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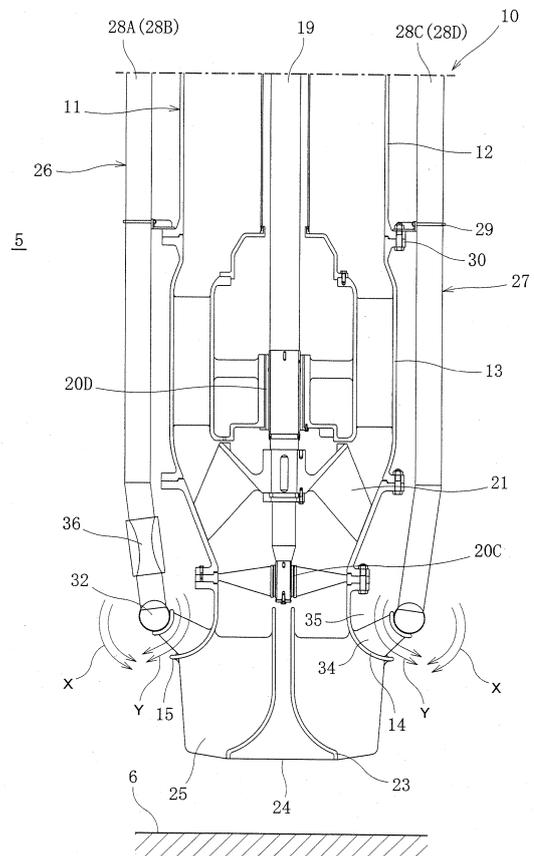
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(54) **VIBRATION DAMPING DEVICE FOR PUMP**

(57) A vibration damping device 26 for a pump 1 includes a liquid flow path 27 which is disposed at an outer peripheral portion of a casing 11 positioned in a suction sump 5 and which accommodates liquid inside itself so that the liquid can flow. The liquid flow path 27 is provided with a liquid flow resistor 36 for suppressing flowing of the liquid in the liquid flow path 27. Flow resistance in combination with an effect of a liquid column dynamic vibration absorber absorbs earthquake vibration energy to thereby suppress vibrations.

Fig. 2



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Description

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0001] The present invention relates to a vibration damping device for a pump.

DESCRIPTION OF RELATED ART

[0002] A building in which a pump is installed has an installation floor. A suction sump is formed below the installation floor and a pump chamber is formed above the installation floor. A vertical pump is inserted through an installation hole in the installation floor and has a casing extending in a vertical direction from the pump chamber into the suction sump. A suction port is formed on a lower end side of the casing positioned in the suction sump. A main shaft to which an impeller is fixed is disposed in the casing and a drive device (motor) is mechanically connected to the main shaft.

[0003] A pump structure including the installation floor (building) and the pump is individually designed to be balanced in consideration of a condition of the installation floor at a site where the pump is to be installed so that vibrations are not generated during operation. However, vibrations caused by variations in rigidity of the actual installation floor of the building are unavoidable. According to a vertical pump disclosed in Japanese Patent Application Laid-open No. 2003-161285, a base member is disposed in an installation hole in an installation floor and a casing is fixed to the base member by means of two-point support. With this arrangement, a resonance phenomenon is prevented and vibrations of the vertical pump and damage to the installation floor are suppressed.

[0004] However, the vertical pump in Japanese Patent Application Laid-open No. 2003-161285 is not prepared for vibrations of unexpected earthquakes at all. Especially, long-period (low-frequency) ground motions which are shakes for a long period are less likely to be damped and produce resonance in a construction to increase the amplitude of the vertical pump, which results in damage to the pump structure.

SUMMARY OF THE INVENTION

[0005] It is an object of the present invention to provide a vibration damping device for a pump, which can suppress vibrations caused by operation and earthquakes to prevent damage to a pump structure.

[0006] The present invention provides a vibration damping device for a pump including a pump casing inserted through an installation hole in an installation floor to extend in a vertical direction in a suction sump, characterized in that the device comprises, a liquid pipe disposed in the suction sump and outside the pump casing and accommodating a liquid so to allow flowing of the

liquid flows; and a liquid flow resistor provided in the liquid pipe to suppress flowing of the liquid in the liquid pipe.

[0007] The vibration damping device includes, outside the pump casing, the liquid pipe housing the liquid so that the liquid can flow. The liquid pipe allows the liquid to flow therethrough to thereby function as a dynamic vibration absorber. Therefore, it is possible to suppress vibrations caused by long-period ground motions. By housing water as the liquid in the liquid pipe, it is possible to give such a natural frequency as to reduce the vibrations during the normal operation. With the effect of the dynamic vibration absorber exerted by the liquid pipe, it is possible to reduce the vibrations applied to a pump structure including the pump and the installation floor. Because the liquid pipe is provided with the liquid flow resistor and flow resistance against the liquid at the liquid flow resistor damps or absorbs the vibrations, it is possible to further reduce the vibrations applied to the pump structure. Moreover, the liquid accommodated in the liquid pipe increases a pump weight and therefore it is possible to counteract exciting forces of the earthquakes. Furthermore, because a lower portion of the liquid pipe is submerged in the liquid stored in the suction sump, generation of a viscous force of the liquid and the additional mass further reduces the vibrations. As a result, it is possible to prevent damage to the pump structure.

[0008] The liquid pipe includes two or more vertical pipes extending along an axis of the pump casing and a lateral pipe connecting lower end sides of the vertical pipes. The liquid pipe having a U-shaped section can reliably suppress vibrations of the pump casing due to fluctuation of a liquid column extending from the one vertical pipe to the other vertical pipe through the lateral pipe. Moreover, with setting of positions of the vertical pipes, it is possible to prevent generation of an air entrained surface vortex extending from a surface of the liquid in the suction sump to a suction port of the pump casing.

[0009] Alternatively, the liquid pipe includes two or more vertical pipes extending along an axis of the pump casing and lower ends of the vertical pipes are open in the suction sump. With the plurality of liquid pipes in shapes of straight pipes and communicating with each other through the suction sump in this manner, it is possible to reliably reduce the vibrations applied to the pump structure. Moreover, because the structure of the vibration damping device can be simplified, it is possible to improve assembly workability. Furthermore, with setting of the positions of the vertical pipes, it is possible to prevent generation of the air entrained surface vortex extending from the surface of the liquid in the suction sump to the suction port of the pump casing.

