an outer circumferential surface of the cylindrical rotor **12**, and a cylindrical thread groove spacer **22** disposed so as to face the outer circumferential surfaces of the cylindrical thread grooves **21**. The thread groove spacer **22** is fixed to the pump casing **9**.

[0103] The turbomolecular pump also includes a stator **25** disposed in the rotor **12**. The stator **25** has a base **26** fixed to a lower flange **91***f* of the pump casing **9** and a sleeve **27** extending axially upwardly from the base **26**. The sleeve **27** of the stator **25** supports a bearing motor assembly **30** including a motor **31** for applying rotational drive forces to the rotational shaft **13** and bearings **32**, **33**, **34** for rotatably supporting the rotational shaft **13**.

[0104] The bearing motor assembly **30** comprises a motor **31** for applying rotational drive forces to the rotational shaft **13**, an upper radial magnetic bearing **32** for radially supporting the rotational shaft **13**, a lower radial magnetic bearing **33** for radially supporting the rotational shaft **13**, and a thrust magnetic bearing **34** for canceling thrust forces generated by the pressure difference developed between the inlet side and the outlet side by evacuation operation of the evacuation assembles. The motor **31** comprises a high-frequency motor. Each of the upper radial magnetic bearing **32**, the lower radial magnetic bearing **33**, and the thrust magnetic bearing **34** comprises an active magnetic bearing.

[0105] The pump casing **9** has an upper flange **9***uf* on its upper end. The inlet port SP is defined radially inwardly of the upper flange **9***uf*. A vacuum container (vacuum chamber) to be evacuated by the vacuum evacuation apparatus is connected to the upper flange **9***uf*. Further, the base **26** of the stator **25** has a flange **26***f*, and the outlet port DP is defined radially inwardly of the flange **26***f*. The evacuation passage component **3** (see FIG. **1**) is connected to the flange **26***f*, and the first vacuum pump **1** comprising a turbomolecular pump communicates with the second vacuum pump **2** by the evacuation passage component **3**.

[0106] FIG. **3** is a schematic cross-sectional view showing structural details of the second vacuum pump **2** of the vacuum evacuation apparatus shown in FIGS. **1**A through **1**C. As shown in FIG. **3**, the second vacuum pump **2** comprises a screw-type dry vacuum pump. The second vacuum pump **2** comprises a pump casing **50**, and two parallel rotational shafts **51***a*, **51***b* disposed in the pump casing **50**. The rotational shafts **51***a*, **51***b* are rotatably supported by respective pairs of bearings **53**. The rotational shaft **51***a* supports a screw rotor **52***a* fixed thereto which has a right-hand screw thread, and the rotational shaft **51***b* supports a screw rotor **52***b* fixed thereto which has a left-hand screw thread. The screw rotors **52***a*, **52***b* are juxtaposed in alignment with each other between the bearings **53** which support the rotational shafts **51***a*, **51***b*.

[0107] As shown in FIG. **3**, small clearances are defined between outer circumferential surfaces of the screw rotors **52***a*, **52***b* and an inner circumferential surface of the pump casing **50**, allowing the screw rotors **52***a*, **52***b* to rotate out of contact with the pump casing **50**. The screw rotors **52***a*, **52***b* have mutually confronting regions where the right- and left-hand screw threads loosely mesh with each other to allow the screw rotors **52***a*, **52***b* to rotate out of contact with each other. Magnet rotors **54** are fixed respectively to ends of the rotational shafts **51***a*, **51***b*. The pump casing **50** has an inlet port SP and an outlet port DP that are formed in a side wall thereof which lies parallel to the sheet of FIG. **3**. The inlet port SP of the second vacuum pump **2** is connected to the outlet port DP of the first vacuum pump **1** by the evacuation passage component **3** (see FIG. **1**). The bearings **53** which are remote from the magnet rotors **54** are fixed to the pump casing **50**, and the other bearings **53** which are close to the magnet rotors **54** are fixed to a bearing housing **55** and a bearing holder **56**. The bearing housing **55** is fixed to the pump casing **50**, and the bearing holder **56** is fixed to the bearing housing **55**.

[0108] FIG. **4** is a cross-sectional view taken along line IV-IV of FIG. **3**. As shown in FIG. **4**, the magnet rotors **54** are identical in structure and disposed parallel to each other. Each of the magnet rotors **54** includes a yoke **54***b* made of a magnetic material and a ring-shaped magnet **54***a* mounted on the outer circumferential surface of the yoke **54***b*. The ring-shaped magnet **54***a* is magnetized into eight poles, so that each magnet rotor **54** has eight magnetic poles on its outer circumferential surface. Though each magnet rotor **54** is shown as a structure having eight magnetic poles in the illustrated embodiment, the number of the magnetic poles should be an even number of magnetic poles (2n: n=1, 2, . . .). The magnet rotors **54** are disposed in facing relation to each other with their different magnetic poles being magnetically attracted to each other, and are disposed so as to keep a clearance C defined therebetween. The screw rotors **52***a*, **52***b* are capable of rotating smoothly in opposite directions in synchronism with each other because of a magnetic coupling between the magnet rotors **54**. In order to increase forces for synchronously rotating the screw rotors **52***a*, **52***b*, a plurality of pairs of magnet rotors **54** may be mounted on the rotational shafts **51***a*, **51***b*.

[0109] The screw-type dry vacuum pump includes two armatures **57** for generating forces to rotate the magnet rotors **54**. Each of the armatures **57** is of a three-phase (U, V, W) configuration with an iron core **57***a* and three windings **57***b* which are disposed in the vicinity of a portion of the outer circumferential surface of one of the magnet rotors **54**. The two armatures **57** are mounted on inner walls of the pump casing **50** remote from the region where the magnet rotors **54** face each other. The magnetic forces which attract the magnet rotors **54** to each other are canceled by attractive forces that act between the magnet rotors **54** and the iron cores **57***a*. Adjacent two of the windings **57***b* in the respective phases of each of the armatures **57** are angularly spaced from each other by 60 degrees about the rotational shaft **51***a* or **51***b*.

[0110] The windings **57***b* in the phases, that are denoted by U_1, V_1, W_1, U_1', V_1', W_1', and the iron cores **57***a* of the armatures **57**, and the magnet rotors **54** jointly make up a dual-shaft synchronous brushless DC motor. The windings **57***b* in the phases U_1', V_1', W_1' are coiled in the opposite direction to the windings **57***b* in the phases U_1, V_1, W_1. Depending on the positions of the magnetic poles of the magnet rotors **54**, six currents I_{UV}, I_{VW}, I_{WU}, I_{VU}, I_{WP}, I_{UW} flowing through the respective windings **57***b* in the phases U_1, V_1, W_1, U_1', V_1', W_1' are switched to rotate the magnet rotors **54**.