[0010] The lower ends the vertical pipes are positioned below an expected lowest level of the liquid stored in the suction sump. This arrangement can reliably suppress vibrations of the pump casing due to fluctuation of the liquid column with maintaining the liquid accommodated in the vertical pipes.

[0011] Upper ends the vertical pipes are positioned above an expected highest level of the liquid stored in the suction sump. If the liquid in the suction sump enters from the upper ends of the vertical pipes, the amount of the liquid in the liquid pipe increases and, as a result, the set natural frequency changes. If the natural frequency changes, it may reduce an effect of the dynamic vibration absorber of the liquid pipe for reducing the vibrations of the pump structure. However, by setting positions of the upper ends of the vertical pipes above the water surface in the suction sump, it is possible to reliably prevent occurrence of such a problem.

[0012] Preferably, the liquid pipe has first and second liquid pipes defined to be fluidically separated from each other. Here, the first and second liquid pipes may be a combination of liquid pipes with different distances between the axis of the pump casing and the vertical pipes and having U-shaped sections or a combination of a liquid pipe having a U-shaped section and a liquid pipe in a shape of a straight pipe. In this manner, it is possible to give different natural frequencies to the first liquid pipe and the second liquid pipe to thereby obtain the effect of suppressing the vibrations of a wide range of long-period ground motions.

[0013] The liquid pipe may have two or more connecting portions and two or more gas pipes. The gas pipes have lower end sides connected to the respective connecting portions of the liquid pipes and having upper end sides communicating with each other. With this arrangement, a fluid system formed by liquid and gas can reliably reduce the vibrations applied to the pump structure. The connecting portions of the liquid pipe having the vertical pipes are the upper ends of the vertical pipes. In the case of the liquid pipe having the U-shaped section, the gas pipe forms a closed circuit through which the liquid and the gas can flow. Therefore, it is possible to maintain the set amount of liquid in the liquid pipe to thereby reliably reduce the vibrations.

[0014] Preferably, the gas pipe is provided with a gas flow resistor for suppressing flowing of gas. With this arrangement, flow resistance against the gas at the gas flow resistor can absorb earthquake vibration energy to thereby further reduce the vibrations.

[0015] The vibration damping device may further include a float disposed to be movable in a vertical direction along the vertical pipe following a water level in the suction sump and movable in a lateral direction with respect to the vertical pipe following a water stream in the suction sump. Because the float covers an air containing vortex at the water surface, it is possible to prevent generation of the air entrained surface vortex.

EFFECTS OF THE INVENTION

[0016] In the vibration damping device for a pump according to the present invention, it is possible to give the pump such a natural frequency as to suppress the vibrations caused by the long-period ground motions by use

of the liquid pipe housing the liquid. The liquid in the liquid pipe functions as the dynamic vibration absorber. As a result, it is possible to reduce the vibrations applied to the pump structure including the pump and the installation floor. Moreover, the liquid pipe is provided with the liquid flow resistor and therefore the flow resistance against the liquid exerts the effect of damping (absorbing) the vibrations to thereby further reduce the vibrations applied to the pump structure. As a result, it is possible to prevent damage to the pump structure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017]

Fig. 1 is a sectional view of a vibration damping device for a pump according to a first embodiment of the present invention;

Fig. 2 is an enlarged sectional view of a part of Fig. 1; Fig. 3A is an enlarged sectional view taken along line A-A in Fig. 1;

Fig. 3B is an enlarged sectional view taken along line B-B of liquid pipes in Fig. 1;

Fig. 4 is a schematic diagram of the vibration damping device according to the first embodiment;

Fig. 5 is a schematic diagram of a vibration damping device according to a modification of the first embodiment;

Fig. 6 is a sectional view of a vibration damping device for a pump according to a second embodiment;

Fig. 7 is a schematic diagram of the vibration damping device according to the second embodiment;

Fig. 8 is a schematic diagram of a vibration damping device according to a modification of the second embodiment;

Fig. 9 is a sectional view of a vibration damping device for a pump according to a third embodiment;

Fig. 10 is a schematic diagram of the vibration damping device according to the third embodiment;

Fig. 11 is a schematic diagram of a vibration damping device according to a modification of the third embodiment;

Fig. 12 is a partial sectional view of a vibration damping device for a pump according to a fourth embodiment; and

Fig. 13 is a sectional view of liquid pipes according to the fourth embodiment and similar to Fig. 3B.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0018] Embodiments of the present invention will be described below with reference to the drawings.

(First Embodiment)

[0019] Fig. 1 shows a vertical pump 10 provided with a vibration damping device 26 of a first embodiment ac-

According to the present invention. The vertical pump 10 includes a casing (pump casing) 11 inserted through an installation floor 2 of a building from above and fixed to extend in a vertical direction in a lower suction sump 5. The vibration damping device 26 in the embodiment is disposed at an outer peripheral portion of the casing 11 substantially positioned in the suction sump 5 and suppresses vibrations during normal operation and vibrations caused by long-period ground motions to thereby prevent damage to a pump structure 1 including the installation floor 2 and the vertical pump 10.

[0020] The casing 11 of the vertical pump 10 includes a column pipe 12 in a shape of a straight pipe which is inserted through an installation hole 3 and ranges from a pump chamber 4 above the installation floor 2 to the suction sump 5 below the installation floor 2. An impeller case 13 is disposed on a lower end side of the column pipe 12 and a suction bell mouth 14 having a diameter gradually increasing downward is disposed at a lower end of the impeller case 13. A suction port 15 at a lower end of the suction bell mouth 14 is disposed to face a bottom wall 6 of the suction sump 5 at a predetermined distance from the bottom wall 6. At an upper end of the column pipe 12, a discharge bend 16 curved 90° so as to change a flow of water from the vertical direction to a horizontal direction is disposed. The discharge bend 16 is disposed in the pump chamber 4. At a lower portion of the discharge bend 16, a fixing flange portion 17 for fixing the discharge bend 16 to a periphery of the installation hole 3 on an upper face of the installation floor 2 is provided. To an outlet of the discharge bend 16, a discharge pipe 18 connected to a discharge sump (not shown) on a downstream side is connected.