[0111] The screw-type dry vacuum pump shown in FIGS. **3** and **4** is capable of rotating the two screw rotors **52***a*, **52***b* synchronously in the opposite directions by a simple structural motor having permanent magnets and windings for rotating the permanent magnets. Therefore, the screw-type dry vacuum pump does not need any timing gears for synchronizing the two screw rotors **52***a*, **52***b*, and hence is free of lubricating oil and realizes low vibrations and low noise. If lubricating oil is used to lubricate the bearings and timing gears, the lubricating oil leaks out when the pump is tilted, and hence mounting posture of the pump is limited. However, the oil-free pump according to the present invention can be mounted in a posture that can freely be selected, and does not produce significant vibrations and noise caused by contact of the timing gears.

[0112] Since the screw-type dry vacuum pump having the above structure is used as the second vacuum pump **2**, any vibrations that are transmitted from the second vacuum pump **2** to the first vacuum pump **1** can be suppressed, and thus the second vacuum pump **2** can be integrally coupled to the first vacuum pump **1**. When the first vacuum pump **1** and the second vacuum pump **2** are integrally coupled to each other, the second vacuum pump **2** can be mounted at a freely selectable posture. Furthermore, when the integral unit of the first vacuum pump **1** and the second vacuum pump **2** is attached to an object to be evacuated, e.g., a vacuum container (vacuum chamber), the integral unit can be mounted at a freely selectable posture.

[0113] A mounting posture for mounting the second vacuum pump **2** shown in FIGS. **3** and **4** on the first vacuum pump **1** will be described below with reference to FIGS. **1**A through **1**C. As shown in FIGS. **1**A through **1**C, the second vacuum pump **2** is mounted on the first vacuum pump **1** with the two screw rotors **52***a*, **52***b* being juxtaposed parallel to the lower surface of the first vacuum pump **1**. Specifically, the screw rotors **52***a*, **52***b* of the second vacuum pump **2** have respective axes **52***ax*, **52***bx* which are perpendicular to the axis **1***x* of the rotational shaft **13** of the first vacuum pump **1** and spaced by the same distance from the lower surface of the first vacuum pump **1**.

[0114] FIGS. **5**A, **5**B and **5**C are views showing another examples of mounting postures in the case where the second vacuum pump **2** is mounted on the first vacuum pump **1**, FIG. **5**A is a front elevational view, partly in cross section, FIG. **5**B is a side elevational view, partly in cross section, and FIG. **5**C is a bottom view, partly in cross section.

[0115] As shown in FIGS. **5**A through **5**C, the second vacuum pump **2** is mounted on the first vacuum pump **1** with the two screw rotors **52***a*, **52***b* being juxtaposed parallel to the lower surface of the first vacuum pump **1**. Specifically, the screw rotors **52***a*, **52***b* of the second vacuum pump **2** have respective axes **52***ax*, **52***bx* which are perpendicular to the axis **1***x* of the rotational shaft **13** of the first vacuum pump **1** and vertically spaced one above the other from the lower surface of the first vacuum pump **1**.

[0116] In the vacuum evacuation apparatus shown in FIGS. **1** and **5**, the first vacuum pump **1** comprising a turbomolecular pump and the second vacuum pump **2** comprising a dry vacuum pump are integrally connected together into an integral unit, and the second vacuum pump **2** have respective rotational shafts whose axes lying perpendicularly to the axis of the rotational shaft of the first vacuum pump **1**.

[0117] When the dry vacuum pump and the turbomolecular pump are in operation, they produce vibrations in substantially the same directions, i.e., their vibrational energies are intensive in substantially the same directions. Specifically, the dry vacuum pump and the turbomolecular pump produce vibrations due to unbalanced rotating bodies in the radial directions of their rotational shafts. If the rotational shaft of the turbomolecular pump and the rotational shafts of the dry vacuum pump in the unitized vacuum evacuation apparatus according to the present invention are disposed parallel to each other, then it is possible, though very small probability, for the turbomolecular pump and the dry vacuum pump to simultaneously produce rotary vibrations in the radial directions perpendicular to the axes of the rotational shafts, causing resonant vibrations. If such radial vibrations are generated, they tend to be added to each other and the added vibrations are transmitted as excessive vibrations to the vacuum container side. According to the present invention, the axes of the rotational shafts of the dry vacuum pump and the axis of the rotational shaft of the turbomolecular pump extend perpendicularly to each other, thereby minimizing radial vibrations generated by the rotational shaft of the first vacuum pump that is attached to the vacuum container.

[0118] As described above, the turbomolecular pump that is generally used as the first vacuum pump can be mounted at a freely selectable posture, and hence can be installed in any desired orientation on the vacuum container. Therefore, the turbomolecular pump as the first vacuum pump makes a great contribution to the degree of freedom of design around the vacuum container. When the two pumps are combined together into a pump unit for use as the vacuum evacuation apparatus according to the present invention, the axis **1***x* of the first vacuum pump **1** to be directly attached to the vacuum container is held in alignment with the center of gravity of the unitized vacuum evacuation apparatus. If the vacuum evacuation apparatus is installed in a horizontal orientation, then no torsional moment occurs around the axis **1***x* of the first vacuum pump **1**, allowing the vacuum container with the vacuum evacuation apparatus installed thereon to be deformed in a simplified manner or allowing the installation process to be simplified. The vibrations produced by the vacuum evacuation apparatus do not include torsional vibrations, and hence can easily be suppressed. It is important to suppress vibrations because the vacuum evacuation apparatus is installed in the vicinity of the vacuum container or is connected directly to the vacuum container.

[0119] The bearings that support the rotational shaft of the first vacuum pump **1** and the bearings that support the rotational shafts of the second vacuum pump **2** may comprise rolling bearings made of a self-lubricating material or including grease in roller races, self-lubricating journal bearings, or non-contact bearings such as gas bearings or magnetic bearings. These bearings allow the rotational shafts to rotate in stable conditions regardless of mounting directions of the vacuum evacuation apparatus. Since the vacuum evacuation apparatus according to the present invention has an appearance as a single pump unit, the user does not usually think that it contains the dry vacuum pump and the turbomolecular pump combined together. General dry vacuum pumps use low-viscosity lubricating oil such as mineral oil to lubricate the bearings, and hence have certain limitations on the mounting directions thereof. On the other hand, turbomolecular pumps have their rotational shafts rotatably supported by ball bearings that are lubricated mainly by grease, or non-contact bearings, so that the turbomolecular pumps are free of limitations with respect to directions in which they are mounted. The dry vacuum pump according to the present invention uses the bearings which can support the rotational shafts without using low-viscosity lubricating oil such as mineral oil, and thus does not pose limitations on the mounting directions of the pump unit.

[0120] A controller for controlling the whole pump unit will be described below. The first vacuum pump **1** and the second vacuum pump **2** have respective actuators, i.e., motors. However, in the case where motor power supplies for the motors have uniformized specifications and are housed in one housing, common components can be used to construct a single controller, thus downsizing the controller and reducing the cost of the controller, compared to the respective controllers. The controller should preferably installed on the first vacuum pump. Specifically, the dry vacuum pump is heated up to a higher temperature than the turbomolecular pump because of the heat generated when the dry vacuum pump compresses a gas up to the atmospheric pressure. The turbomolecular pump has a vibration level much lower than the positive displacement dry vacuum pump. Accordingly, the controller having a number of electronic precision components should be installed on the turbomolecular pump, rather than the dry vacuum pump, as the turbomolecular pump is less liable to exert unwanted thermal and vibrational effects on the controller. The controller thus installed is effective to increase the overall reliability of the pump unit.

[0121] FIGS. **6**A and **6**B are front elevational views showing a vacuum evacuation apparatus with a controller **4** installed on the first vacuum pump **1**.

[0122] In an example of FIG. **6**A, the controller **4** is attached to an outer circumferential surface of the first vacuum pump **1**.

[0123] In an example of FIG. **6**B, the controller **4** is attached to a lower surface of the first vacuum pump **1**. The controller **4** may be attached to the first vacuum pump **1** through a mount portion incorporating a vibro-isolating mechanism therein. The vibro-isolating mechanism may comprise a vibro-isolating rubber (natural rubber, nitrile rubber, silicone rubber, fluoro rubber, etc.) or a spring.

[0124] In FIGS. **6**A and **6**B, the controller **4** is installed on the first vacuum pump **1**. However, the controller **4** may be installed in any selected position spaced from the first vacuum pump **1**.

[0125] FIGS. **7**A and **7**B are cross-sectional views showing embodiments in which a bottom component of the first vacuum pump **1** and a pump casing of the second vacuum pump **2** are integrally joined to each other.

[0126] In an example of FIG. **7**A, a bottom component **40** of the first vacuum pump **1** and a pump casing **50** of the second vacuum pump **2** are integrally joined to each other to form an integral unit **60**.

[0127] In an example of FIG. **7**B, a bottom component **40** of the first vacuum pump **1** and a pump casing **50** of the second vacuum pump **2** are integrally joined to each other to form an integral unit **60** which has an evacuation passage **3***a* defined therein which provides fluid communication between the first vacuum pump **1** and the second vacuum pump **2**.

[0128] As shown in FIGS. **7**A and **7**B, the bottom component **40** and the pump casing **50** are integrated into a common part, so that the number of parts used is reduced and hence the cost thereof is reduced, and the overall unit takes up a reduced volume. As shown in FIG. **7**B, the integral unit **60** may incorporate the evacuation passage **3***a* for the two pumps. If the evacuation path of the two pumps can be shortened, the conductance of the pump unit is increased, and the volume of the second vacuum pump **2** can be reduced. Then, the cost of the entire pump unit can be further reduced and the volume taken up by the entire pump unit can be reduced. Furthermore, since the bottom component **40** and the pump casing **50** are integrated, thermal conductivity of the two pumps can be improved. The second vacuum pump **2** which compresses a gas up to the atmospheric pressure consumes more electric power and generates more heat than the first vacuum pump **1** at the ultrahigh vacuum side. If the second vacuum pump **2** is cooled by cooling water, the increased thermal conductivity between the two pumps allows only a cooling mechanism incorporated in the first vacuum pump **1** to cool the two pumps efficiently (to radiate heat from the two pumps efficiently).

[0129] If the second vacuum pump **2** is not cooled by cooling water, then in order to lower the thermal conductivity between the fastening surfaces of the first vacuum pump **1** and the second vacuum pump **2**, it is effective to combine a thermal insulation with the fastening portion or to reduce the cross-sectional area of a contacting region of the fastening portion, or both to combine a thermal insulation with the fastening portion and to reduce the cross-sectional area of a contacting region of the fastening portion. If the second vacuum pump **2** is not cooled by cooling water, then it is forcedly air-cooled. As described above, the second vacuum pump **2** which compresses a gas up to the atmospheric pressure consumes more electric power and generates more heat than the first vacuum pump **1**. If the second vacuum pump **2** is forcedly air-cooled, its exhaust heat performance is much lower than the cooling water. If the thermal conductivity between the two pumps is high, the heat may be transferred from the second vacuum pump **2** to the first vacuum pump **1**, possibly impairing the normal operation of the first vacuum pump **1**. Consequently, the thermal conductivity between the two pumps is lowered to minimize the heat transfer from the second vacuum pump **2** to the first vacuum pump **1**. An air-cooling fan that is designed to match the cross-sectional area of the second vacuum pump **2** is used to locally air-cool the second vacuum pump **2** to discharge the heat therefrom. If the heat from the second vacuum pump **2** is transferred to the first vacuum pump **1** and both the first vacuum pump **1** and the second vacuum pump **2** need to be air-cooled, then it is necessary to install the fan and to design and install a duct or cover for guiding an air flow in order to apply the air flow efficiently to the two pumps. If only the second vacuum pump **2** is locally air-cooled, the installation of the fan and the designing and installation of the duct or cover are simplified. The thermal insulation material may be ceramics (alumina, yttria, zirconia, etc.), stainless steel alloy, or plastics (PEEK, PTFE, etc.).

[0130] FIG. **8** is a schematic front elevation view showing an embodiment in which a vibro-isolating mechanism **61** is provided between fastening surfaces of the first vacuum pump **1** and the second vacuum pump **2**. According to the present invention, since the screw rotors **52***a*, **52***b* of the second vacuum pump **2** are capable of rotating in opposite directions in synchronism with each other because of a magnetic coupling between the magnet rotors **54**, the second vacuum pump **2** does not need any timing gears for synchronizing the two screw rotors **52***a*, **52***b*, so that any vibrations of the second vacuum pump **2** are greatly reduced. Even so, the second vacuum pump **2** which compresses a gas up to the atmospheric pressure vibrates to an extent greater than the first vacuum pump **1** comprising a turbomolecular pump. Therefore, as shown in FIG. **8**, the vibro-isolating mechanism **61** for isolating vibrations from the second vacuum pump **1** is provided at the fastening portion of the first vacuum pump **1** and the second vacuum pump **2**, and thus any vibrations that are transmitted from the second vacuum pump **2** to the first vacuum pump **1** can be reduced. The vibro-isolating mechanism **61** may comprise a vibro-isolating rubber (natural rubber, nitrile rubber, silicone rubber, fluoro rubber, etc.) or a spring.