[0021] In the casing 11, a main shaft 19 extending in the vertical direction along an axis of the column pipe 12 is disposed. The main shaft 19 is rotatably supported by bearings 20A to 20D in the column pipe 12. A lower end of the main shaft 19 passes through the impeller case 13 and is rotatably supported by the bearing 20C positioned in the suction bell mouth 14. An impeller 21 is fixed to the lower end side of the main shaft 19 positioned in the impeller case 13 and rotatably supported by the bearing 20D. To an upper end of the main shaft 19 protruding outside the casing 11 from the discharge bend 16, a driving machine 22 is connected. As the driving machine 22, an electric motor or an internal combustion engine can be used. If the electric motor is used, it is preferable to use a waterproof (submersible) motor in which a rotor and a stator are disposed in a motor casing in a watertight manner.

[0022] In the suction bell mouth 14 in the embodiment, a shaft center bell mouth 23 with which a submerged vortex preventing rib 25 is formed integrally is disposed. The shaft center bell mouth 23 is made of a resin such as FRP (fiber-reinforced plastic) and in a shape of a conical cylinder extending along an axis of the suction bell mouth 14. A lower end opening 24 of the shaft center bell mouth 23 is positioned closer to the bottom wall 6 of the

suction sump 5 than a suction port 15 of the suction bell mouth 14 so as to be positioned above the bottom wall 6 at a predetermined distance from the bottom wall 6. The submerged vortex preventing rib 25 is a straightening vane which can effectively eliminate a submerged vortex and provided in the shaft center bell mouth 23 to protrude radially outward. An upper edge of the submerged vortex preventing rib 25 is formed into a shape conforming to an inner face of the suction bell mouth 14 and connected to the suction bell mouth 14 by use of bolts or the like.

[0023] With reference to Figs. 1 and 4, the vibration damping device 26 is provided for purposes of damping the long-period ground motions which are shakes for a long period and preventing the vibrations of the casing 11 during operation as well. The vibration damping device 26 includes a liquid pipe 27 disposed at an outer peripheral portion of a lower side of the casing 11 positioned in the suction sump 5 and a gas pipe 37 disposed at an outer peripheral portion of an upper side of the casing 11. In the embodiment, the liquid pipe 27 and the gas pipe 37 form an endless closed circuit through which liquid and gas can flow.

[0024] The liquid pipe 27 accommodates the liquid (water, in the embodiment, but not limited to water) inside itself so that the liquid can flow and suppresses the long-period ground motions applied to the casing 11. Moreover, the liquid pipe 27 serves as a weight variable portion for changing a weight of a lower portion of the casing 11 so that a natural frequency of the vertical pump 10 deviates from an excitation frequency. The liquid pipe 27 includes liquid vertical pipes 28A to 28D extending parallel along an axis of the casing 11 and a liquid lateral pipe 32 connected to lower ends of the respective liquid vertical pipes 28A to 28D. These liquid pipes 28A to 28D and 32 are formed by resin pipes made of FRP or the like. Out of these pipes, the liquid vertical pipe 28A is provided with a liquid flow resistor 36 at a portion submerged in the accommodated water.

[0025] As shown in Figs. 2 and 3A, the liquid vertical pipes 28A to 28D are disposed at intervals of 90° in a circumferential direction at the outer peripheral portion of the casing 11. Each of the liquid vertical pipes 28A to 28D is mounted by use of a mounting member 29 at a predetermined distance from the casing 11 on a radially outer side. The position of the mounting member 29 by which each of the liquid vertical pipes 28A to 28D is mounted is preferably a portion where the column pipe 12 is highly likely to be vibrated. In the embodiment, the mounting member 29 fixes each of the liquid vertical pipes 28A to 28D at a connecting flange portion 30 of the column pipe 12. Upper ends of the liquid vertical pipes 28A to 28D are positioned above an expected highest water level of the water stored in the suction sump 5. As is clearly shown in Fig. 1, at the upper ends of the liquid vertical pipes 28A to 28D, connecting portions 31A to 31D for connecting gas vertical pipes 38A to 38D (described later) in liquid-tight and airtight manners are pro-

vided. The lower ends of the liquid vertical pipes 28A to 28D are positioned on the same level as an outer peripheral portion of the suction bell mouth 14.

[0026] The liquid vertical pipes 28A and 28B are disposed on an upstream side of the main shaft 19 (the suction bell mouth 14) in an inflow direction of the water into the suction sump 5. The liquid vertical pipes 28C and 28D are disposed on a downstream side of the main shaft 19 in the inflow direction into the suction sump 5. A downstream side in the suction sump 5 in the inflow direction is closed with a vertical wall (not shown). Because of collision of drainage water with the vertical wall, a vortex flow becomes more likely to be generated to roll from opposite sides to an inner side. If the vortex flow grows, a vortex (air entrained surface vortex) which draws in air from a water surface to the suction port 15 is generated. The downstream liquid vertical pipes 28C and 28D are disposed in an area where the air suction vortex is likely to be generated. To newly form a pump structure 1 including the suction sump 5, it is preferable to install piping so that the liquid vertical pipes 28A to 28D are positioned at all four points of a compass.

[0027] The liquid lateral pipe 32 is the annular pipe disposed to be positioned on the lower end side of the casing 11. As is clearly shown in Fig. 3B, the liquid lateral pipe 32 in the embodiment is formed into an annular shape by connecting paired semicircular pipes 33A and 33B. The lower ends of the respective liquid vertical pipes 28A to 28D are joined to the liquid lateral pipe 32 in a liquid-tight manner to allow the respective liquid vertical pipes 28A to 28D to communicate with each other. The liquid lateral pipe 32 is supported by supporting portions 34 provided at the outer peripheral portion of the suction bell mouth 14 so as to surround a reduced diameter portion of the suction bell mouth 14 at an outward distance from the reduced diameter portion. The support portions 34 are provided at four positions at intervals of 90° and serve as straightening vanes for preventing a swirling flow generated at the outer peripheral portion of the suction bell mouth 14.

[0028] Between the liquid lateral pipe 32 and the suction bell mouth 14, a sub flow path 35 flared downward from an upper position and radially outward is formed. As shown in Fig. 2, a water stream (air entrained surface vortex) flowing from the water surface toward the suction port 15 is divided into a main stream X flowing outside the liquid lateral pipe 32 and a sub stream Y flowing through the sub flow path 35. Out of these streams, the main stream X flows radially inward from the water surface toward the suction port 15 of the suction bell mouth 14 and the sub stream Y flows radially outward along an outer peripheral face of the suction bell mouth 14. The main stream X and the sub stream Y collide with each other at an outer peripheral portion of the lower end of the suction bell mouth 14 to disappear and therefore it is possible to prevent generation of the air suction vortex.