[0131] In the vacuum evacuation apparatus shown in FIG. **8**, the evacuation passage component **3** interconnecting the outlet port of the first vacuum pump **1** and the inlet port of the second vacuum pump **2** is made of a vibro-isolating material. If the evacuation passage component **3** is made of a highly rigid material or has a highly rigid structure, then it may transmit vibrations from the second vacuum pump **2** to the first vacuum pump **1**. Since the evacuation passage component **3** is made of a vibro-isolating material, it can minimize vibrations transmitted from the second vacuum pump **2** to the first vacuum pump **1**. The vibro-isolating material may be a rubber material such as natural rubber, nitrile rubber, silicone rubber or fluoro rubber, and may be in the shape of a tube or a block. When a vacuum is created in the evacuation passage component **3** which is made of a vibro-isolating material such as rubber, it tends to be deformed under the differential pressure between the pressure in the evacuation passage component **3** and the atmospheric pressure. Though the evacuation passage component **3** is deformed to different degrees depending on the material and shape thereof, a helical spring of metal may be placed in the evacuation passage component **3** to prevent the evacuation passage component **3** from being deformed. The helical spring thus placed in the evacuation passage component **3** does not prevent the evacuation passage component **3** from being bent or curved. The length of the helical spring may be determined as desired relative to the length of the evacuation passage component **3**.

[0132] FIG. **9** is a schematic side elevational view showing an embodiment in which the first vacuum pump **1** and the second vacuum pump **2** are fastened to each other by a fastening component combined with a vibro-isolating mechanism. As shown in FIG. **9**, a fastening component **62** is disposed between the first vacuum pump **1** and the second vacuum pump **2**. A plurality of vibro-isolating bushings **63** are mounted on the fastening component **62**. The fastening component **62** is fixed to the first vacuum pump **1** by fastening bolts **64** that are threaded through the respective vibro-isolating bushings **63** into the first vacuum pump **1**.

[0133] The fastening component **62** has an evacuation passage **62***a* defined therein which is held in fluid communication with the inlet port SP of the second vacuum pump **2** and an evacuation passage **62***b* defined therein which is held in fluid communication with the outlet port DP of the second vacuum pump **2**. The evacuation passage **62***a* of the fastening component **62** is connected to the outlet port DP (see FIG. **2**) of the first vacuum pump **1** by an evacuation passage component **3**. The evacuation passage **62***b* of the fastening component **62** serves to vent the outlet port DP of the second vacuum pump **2** to the atmosphere. The evacuation passage component **3** is made of a vibro-isolating material such as rubber or the like.

[0134] FIGS. **10**A, **10**B and **10**C are views showing the structure of a fastening assembly comprising the fastening component **62** and the vibro-isolating bushings **63**. FIG. **10**A is a cross-sectional view of the fastening assembly, FIG. **10**B is a bottom view of the fastening assembly, and FIG. **10**C is an exploded perspective view of one of the vibro-isolating bushings **63**.

[0135] As shown in FIGS. **10**A and **10**B, the fastening component **62** has a plurality of through holes **62***h*, and flanges **62***f* (see FIG. **10**A) projecting radially inwardly from the inner circumferential wall surfaces of the through holes **62***h*. As shown in FIG. **10**C, each of the vibro-isolating bushings **63** includes an upper member **63***a* comprising a large-diameter ring-shaped portion and a small-diameter ring-shaped portion, and a lower member **63***b* comprising a ring-shaped portion. As shown in FIG. **10**A, the upper member **63***a* is mounted on the fastening component **62** in such a manner that the small-diameter ring-shaped portion is fitted in a circular hole defined by the inner circumferential surface of the flange **62***f* of the fastening component **62** and the large-diameter ring-shaped portion having a lower surface is held against the upper surface of the flange **62***f*. The lower member **63***b* is fitted over the outer circumferential surface of the small-diameter ring-shaped portion of the upper member **63***a* and held against the lower surface of the flange **62***f*. The fitting surfaces of the upper member **63***a* and the lower member **63***b* are integrally united together by an adhesive bonding or the like, causing the upper member **63***a* and the lower member **63***b* to grip the flange **62***f* of the fastening component **62**. In this manner, all the vibro-isolating bushings **63** are mounted in place on the fastening component **62**. Then, the fastening bolts **64** are inserted through the respective vibro-isolating bushings **63**, and threaded into the first vacuum pump **1** with washers **65** interposed between the heads of the fastening bolts **64** and the vibro-isolating bushings **63**. Therefore, the fastening component **62** is securely fastened to the first vacuum pump **1** with the vibro-isolating bushings **63** disposed therebetween. The fastening component **62** and the second vacuum pump **2** are fastened to each other by bolts or the like.

[0136] As shown in FIGS. **10**A through **10**C, since the first vacuum pump **1** and the second vacuum pump **2** are fastened to each other using a vibro-isolating mechanism comprising a plurality of vibro-isolating bushings **63**, the level of vibrations that are transmitted from the second vacuum pump **2** to the first vacuum pump **1** can be lowered.

[0137] FIGS. **11**A and **11**B are front elevation views showing embodiments in which a pump unit (vacuum evacuation apparatus) having the first vacuum pump **1** and the second vacuum pump **2** that are integrated is mounted on a vacuum container (vacuum chamber) **5**. In FIGS. **11**A and **11**B, the pump unit (vacuum evacuation apparatus) shown in FIG. **1** is mounted on the vacuum container (vacuum chamber) **5**.

[0138] In the embodiment shown in FIG. **11**A, the pump unit which includes the first vacuum pump **1** and the second vacuum pump **2** that are integrally connected to each other is mounted on a lower surface of the vacuum container **5** with the axis of the first vacuum pump **1** extending vertically. The axes of the screw rotors **52***a*, **52***b* of the second vacuum pump **2** are perpendicular to the axis of the first vacuum pump **1**.

[0139] In the embodiment shown in FIG. **11**B, the pump unit which includes the first vacuum pump **1** and the second vacuum pump **2** that are integrally connected to each other is mounted on a side surface of the vacuum container **5** with the axis of the first vacuum pump **1** extending horizontally. The axes of the screw rotors **52***a*, **52***b* of the second vacuum pump **2** are perpendicular to the axis of the first vacuum pump **1**.

[0140] The pump unit which includes the first vacuum pump **1** and the second vacuum pump **2** that are integrally connected to each other may be mounted on an upper surface of the vacuum container **5**. Further, the pump unit which includes the first vacuum pump **1** and the second vacuum pump **2** that are integrally connected to each other as shown in FIGS. **5**A through **5**C may be mounted on the vacuum container **5** in the same mounting postures as those shown in FIGS. **11**A and **11**B.

[0141] Another mounting posture in which the second vacuum pump **2** is mounted on the first vacuum pump **1** will be described below.

[0142] FIGS. **12**A and **12**B are views showing a mounting posture in which the second vacuum pump **2** is mounted on a side surface of the first vacuum pump **1**, FIG. **12**A is a side elevational view, partly in cross section and FIG. **12**B is a bottom view.

[0143] As shown in FIGS. **12**A and **12**B, the second vacuum pump **2** is mounted on a side surface of the first vacuum pump **1**. Specifically, the first vacuum pump **1** has a cylindrical pump casing with a flat cut surface on an outer circumferential surface thereof, and the second vacuum pump **2** is fixed to the flat cut surface. In the embodiment shown in FIGS. **12**A and **12**B, the axis **1***x* of the first vacuum pump **1** and the axes **52***ax*, **52***bx* of the respective screw rotors **52***a*, **52***b* of the second vacuum pump **2** are parallel to each other. In the embodiments shown in FIGS. **1** and **5**, the rotational shaft of the first vacuum pump **1** and the rotational shafts of the second vacuum pump **2** are perpendicular to each other to prevent radial resonant vibrations from being produced. According to the present invention, since the screw rotors **52***a*, **52***b* of the second vacuum pump **2** are capable of rotating in opposite directions in synchronism with each other because of a magnetic coupling between the magnet rotors **54**, the second vacuum pump **2** does not need any timing gears for synchronizing the two screw rotors **52***a*, **52***b*, so that any vibrations of the second vacuum pump **2** can be greatly reduced. Consequently, no significant radial resonant vibrations are not produced even though the rotational shaft of the first vacuum pump **1** and the rotational shafts of the second vacuum pump **2** are perpendicular to each other.

[0144] FIGS. **13**A, **13**B and **13**C are views showing an embodiment in which the second vacuum pump **2** is mounted on a side surface of the first vacuum pump **1**, and the first vacuum pump **1** and the second vacuum pump **2** are fastened to each other by a fastening component combined with a vibro-isolating mechanism. FIG. **13**A is a side elevational view, partly in cross section, of the first vacuum pump **1** and the second vacuum pump **2**, FIG. **13**B is a bottom view, partly in cross section, of the first vacuum pump **1** and the second vacuum pump **2**, and FIG. **13**C is a cross-sectional view showing structural details of a fastening assembly that fastens the first vacuum pump **1** and the second vacuum pump **2** shown in FIGS. **13**A and **13**B.

[0145] As shown in FIGS. **13**A and **13**B, the second vacuum pump **2** is mounted on a side surface of the first vacuum pump **1**, and a fastening component **62** is disposed between the first vacuum pump **1** and the second vacuum pump **2**. A plurality of vibro-isolating bushings **63** are mounted on the fastening component **62**. The fastening component **62** is fixed to the first vacuum pump **1** by fastening bolts **64** that are threaded through the respective vibro-isolating bushings **63** into the first vacuum pump **1**. As shown in FIG. **13**C, the fastening component **62**, the vibro-isolating bushings **63**, and the fastening bolts **64** are identical in structure to those shown in FIGS. **10**A through **10**C, and are installed in position in the same manner as shown in FIGS. **10**A through **10**C.

[0146] FIG. **14** is a schematic front elevation view showing an embodiment in which a check valve **6** is provided in an evacuation passage component **3** which interconnects an outlet port of the first vacuum pump **1** and an inlet port of the second vacuum pump **2**. As shown in FIG. **14**, the pump unit which includes the first vacuum pump **1** and the second vacuum pump **2** that are integrally connected to each other is mounted on the vacuum container **5**. The check valve **6** is disposed in the evacuation passage component **3** which interconnects the outlet port of the first vacuum pump **1** and the inlet port of the second vacuum pump **2**.

[0147] According to the present invention, the first vacuum pump **1** comprising a turbomolecular pump and the second vacuum pump **2** comprising a dry vacuum pump are integrally connected together into an integral pump unit including the evacuation passage component **3** therein. Therefore, the pressure conditions for the evacuation passage component **3** are known. When one of the first and second vacuum pumps **1**, **2** fails to operate, e.g., when the dry vacuum pump becomes faulty in operation, the back pressure of the turbomolecular pump increases suddenly. By providing the check valve **6** which automatically closes under the differential pressure in the evacuation passage component, the pressure at the exhaust side of the turbomolecular pump can be prevented from abruptly rising.

[0148] FIG. **15** is a schematic front elevation view showing an embodiment in which a bypass pipe **7** interconnecting the inlet port of the first vacuum pump **1** and the inlet of the second vacuum pump **2** is provided for bypassing the first vacuum pump **1**. As shown in FIG. **15**, the bypass pipe **7** interconnects the inlet port of the first vacuum pump **1** and the inlet of the second vacuum pump **2** is provided. The bypass pipe **7** serves to directly discharge a gas from the inlet port of the first vacuum pump **1** into the inlet of the second vacuum pump **2**, thereby bypassing the first vacuum pump **1**. Consequently, even when the vacuum in the vacuum container **5** breaks, a sudden load buildup can be prevented from being exerted on the first vacuum pump **1**, and hence the rotating body of the first vacuum pump can be protected against damage.

[0149] Further, a bypass valve **8** which is opened to connect the inlet port of the first vacuum pump **1** directly to the inlet of the second vacuum pump **2** is provided in the bypass pipe **7** in the event of an abrupt increase of the pressure in the vacuum container **5**. The bypass valve **8** can be automatically opened and closed under pressure conditions in the bypass pipe **7**. Such pressure conditions can be established with ease because the bypass pipe **7** is constructed under optimum conditions between the first vacuum pump **1** and the second vacuum pump **2** which are integrally connected together into a pump unit according to the present invention.

[0150] In the above embodiments, the second vacuum pump **2** is illustrated and described as a screw-type dry pump. However, the second vacuum pump **2** may comprise a roots dry pump, a diaphragm pump, or a scroll pump. However, if the second vacuum pump **2** comprises a diaphragm pump, then because the diaphragm pump is a pump having an evacuation principle for evacuating a gas by moving a diaphragm up and down to cause volumetric changes, the vertically moving direction (vibrating direction) of the diaphragm and the axial direction of the first vacuum pump should preferably be parallel to each other for the purpose of reducing overall vibrations of the vacuum evacuation apparatus.

[0151] Next, a controlling process of the controller which controls the first vacuum pump **1** and the second vacuum pump **2** will be described below.