[0029] The liquid flow resistor 36 is provided on a lower end side of the liquid vertical pipe 28A and suppresses

a flow of the water flowing through the liquid pipe 27. The liquid flow resistor 36 is formed by an orifice having a smaller opening area at a middle portion than at an inlet and an outlet so as to be able to suppress a capacity of the liquid which can pass through the liquid flow resistor 36. As the liquid flow resistor 36, a valve an opening ratio of which can be adjusted by manual operation may be used instead of the orifice. It is also possible to use a solenoid valve which is controlled to open and close by input of a signal. The liquid flow resistor 36 may be provided not in the liquid vertical pipe 28A only but in each of the paired liquid vertical pipes 28A and 28B or in each of all the liquid vertical pipes 28A to 28D. It is also possible to provide only one liquid flow resistor 36 in the liquid lateral pipe 32.

[0030] The gas pipe 37 accommodates the gas (air) inside itself so that the gas can flow and suppresses the long-period ground motions applied to the casing 11 similarly to the liquid pipe 27. The gas pipe 37 includes gas vertical pipes 38A to 38D extending parallel along the axis of the casing 11 and a gas lateral pipe 39 connected to upper ends of the respective gas vertical pipes 38A to 38D. These gas pipes 38A to 38D and 39 are formed by resin pipes made of FRP or the like. The gas lateral pipe 39 is provided with a gas flow resistor 40.

[0031] As shown in Figs. 1 and 4, the gas vertical pipes 38A to 38D are disposed at intervals of 90° in the circumferential direction at the outer peripheral portion of the casing 11 so as to be positioned along axes of the liquid vertical pipes 28A to 28D. Lower end sides of the gas vertical pipes 38A to 38D are connected to the respective connecting portions 31A to 31D of the liquid vertical pipes 28A to 28D. Upper end sides of the gas vertical pipes 38A to 38D pass through the installation hole 3 in the installation floor 2 and are disposed in the pump chamber 4.

[0032] The gas lateral pipe 39 is the annular pipe disposed to be positioned at an outer peripheral portion of the discharge bend 16 in the pump chamber 4. The liquid lateral pipe 32 in the embodiment is formed into an annular shape by connecting paired semicircular pipes similarly to the liquid lateral pipe 32. The upper ends of the respective gas vertical pipes 38A to 38D are joined to the gas lateral pipe 39 in an airtight manner and the respective gas vertical pipes 38A to 38D fluidically communicate with each other through the gas lateral pipe 39.

[0033] The gas flow resistor 40 is provided in the gas lateral pipe 39 and suppresses flowing of the air flowing through the gas pipe 37. The gas flow resistor 40 is formed by a valve in which an opening area of a middle portion with respect to opening areas of an outlet and an inlet can be adjusted by manual operation and which can suppress a capacity of gas passing through the gas flow resistor 40. As the gas flow resistor 40, a solenoid valve or an orifice may be used instead of the valve. The gas flow resistor 40 may be provided in one of the gas vertical pipes 38A to 38D, in each of the paired gas vertical pipes 38A and 38B, or in each of all the gas vertical pipes 38A

to 38D.

[0034] The vibration damping device 26 in the embodiment includes a water supply portion 41 for supplying a predetermined amount of liquid into the liquid pipe 27 and an air supply portion 42 for adjusting air pressure in the gas pipe 37 to predetermined pressure. A discharge portion 43 for drainage of the liquid in the liquid pipe 27 and depressurization in the gas pipe 37 is provided.

The water supply portion 41 includes a pump disposed in the pump chamber 4 and the pump is connected to the gas lateral pipe 39. The water supply portion 41 supplies the water, which is an example of the liquid having a greater specific gravity than air, into the liquid pipe 27 from a source of the water (not shown) through the gas pipe 37. A water supply amount is set to such an amount as to be able to give the pump structure 1 including the vertical pump 10 a natural frequency for reducing the vibrations during the normal operation by housing of the water in the liquid pipe 27. Moreover, the water supply amount is set to such an amount that the vibrations caused by the long-period ground motions can be suppressed by a function of a dynamic vibration absorber (described later). To put it concretely, the water is supplied into the liquid lateral pipe 32 to reach such a level as to submerge at least the liquid flow resistor 36 of the liquid vertical pipe 28A.

[0035] The liquid vertical pipes 28A to 28D of the liquid pipe 27 in the embodiment communicate with each other through the liquid lateral pipe 32. Out of the liquid vertical pipes 28A to 28D, the paired opposed liquid vertical pipes 28A and 28D or 28B and 28C form the liquid pipe 27 having a U-shaped section with which an effect of the dynamic vibration absorber can be obtained. An entire length of a liquid column formed by the water from the one liquid vertical pipe 28A or 28B to the other liquid vertical pipe 28D or 28C is set to such a length as to be able to suppress expected influences of horizontal vibrations due to earthquakes. Due to fluctuation of the liquid column, it is possible to obtain the effect of the dynamic vibration absorber to thereby suppress the vibrations of the casing 11.

[0036] The air supply portion 42 includes a compressor disposed in the pump chamber 4 and the compressor is connected to the gas lateral pipe 39. The air supply portion 42 supplies compressed air into the liquid lateral pipe 32 and the liquid vertical pipes 28A to 28D to thereby adjust (increase) the air pressure in the liquid pipe 27. If the air supply portion 42 makes the air pressure in the gas pipe 37 higher than atmospheric pressure, the water in the liquid pipe 27 flows faster to thereby increase the natural frequency. If the air supply portion 42 makes the air pressure in the gas pipe 37 lower than atmospheric pressure, the water in the liquid pipe 27 flows slower to thereby decrease the natural frequency. Therefore, by adjusting the pressure in the gas pipe 37 by use of the air supply portion 42, it is possible to adjust the natural

frequency (the natural frequency of the pump structure 1 including the vertical pump 10) given by the water in the liquid pipe 27.

[0037] The discharge portion 43 includes a drain valve disposed in the pump chamber 4 and is connected to the gas lateral pipe 39. The discharge portion 43 can decrease pressure or exhaust air in the gas pipe 37 when it is opened. By causing the air supply portion 42 to operate in the open state of the discharge portion 43, it is possible to push the water in the liquid pipe 27 up into the gas pipe 37 with the air pressure to drain the water through the discharge portion 43. In other words, the discharge portion 43, the water supply portion 41, and the air supply portion 42 cooperate to serve as a water amount adjusting portion for adjusting a water amount in the liquid pipe 27. The discharge portion 43 and the air supply portion 42 cooperate to serve as a pressure adjusting portion for adjusting the air pressure in the gas pipe 37. It is also possible to connect the discharge portion 43 to the liquid lateral pipe 32 so as to improve drainage performance.