[0152] (1) Usually, the evacuation rate of a pump is controlled by adjusting the opening area of the suction side with a control valve or the like. According to the present invention, however, the pressure in the vacuum container to be evacuated is controlled by controlling at least one of the rotational speed of the first vacuum pump **1** and the rotational speed of the second vacuum pump **2**, rather than by adjusting the opening (opening area) of a valve disposed between the vacuum container and the pump. In this manner, the evacuation rate of each of the vacuum pumps **1**, **2** is adjusted to adjust the overall evacuation rate of the pump system as the vacuum evacuation apparatus. In other words, the pressure in the vacuum container can be controlled by the single pump system without the need for a control valve other than the vacuum pumps.

[0153] (2) FIG. **16** is a set of graphs showing comparison results in which the rotational speeds of first and second vacuum pumps were changed to adjust the pressure in a vacuum container in a pump rotational speed control process which was performed on a vacuum evacuation apparatus according to the present invention and a vacuum evacuation apparatus according to the related art, in the case of the first vacuum pump comprising a turbomolecular pump and the second vacuum pump comprising a dry pump.

[0154] With the vacuum evacuation apparatus according to the present invention, the piping interconnecting the first vacuum pump (turbomolecular pump) and the second vacuum pump (dry pump) is very short. After pressure adjustment in the vacuum container is started, the rotational speed of the first vacuum pump is lowered, and when the pressure in the vacuum container reaches a certain level (start point of deceleration of the second pump), the second vacuum pump starts to reduce the rotational speed thereof. Since the piping interconnecting the first vacuum pump and the second vacuum pump is short, the pressure in the vacuum container quickly changes in response to the reduction in the rotational speed of the second vacuum pump. As a result, the pressure in the vacuum container can reach a target pressure, i.e., the adjustment of the pressure in the vacuum container can be completed, in the shortest period of time. With the vacuum evacuation apparatus according to the related art, however, since the piping interconnecting the first vacuum pump and the second vacuum pumps is longer, the pressure in the vacuum container changes with a delay in response to the reduction in the rotational speed of the second vacuum pump, with the result that it consumes a certain period of time for the pressure in the vacuum container to reach a target pressure.

[0155] When the first vacuum pump **1** and the second vacuum pump **2** are integrally connected together into an integral pump system, the second vacuum pump **2** should desirably be mounted on the first vacuum pump **1**. Consequently, it is desirable for the second vacuum pump **2** to have outer dimensions smaller than those of the first vacuum pump **1**.

[0156] Next, specific numerical values of the outer dimensions of the first vacuum pump **1** and the second vacuum pump **2** will be described below. The dimensions described below do not include those of electric components such as drivers, a controller, air-cooling fans, etc., but include only pump evacuation sections and actuators (motors).

[0157] (1) In the case where the second vacuum pump according to the present invention comprises a dual-shaft positive displacement pump (screw rotors) and a magnetic coupling motor, the ultimate performance that can be achieved by the second vacuum pump is 400 Pa or lower.

TABLE 1

	General evacuation rates	General outer dimensions mm	General axial dimensions mm	General volume ratios
First vacuum pump	100 L/s 6000 L/min	Diameter: 100	110-150	1
Second vacuum pump	15 L/min	Width: 90	110	0.4

[0158] The ratio of the general evacuation rate of the second vacuum pump and the general evacuation rate, which is assumed to be 1, of the first vacuum pump: 1/400

[0159] The ratio of the general axial dimension of the second vacuum pump and the general axial dimension, which is assumed to be 1, of the first vacuum pump: 1-0.7

[0160] The ratio of the general volume of the second vacuum pump and the general volume, which is assumed to be 1, of the first vacuum pump: 0.4

TABLE 2

	General evacuation rates	General outer dimensions mm	General axial dimensions mm	General volume ratios
First vacuum pump	300 L/s 18000 L/min	Diameter: 150	200-240	1
Second vacuum pump	45 L/min	Width: 130	160	0.4

[0161] The ratio of the general evacuation rate of the second vacuum pump and the general evacuation rate, which is assumed to be 1, of the first vacuum pump: 1/400

[0162] The ratio of the general axial dimension of the second vacuum pump and the general axial dimension, which is assumed to be 1, of the first vacuum pump: 0.8-0.6

[0163] The ratio of the general volume of the second vacuum pump and the general volume, which is assumed to be 1, of the first vacuum pump: 0.4

[0164] (2) In the case where the second vacuum pump that can be used in the above combination is a diaphragm pump, the ultimate performance that can be achieved by the second vacuum pump is 400 Pa or lower.

TABLE 3

	General evacuation rates	General outer dimensions mm	General axial dimensions mm	General volume ratios
First vacuum pump	100 L/s 6000 L/min	Diameter: 100	110-150	1
Second vacuum pump	5 L/min	Width: 80	200	1

[0165] The ratio of the general evacuation rate of the second vacuum pump and the general evacuation rate, which is assumed to be 1, of the first vacuum pump: 1/1200

[0166] The ratio of the general axial dimension of the second vacuum pump and the general axial dimension, which is assumed to be 1, of the first vacuum pump: 1.8-1.3

[0167] The ratio of the general volume of the second vacuum pump and the general volume, which is assumed to be 1, of the first vacuum pump: 0.4

TABLE 4

	General evacuating rates	General outer dimensions mm	General axial dimensions mm	General volume ratios
First vacuum pump	300 L/s 18000 L/min	Diameter: 150	200-240	1
Second vacuum pump	20 L/min	Width: 160	330	2.6

[0168] The ratio of the general evacuation rate of the second vacuum pump and the general evacuation rate, which is assumed to be 1, of the first vacuum pump: 1/900

[0169] The ratio of the general axial dimension of the second vacuum pump and the general axial dimension, which is assumed to be 1, of the first vacuum pump: 1.7-1.4

[0170] The ratio of the general volume of the second vacuum pump and the general volume which is assumed to be 1, of the first vacuum pump: 2.6

[0171] As can be seen from the above comparison results, in the case where the first vacuum pump comprises a turbomolecular pump and the second vacuum pump comprises a dual-shaft positive displacement pump (screw rotors) with magnetic coupling motor, the volume of the second vacuum pump can be smaller than the volume of the first vacuum pump, and thus there is no limitation on the mounting posture when the second vacuum pump is mounted on the first vacuum pump.

[0172] As a turbomolecular pump and a dual-shaft positive displacement pump are used respectively as the first vacuum pump and the second vacuum pump, it is possible to integrally connect a plurality of second vacuum pumps to the first vacuum pump which has an evacuation capacity that is several times greater than each of the second vacuum pumps.