The vertical pump 10 is designed to secure its balance based on rigidity of the installation floor 2 of a pump station where the vertical pump 10 is to be installed. Then, after the vertical pump 10 is installed on the installation floor 2, the discharge portion 43 is opened and the water is supplied from the water supply portion 41 into the liquid pipe 27 through the gas pipe 37. With this arrangement, the water is supplied so that the liquid lateral pipe 32 is filled with the water and that entire lengths of the liquid columns in the liquid vertical pipes 28A to 28D reach the preset lengths. As a result, the liquid flow resistor 36 provided in the liquid pipe 27 is submerged.

[0038] Then, test operation of the vertical pump 10 is carried out and vibrations applied to the installation floor 2 are detected by a known vibration sensor or the like. If a detection value does not fall within an acceptable range, it is determined that vibrations of an acceptable or greater value are generated and the vibration damping device 26 is adjusted so as to suppress the vibrations.

[0039] A principle of vibration suppression by the vibration damping device 26 will be described.

[0040] First, a conventional vertical pump 10 not provided with the vibration damping device 26 is a structure which is a single-degree-of-freedom vibration system having a single natural frequency component which resonates with a rotation speed of the driving machine 22 or the like. The vertical pump 10 which is the single-degree-of-freedom vibration system vibrates significantly due to the resonance when an excitation frequency Ω and a natural frequency ω coincide with each other because of a balance between the rigidity of the installation floor 2 and the casing 11. Therefore, if the natural frequency ω of the vertical pump 10 is adjusted to deviate from the excitation frequency Ω , it is possible to suppress the vibrations due to the resonance.

[0041] Because the vertical pump 10 provided with the vibration damping device 26 in the embodiment has the liquid pipe 27 connected to the casing 11 by the supporting portions 34, the vertical pump 10 forms a structure which is a two-degree-of-freedom vibration system having two different natural frequency components. In other words, the first natural frequency ω_1 on the side of the casing 11 (primary system) and the second natural frequency ω_2 on the side of the liquid pipe 27 (secondary system) are generated. The excitation frequency Ω is set to an intermediate frequency between the two natural frequencies ω_1 and ω_2 ($\omega_1 < \Omega < \omega_2$). As a result, a vibration of the primary system and a vibration of the secondary system have opposite phase from an exciting force on a side of a low-order mode and the vibration of the primary system is in phase with the exciting force and the vibration of the secondary system has opposite phase from the exciting force on a side of a high-order mode. If the respective vibrational modes are added, the low-order vibrational mode and the high-order vibrational mode of the vibration of the primary system cancel each other out.

[0042] The above relationship relates to a mass ratio μ between the casing 11 and the liquid pipe 27. Therefore, by supplying the water into the liquid pipe 27 which is the secondary system to adjust a mass or a weight, positions of waveforms of the natural frequencies ω_1 and ω_2 with respect to the excitation frequency Ω can be shifted (adjusted). To put it concretely, by increasing the water supply amount to increase the mass, it is possible to decrease the natural frequencies. On the other hand, by decreasing the water supply amount to decrease the mass, it is possible to increase the natural frequencies. By causing a lower limit peak value at the intermediate position between the two natural frequencies ω_1 and ω_2 and the excitation frequency Ω to coincide with each other, it is possible to suppress or substantially prevent the vibrations of the vertical pump 10 with the effect of the dynamic vibration absorber.

[0043] To adjust the natural frequencies of a pump structure 1 including the vertical pump 10, there is the method which adjusts the water amount in the liquid pipe 27 by using the water supply portion 41 and a method which adjusts the pressure in the gas pipe 37 by using the air supply portion 42. To put it concretely, to increase the natural frequencies, the liquid amount in the liquid pipe 27 is decreased or the air pressure in the gas pipe 37 is increased. To decrease the natural frequencies, the liquid amount in the liquid pipe 27 is increased or the air pressure in the gas pipe 37 is decreased.

[0044] However, in the embodiment, the entire lengths of the liquid columns in the liquid pipe 27 are set so as to be able to suppress the horizontal vibrations due to the expected earthquakes. Therefore, the natural frequencies are adjusted by the adjustment of the pressure in the gas pipe 37 by the air supply portion 42. In other words, after the water is supplied into the liquid vertical pipes 28A to 28D by the water supply portion 41 to reach

such a predetermined level as to submerge the liquid flow resistor 36, the air supply portion 42 changes the pressure in the gas pipe 37 to adjust the natural frequencies.

5 **[0045]** In a state in which the vibrations of the vertical pump 10 are suppressed by the vibration damping device 26, a controller (not shown) carries out drainage operation according to a preset program.

[0046] During the drainage operation, the water is supplied into the liquid pipes 28A to 28D and 32 and the natural frequencies ω_1 and ω_2 of the casing 11 are adjusted to deviate from the excitation frequency Ω and therefore the vibrations can be suppressed. Moreover, because the vertical pump 10 is formed as the structure which is the two-degree-of-freedom vibration system, it is possible to easily and reliably suppress or substantially prevent the vibrations as compared with a structure which is the single-degree-of-freedom vibration system. As a result, it is possible to reliably prevent damage to the installation floor 2 on which the vertical pump 10 is installed. Furthermore, because lower portions of the liquid vertical pipes 28A to 28D and the liquid lateral pipe 32 are submerged, generation of resistance (a viscous force) of the water in the suction sump 5 and the additional mass further reduces the vibrations.

[0047] If the water in the suction sump 5 is drained to a position near the impeller 21, the air entrained surface vortex is likely to be generated in an area on a downstream side of the suction bell mouth 14 in the inflow direction into the suction sump 5. However, the vertical pump 10 in the embodiment has the liquid vertical pipes 28C and 28D having the effect of preventing generation of the air entrained surface vortex in the area and therefore it is possible to effectively suppress generation of the air entrained surface vortex at the water surface. Moreover, the water stream flowing from the water surface toward the suction port 15 is divided into the main stream X and the sub stream Y as shown in Fig. 2 and they collide with each other and disappear and therefore it is possible to reliably prevent generation of the air entrained surface vortex.

[0048] Because the liquid lateral pipe 32 is in the annular shape surrounding the casing 11, it can uniformly add the weight to the lower portion of the casing 11 when the water is supplied. Therefore, it is possible to reliably suppress the vibrations without losing the balance. The liquid pipes 28A to 28D and 32 and the gas pipes 38A to 38D and 39 are formed by resin pipes, which greatly improves ease of installation.

50 **[0049]** Moreover, the vibration damping device 26 in the embodiment can suppress not only the vibrations during the normal operation but also the influences of the long-period ground motions. To put it concretely, if the vertical pump 10 receives an earthquake load (an inertial force generated when the vertical pump 10 vibrates due to the earthquake) from the earthquake, the liquid columns extending through the respective liquid vertical pipes 28A to 28D and having the U-shaped sections fluc-

tuates to exert the effect of the liquid column dynamic vibration absorber. The entire lengths of the liquid columns in the liquid pipe 27 are set to such lengths as to be able to suppress the horizontal vibrations due to the expected earthquakes and therefore it is possible to reduce the vibrations applied to the pump structure 1 by the earthquakes.

[0050] Because the liquid pipe 27 and the gas pipe 37 in the embodiment are provided with the resistors 36 and 40 which can suppress the flows, flow resistance against the water at the liquid flow resistor 36 and flow resistance against the gas at the gas flow resistor 40 absorb earthquake vibration energy. In other words, the water flowing through the liquid pipe 27 is retained at the liquid flow resistor 36 to thereby absorb the earthquake vibration energy and the air flowing through the gas pipe 37 due to the flow of the water is retained at the gas flow resistor 40 to thereby absorb the earthquake vibration energy. This can further reduce the vibrations applied to the pump structure 1. Moreover, the additional mass due to the water and increase in a pump weight due to the liquid accommodated in the liquid pipe 27 can counteract exciting forces of the earthquakes. Therefore, it is possible to obtain an effect of improving resistance against the earthquakes to thereby increase reliability of the pump.

(Modifications of First Embodiment)

[0051] Although the gas flow resistor 40 is provided in the gas pipe 37 in the first embodiment, the gas flow resistor 40 may not be provided. Although the air supply portion 42 and the discharge portion 43 for adjusting the pressure in the gas pipe 37 are provided, the air supply portion 42 and the discharge portion 43 may not be provided. The water supply portion 41 may not be provided and a vibration damping device 26 may be assembled after housing a predetermined amount of water into a liquid pipe 27.

[0052] As shown in Fig. 5, the gas pipe 37 itself may not be provided. In this case, upper ends of liquid vertical pipes 28A to 28D set to be higher than a highest water level of drainage water stored in the suction sump 5 are preferably sealed in a liquid-tight manner, but they may be open. When the upper ends of the liquid vertical pipes 28A to 28D are open, if the drainage water enters, an amount or a weight of liquid in the liquid pipe 27 increases and therefore set natural frequencies change. However, the upper ends of the liquid vertical pipes 28A to 28D are set to be higher than the highest water level in the embodiment, such a problem does not occur.

(Second Embodiment)

[0053] Figs. 6 and 7 show a vibration damping device 26 for a vertical pump 10 according to a second embodiment. The second embodiment is different from the first embodiment in that a liquid pipe 27 is formed only by liquid vertical pipes 28A to 28D extending along a casing

11 without provision of the liquid lateral pipe 32.

[0054] The liquid vertical pipes 28A to 28D in shapes of straight pipes are disposed at intervals of 90° at an outer peripheral portion of the casing 11 by use of mounting members 29 as in the first embodiment. Upper ends of the liquid vertical pipes 28A to 28D are positioned above an expected highest water level of the water stored in a suction sump 5. Lower ends of the liquid vertical pipes 28A to 28D in the second embodiment are positioned below an expected lowest water level of the water stored in the suction sump 5 and are open in the suction sump 5. To put it concretely, the lower ends of the liquid vertical pipes 28A to 28D are positioned closer to a bottom wall 6 than a suction port 15 at a lower end of the suction bell mouth 14. The liquid vertical pipe 28A is provided with a liquid flow resistor 36 for suppressing flowing of the flowing water.

[0055] As shown in Fig. 7, in the vibration damping device 26 in the second embodiment, a gas pipe 37 is connected to connecting portions 31A to 31D at the upper ends of the liquid vertical pipes 28A to 28D which form the liquid pipe 27 and which are in the shapes of the straight pipes as in the first embodiment. A gas lateral pipe 39 of the gas pipe 37 is provided with a gas flow resistor 40, a water supply portion 41, and a discharge portion 43 as in the first embodiment. However, an air supply portion 42 is not provided in the second embodiment.

[0056] The vertical pump 10 in the second embodiment is disposed on the installation floor 2 and the vibration damping device 26 suppresses vibrations as in the first embodiment. To adjust natural frequencies of the vertical pump 10 for suppression of the vibrations, the water is supplied into the liquid pipe 27 through the gas pipe 37 by the water supply portion 41 in a state in which the lower ends of the liquid vertical pipes 28A to 28D are submerged in drainage water in the suction sump 5. At this time, the discharge portion 43 is in a closed state and not communicating with an outside. This allows the water to be accommodated to reach set heights in the respective liquid vertical pipes 28A to 28D.

[0057] Then, if drainage operation is carried out, the vibrations during operation can be reduced and generation of an air suction vortex can be prevented as in the first embodiment. Moreover, the respective liquid vertical pipes 28A to 28D communicate with each other through the drainage water stored in the suction sump 5. Therefore, liquid columns extending through the respective liquid vertical pipes 28A to 28D through the suction sump 5 and having U-shaped sections fluctuate to exert an effect of a liquid column dynamic vibration absorber. As a result, it is possible to suppress an influence of long-period ground motions to thereby reliably reduce the vibrations applied to a pump structure 1. Furthermore, the vibration damping device 26 does not have the liquid lateral pipe 32 to be connected to the liquid vertical pipes 28A to 28D, which can simplify the structure and improve assembly workability.

(Modifications of Second Embodiment)

[0058] Although the gas flow resistor 40 is provided in the gas pipe 37 in the second embodiment, the gas flow resistor 40 may not be provided. Although the water supply portion 41 and the discharge portion 43 for adjusting the amount of the water in the liquid pipe 27 are provided, the water supply portion 41 and the discharge portion 43 may not be provided. As shown in Fig. 8, the gas pipe 37 itself may not be provided. In this case, upper ends of liquid vertical pipes 28A to 28D are preferably sealed in a liquid-tight manner, but they may be open.