[0173] FIG. **17** is a schematic view showing a vacuum evacuation apparatus according to an embodiment of the present invention, which includes a single first vacuum pump **1** and a plurality of second vacuum pumps **2** integrally connected to the first vacuum pump **1**. As shown in FIG. **17**, the two second vacuum pumps **2** are integrally connected to the single first vacuum pump **1**. The outlet port of the first vacuum pump **1** is connected to the inlet ports of the second vacuum pumps **2** by respective individual evacuation passage components **3**. Since the plural second vacuum pumps **2** are integrally connected to the single first vacuum pump **1**, it is possible to construct a roughing pump system having an evacuation capacity which matches the evacuation capacity of the first vacuum pump **1**.

[0174] FIG. **18** is a schematic view showing a vacuum evacuation apparatus according to an embodiment of the present invention, which includes a single first vacuum pump **1** and a plurality of second vacuum pumps **2** integrally connected to the first vacuum pump **1** by evacuation passages. As shown in FIG. **18**, the two second vacuum pumps **2** are integrally connected to the single first vacuum pump **1**, providing an integral pump unit that is mounted on a lower surface of the vacuum container **5**. The outlet port of the first vacuum pump **1** is connected to the inlet ports of the second vacuum pumps **2** by an evacuation passage component **3**. Since the plural second vacuum pumps **2** are integrally connected to the single first vacuum pump **1**, it is possible to construct a roughening pump system having an evacuation capacity which matches the evacuation capacity of the first vacuum pump **1**.

[0175] Inasmuch as the two second vacuum pumps **2** are connected in a parallel layout to the single first vacuum pump **1**, the second vacuum pumps **2** have their overall evacuation capacity doubled. When the pressure control in the vacuum container is performed, the two parallel second vacuum pumps **2** can control the pressure in the vacuum container **5** more finely and quickly than a single second vacuum pump **2**.

[0176] If a single second vacuum pump **2** is used, a failure of the second vacuum pump **2** leads to a shutdown of the first vacuum pump **1**, resulting in a quick pressure buildup in the vacuum container **5**. However, in the case where the vacuum evacuation apparatus includes the two second vacuum pumps **2**, even if one of the second vacuum pumps **2** fails to operate, the other second vacuum pump **2** operates to keep the pressure in the outlet port of the first vacuum pump **1** below an allowable pressure level. Therefore, a situation where the first vacuum pump **1** shuts down to cause a quick pressure buildup in the vacuum container **5** can be avoided.

[0177] FIG. **19** is a schematic view showing a vacuum evacuation apparatus according to an embodiment of the present invention, which includes a plurality of first vacuum pumps **1** and a single second vacuum pump **2** which are integrally connected by evacuation passages. As shown in FIG. **19**, two parallel first vacuum pumps **1** and a single second vacuum pump **2** are integrally connected together into an integral pump unit that is mounted on a lower surface of the vacuum container **5**. The outlet ports of the two first vacuum pumps **1** and the inlet port of the second vacuum pump **2** are interconnected by an evacuation passage component **3**. In this manner, the plural first vacuum pumps **1** and a single second vacuum pump **2** are integrally connected together into an integral pump unit, and hence each of the first vacuum pumps **1** is reduced in size.

[0178] With the two parallel first vacuum pumps **1** and the single second vacuum pump **2** being integrally connected together, it is not necessary for each of the first vacuum pumps to have a large-size pump rotor which rotates at a high speed for an increased evacuation capacity. Therefore, a safe vacuum evacuation system can be constructed.

[0179] FIG. **20** is a block diagram of a control circuit for controlling a vacuum evacuation apparatus including two first vacuum pumps **1** and a single second vacuum pump **2** which are integrally connected into an integral pump unit. As shown in FIG. **20**, the control circuit includes a motor for one of the two first vacuum pumps **1**, i.e., TMP (turbomolecular pump) **1**, a motor for the other first vacuum pump **1**, i.e., TMP**2**, an inverter (INV) for the TMP**1**, an inverter (INV) for the TMP**2**, a motor for the second vacuum pump **1**, i.e., a DRY (dry) pump, and an inverter (INV) for the DRY pump. The control circuit also includes a single controller (CPU) for integrally controlling the three inverters, i.e., the INV for the TMP**1**, the INV for the TMP**2**, and the INV for the DRY pump. The CPU is capable of optimally controlling the pressure in the vacuum container by controlling the rotational speeds of the motors of the first and second vacuum pumps **1**, **2** at desired rotational speed control rates with the inverters without the need for pressure detectors in the evacuation pipes connected to the first and second vacuum pumps **1**, **2**. The control circuit shown in FIG. **20** also includes a power factor controller (PFC) and a DC/DC converter (DC/DC).

[0180] FIG. **21** is a graph showing how the rotational speeds of a single first vacuum pump and two second vacuum pumps were changed to adjust the pressure in a vacuum container in a pump rotational speed control process which was performed on a vacuum evacuation apparatus according to the present invention, in the case of the first vacuum pump comprising a turbomolecular pump and the two second vacuum pumps comprising a dry pump.

[0181] With the single first vacuum pump (turbomolecular pump) and the two second vacuum pumps (dry pumps) being integrally connected together by evacuation passages, after pressure adjustment in the vacuum container is started, the rotational speed of the first vacuum pump is lowered, and when the pressure in the vacuum container rises, one of the second vacuum pumps starts to reduce the rotational speed thereof. At this time, the first vacuum pump continues speed reduction. After the first vacuum pump has stopped reducing its rotational speed, the other second vacuum pump starts to reduce the rotational speed thereof. Then, the second vacuum pump which has started reducing its rotational speed earlier stops reducing its rotational speed. The other second vacuum pump continuously reduces its rotational speed, and when the pressure in the vacuum container reaches a desired pressure level, the other second vacuum pump stops reducing its rotational speed. At this time, the pressure adjustment in the vacuum container is completed.

[0182] Since the three vacuum pumps are interconnected, the pressure in the vacuum container changes quickly in response to the reduction in the rotational speeds of the second vacuum pumps, and thus the pressure in the vacuum container can reach a target pressure (pressure adjustment completing point), in the shortest period of time. In addition, since the two second vacuum pumps start and stop reducing their rotational speeds at different times, the pressure in the vacuum container can be adjusted finely.

[0183] FIGS. **22** through **25** are schematic cross-sectional views showing various different turbomolecular pumps for use in the vacuum evacuation apparatus according to the present invention.

[0184] As shown in FIG. **22**, the first vacuum pump **1** comprises a turbomolecular pump having a pump casing **109**, and rotor blades **111** and stator blades **114** that are alternately mounted on a rotational shaft **113** and arranged successively from a central inlet port defined in the pump casing **109** toward left and right opposite ends of the rotational shaft **113**. The multistage rotor blades **111** are integrally formed on the rotational shaft **113**, and the multistage stator blades **114** are fixed to the pump casing **109**.

[0185] A second vacuum pump **2** that is integrally connected to the first vacuum pump **1** is structurally identical to the screw-type dry vacuum pump shown in FIG. **3**.