(Third Embodiment)

[0059] Figs. 9 and 10 show a vibration damping device 26 for a vertical pump 10 according to a third embodiment. The third embodiment is different from the first and second embodiments in that first and second vibration damping units 26A and 26B defined so as not to communicate with each other are provided. A first liquid pipe 27A of the first vibration damping unit 26A has the same structure as that in the first embodiment shown in Fig. 4 and a second liquid pipe 27B of the second vibration damping unit 26B has the same structure as that in the modification of the second embodiment shown in Fig. 8.

[0060] The first liquid pipe 27A is provided with a gas pipe 37 as in the first embodiment so that an endless closed circuit through which liquid and gas can flow is formed. The gas pipe 37 is provided with a gas flow resistor 40, a water supply portion 41, an air supply portion 42, and a discharge portion 43.

[0061] The second liquid pipe 27B is positioned at an outer peripheral portion of the first liquid pipe 27A. The second liquid pipe 27B formed by liquid vertical pipes 28A2 to 28D2 is not provided with a gas pipe 37. The liquid vertical pipes 28A2 to 28D2 have lower ends positioned below a lowest water level and upper ends positioned above a highest water level. The liquid vertical pipes 28A2 to 28D2 communicate with each other through a suction sump 5.

[0062] According to the third embodiment formed as described above, it is possible to obtain similar functions and effects to those in the first and second embodiments. The first and second liquid pipes 27A and 27B are different from each other in distance from an axis of a casing 11 to each of the liquid vertical pipes 28A1 to 28D1 or 28A2 to 28D2. Moreover, because the first and second liquid pipes 27A and 27B are different pipes independent of each other, it is possible to set different natural frequencies for them. As a result, it is possible to suppress a wide range of long-period ground motions.

(Modifications of Third Embodiment)

[0063] Although the second liquid pipe 27B is not provided with the gas pipe 37 in the third embodiment, it may be provided with the gas pipe 37 as in the second em-

bodiment. The first liquid pipe 27A may not be provided with the gas pipe 37 and the second liquid pipe 27B may be provided with the gas pipe 37. Both the first and second liquid pipes 27A and 27B may not be provided with the gas pipe 37.

[0064] Although the first liquid pipe 27A similar to that in the first embodiment and the second liquid pipe 27B similar to that in the second embodiment are combined in the third embodiment, it is also possible to combine a first liquid pipe 27A (liquid vertical pipes 28A1 to 28D1 and a liquid lateral pipe 32A) similar to that in the first embodiment and a second liquid pipe 27B (liquid vertical pipes 28A2 to 28D2 and a liquid lateral pipe 32B) different from the first liquid pipe 27A in distance from an axis of a casing 11 and substantially similar to that in the first embodiment as shown in Fig. 11. As shown in the figure, the gas pipes 37A and 37B may not be provided with the gas flow resistors 40. The water supply portion 41, the air supply portion 42, and the discharge portion 43 may not be provided.

[0065] The vibration damping device 26 of the pump 10 in the present invention is not limited to the structures in the above-described embodiments but may be changed in various ways.

[0066] For example, although the vertical pipes 28A to 28D and 38A to 38D are connected by the annular lateral pipes 32 and 39, respectively, lateral pipes 32 and 39 may connect pipes so that a pair of opposed liquid vertical pipes 28A and 28D and a pair of opposed gas vertical pipes 38A and 38D communicate with each other, respectively, and that the other pair of opposed liquid vertical pipes 28B and 28C and the other pair of opposed gas vertical pipes 38B and 38C communicate with each other, respectively. This arrangement can easily form two or more U-shaped closed circuits. Although the two vibration damping units are provided in the third embodiment, three or more vibration damping units may be provided.

[0067] In the first embodiment the liquid pipe 27 is formed by the liquid vertical pipes 28A to 28D and the liquid lateral pipe 32, and in the second embodiment the liquid pipe 27 is formed by the plurality of liquid vertical pipes 28A to 28D communicating with each other through the suction sump 5 and the gas pipe 37 is connected to each of the liquid vertical pipes 28A to 28D. However, connecting portions may be provided in the liquid lateral pipe 32 in the first embodiment and gas vertical pipes 38A to 38D may be directly connected to the liquid lateral pipe 32, for example.

[0068] Although the vibration damping device 26 according to the present invention is applied to the vertical pump 10 in the above-described embodiments, the vibration damping device 26 may be applied to a horizontal shaft type pump having a main shaft 19 disposed in a lateral direction with respect to a casing 11 and similar functions and effects can be obtained in this case. In other words, if a casing 11 is disposed to extend vertically downward through an installation hole 3 in an installation

floor 2, the vibration damping device 26 can be applied to the both types of pumps.

(Fourth Embodiment)

[0069] A vibration damping device 26 for a vertical pump 10 according to a fourth embodiment of the present invention shown in Figs. 12 and 13 is different from the first embodiment in that the vibration damping device 26 includes floats 56A and 56B.

[0070] The floats 56A and 56B are movably attached to liquid vertical pipes 28A and 28B disposed to be adjacent to a vertical wall on a back side in an inflow direction of water into a suction sump 5. The floats 56A and 56B in the embodiment may have hollow structures or solid structures, as long as they can float in the water. For example, the floats 56A and 56B are made of a light-weight resin.

[0071] The floats 56A and 56B move in a vertical direction along liquid vertical pipes 28A and 28B following change in water level in the suction sump 5, i.e., rising and lowering of a water surface. The floats 56A and 56B move in a horizontal direction following a water stream into the suction sump 5. The floats 56A and 56B are in annular shapes having insertion portions 57 with inside diameters larger than outside diameters of the liquid vertical pipes 28A and 28B and the liquid vertical pipes 28A and 28B are inserted through the respective insertion portions 57. Therefore, the floats 26A and 26B can move in the vertical direction along the liquid vertical pipes 28A and 28B and can move in the horizontal direction in movable ranges defined by dimension setting of the insertion portions 57 and the liquid vertical pipes 28A and 28B.