[0186] The second vacuum pump **2** has a pair of parallel screw rotors which are parallel to a lower surface of the first vacuum pump **1**. The screw rotors have respective axes parallel to the axis of the rotational shaft **113** of the first vacuum pump **1**.

[0187] FIG. **23** shows a different posture when the second vacuum pump **2** is mounted on the first vacuum pump **1**.

[0188] As shown in FIG. **23**, the axes of the screw rotors of the second vacuum pump **2** are perpendicular to the axis of the rotational shaft **113** of the first vacuum pump **1**, and extend parallel to each other and are spaced by a common distance from the lower surface of the first vacuum pump **1**.

[0189] FIG. **24** shows a vacuum evacuation apparatus in which the fastening component **62** and the vibro-isolating bushings **63** shown in FIGS. **9** and **10** are disposed between the first vacuum pump **1** and the second vacuum pump **2** shown in FIG. **22**.

[0190] FIG. **25** shows a vacuum evacuation apparatus in which the fastening component **62** and the vibro-isolating bushings **63** shown in FIGS. **9** and **10** are disposed between the first vacuum pump **1** and the second vacuum pump **2** shown in FIG. **23**. As shown in FIGS. **24** and **25**, since the first vacuum pump **1** and the second vacuum pump **2** are fastened to each other using a vibro-isolating mechanism including the vibro-isolating bushings **63**, the level of vibrations that are transmitted from the second vacuum pump **2** to the first vacuum pump **1** can be lowered.

[0191] Although preferred embodiments have been described in detail above, it should be understood that the present invention is not limited to the illustrated embodiments, but many changes and modifications can be made therein without departing from the appended claims.

What is claimed is:

1. A vacuum evacuation apparatus for evacuating a container from an atmospheric pressure to a high vacuum or less, comprising:

a first vacuum pump for evacuating the container to a high vacuum or less; and

a second vacuum pump for evacuating the container from an atmospheric pressure to a medium or low vacuum;

wherein said first vacuum pump and said second vacuum pump are integrally connected to each other into an integral unit.

2. A vacuum evacuation apparatus according to claim **1**, wherein said first vacuum pump has a rotational shaft and said second vacuum pump has a rotational shaft, and said rotational shaft of said first vacuum pump and said rotational shaft of said second vacuum pump have respective axes which are perpendicular to each other.

3. A vacuum evacuation apparatus according to claim **1**, wherein said first vacuum pump has a rotational shaft and said second vacuum pump has a rotational shaft, and said rotational shaft of said first vacuum pump and said rotational shaft of said second vacuum pump are rotatably supported by one of self-lubricating bearings, bearings having a semi-solid lubricant or a solid lubricant therein, gas bearings, and magnetic bearings; and

wherein said rotational shaft of said first vacuum pump and said rotational shaft of said second vacuum pump are rotatable regardless of directions in which said first vacuum pump and said vacuum pump are installed.

4. A vacuum evacuation apparatus according to claim **1**, wherein said first vacuum pump has a bottom component and said second vacuum pump has a casing, and said bottom component and said casing are integrally connected to each other, thereby integrally connecting said first vacuum pump and said second vacuum pump.

5. A vacuum evacuation apparatus according to claim **1**, wherein said first vacuum pump and said second vacuum pump are integrally connected to each other through a heat insulation member or a small area of contact.

6. A vacuum evacuation apparatus according to claim **1**, wherein said first vacuum pump and said second vacuum pump are integrally connected to each other through a vibro-isolating mechanism.

7. A vacuum evacuation apparatus according to claim **1**, wherein said first vacuum pump has an outlet port and said second vacuum pump has an inlet port, and said outlet port and said inlet port are interconnected by an evacuation passage component comprising a vibro-isolating material.

8. A vacuum evacuation apparatus according to claim **1**, wherein said first vacuum pump has an inlet port and said second vacuum pump has an inlet port, and said inlet port of said first vacuum pump and said inlet port of said second vacuum pump are interconnected by a bypass passage for bypassing said first vacuum pump.

9. A vacuum evacuation apparatus according to claim **1**, wherein said first vacuum pump has an outlet port and said second vacuum pump has an inlet port, and said outlet port and said inlet port are interconnected by an evacuation passage component incorporating therein a check valve for preventing a fluid from flowing back from said second vacuum pump to said first vacuum pump while said first vacuum pump is in operation.

10. A vacuum evacuation apparatus according to claim **1**, further comprising:

a controller for controlling said first vacuum pump and said second vacuum pump;

wherein said controller is integrally connected to said first vacuum pump or is installed separately from said first vacuum pump.

11. A vacuum evacuation apparatus according to claim **10**, wherein when each of said first vacuum pump and said second vacuum pump reaches a rated rotational speed and no gas is introduced into the container, said controller lowers a voltage applied to a motor of at least one of said first vacuum pump and said second vacuum pump and continuously operates said motor at a motor maximum efficient point.

12. A vacuum evacuation apparatus according to claim **10**, wherein said controller is capable of controlling the pressure in the container at a target pressure level by individually controlling respective rotational speeds of said first vacuum pump and said second vacuum pump depending on flow rates of the gas evacuated therefrom.

13. A vacuum evacuation apparatus according to claim **1**, wherein said first vacuum pump comprises a turbomolecular pump, and said second vacuum pump comprises a dry vacuum pump.

14. A vacuum evacuation apparatus according to claim **1**, wherein said second vacuum pump comprises a dry vacuum pump having a pair of pump rotors with respective magnet rotors mounted thereon, said magnet rotors have equal numbers of magnetic poles and are disposed so that their different magnetic poles are magnetically attracted to each other, and currents supplied to a multiphase armature including an iron core and a plurality of windings disposed radially outwardly of at least one of said magnet rotors are switched to actuate said at least one of said magnet rotors for thereby rotating said pump rotors in opposite directions in synchronism with each other.

15. A vacuum evacuation apparatus according to claim **1**, wherein one of said first vacuum pump and said second vacuum pump comprises a single vacuum pump and the other of said first vacuum pump and said second vacuum pump comprises either a single vacuum pump or a plurality of vacuum pumps.

16. A vacuum evacuation apparatus according to claim **15**, wherein said first vacuum pump and said second vacuum pump are integrally connected to each other by at least one evacuation passage.

17. A vacuum evacuation apparatus according to claim **1**, wherein the ratio of an axial dimension of said second vacuum pump and an axial dimension, which is assumed to be 1, of said first vacuum pump is in a range from 1 to 0.6, and the ratio of a volume of said second vacuum pump and a volume, which is assumed to be 1, of said first vacuum pump is in a range from 0.3 to 0.5.

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