[0072] When an air entrained surface vortex is generated, a water stream extending from a water surface to a suction port is generated. This water stream generates the air entrained surface vortex which intermittently or continuously contains air. The floats 56A and 56B are always positioned at the water surface in the suction sump 5 and move in the horizontal direction in such manners as to be pulled into the generated water stream. As a result, the floats 56A and 56B cover the air entrained surface vortex, which is at an early stage of generation, on the water surface, and intercept supply of the air into the air entrained surface vortex. As a result, the air entrained surface vortex does not grow and disappears at the early stage of generation. In other words, with the floats 56A and 56B, it is possible to further effectively prevent generation of the air entrained surface vortex.

Claims

1. A vibration damping device for a pump including a casing inserted through an installation hole in an installation floor to extend in a vertical direction in a suction sump, **characterized in that** the device comprises,

a liquid pipe disposed in the suction sump and outside the casing and accommodating a liquid so to allow flowing of the liquid flows; and
a liquid flow resistor provided in the liquid pipe to suppress flowing of the liquid in the liquid pipe.

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2. The vibration damping device for a pump according to claim 1, **characterized in that** the liquid pipe includes two or more vertical pipes extending along an axis of the casing and a lateral pipe connecting lower end sides of the vertical pipes.

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3. The vibration damping device for a pump according to claim 1, **characterized in that** the liquid pipe includes two or more vertical pipes extending along an axis of the casing and lower ends of the vertical pipes are open in the suction sump.

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4. The vibration damping device for a pump according to claim 3, **characterized in that** the lower ends the vertical pipes are positioned below an expected lowest level of the liquid stored in the suction sump.

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5. The vibration damping device for a pump according to claims 2 to 4, **characterized in that** upper ends the vertical pipes are positioned above an expected highest level of the liquid stored in the suction sump.

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6. The vibration damping device for a pump according to claims 1 to 5, **characterized in that** the liquid pipe has first and second liquid pipes defined to be fluidically separated from each other.

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7. The vibration damping device for a pump according to claims 1 to 6, **characterized in that** the liquid pipe has two or more connecting portions, and two or more gas pipes are further provided, the gas pipes having lower end sides connected to the respective connecting portions of the liquid pipes and having upper end sides communicating with each other.

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8. The vibration damping device for a pump according to claim 7, **characterized in that** the gas pipe is provided with a gas flow resistor for suppressing flowing of gas.

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9. The vibration damping device for a pump according to claim 2, **characterized in that** the vibration damping device further comprises a float disposed to be movable in a vertical direction along the vertical pipe following a water level in the suction sump and movable in a lateral direction with respect to the vertical pipe following a water stream in the suction sump.

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10. The vibration damping device for a pump according

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to claim 9, **characterized in** the float is formed in an annular shape having an insertion portion with an inside diameter larger than outside diameters of the vertical pipes.

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Fig. 2

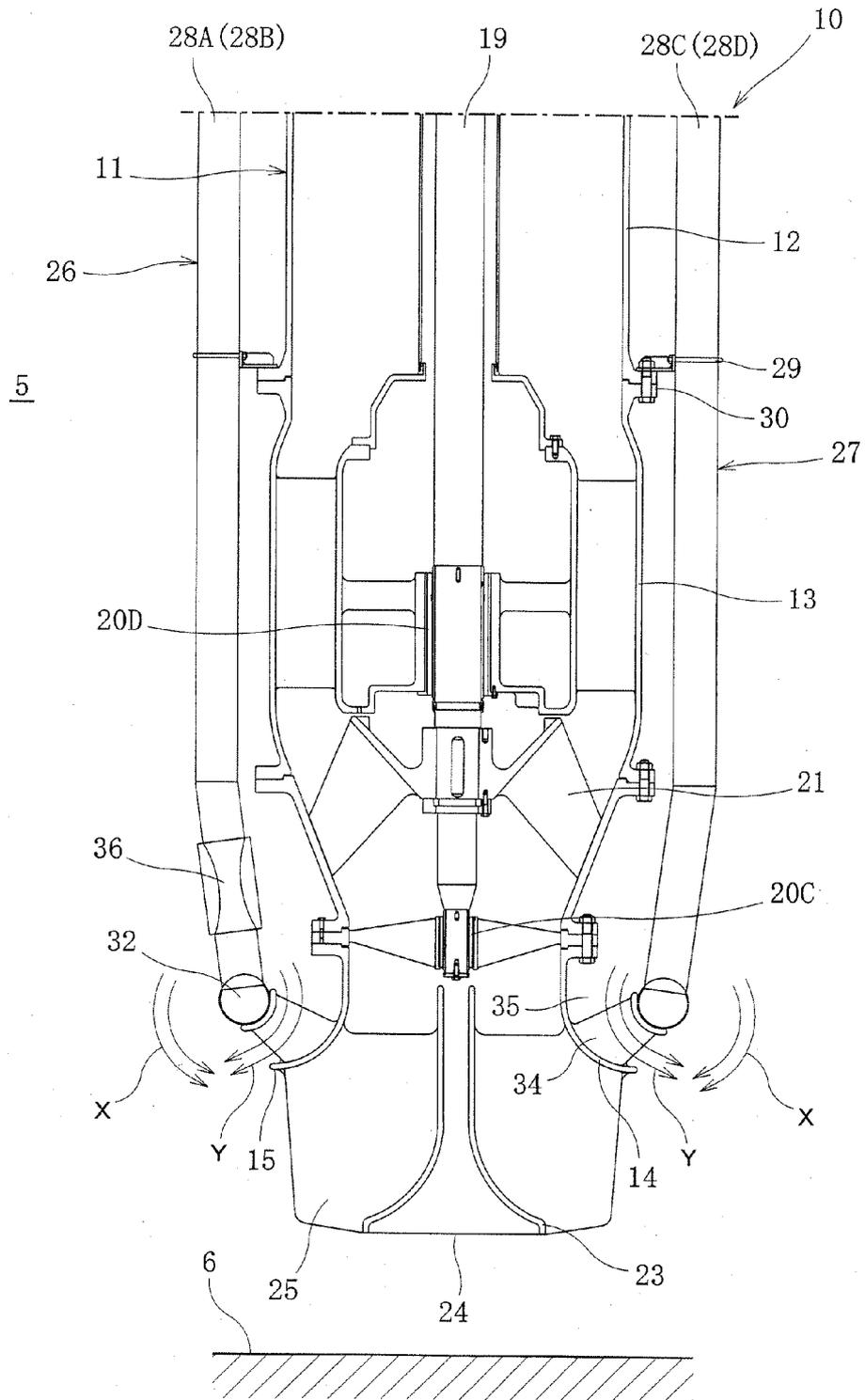


Fig. 3A

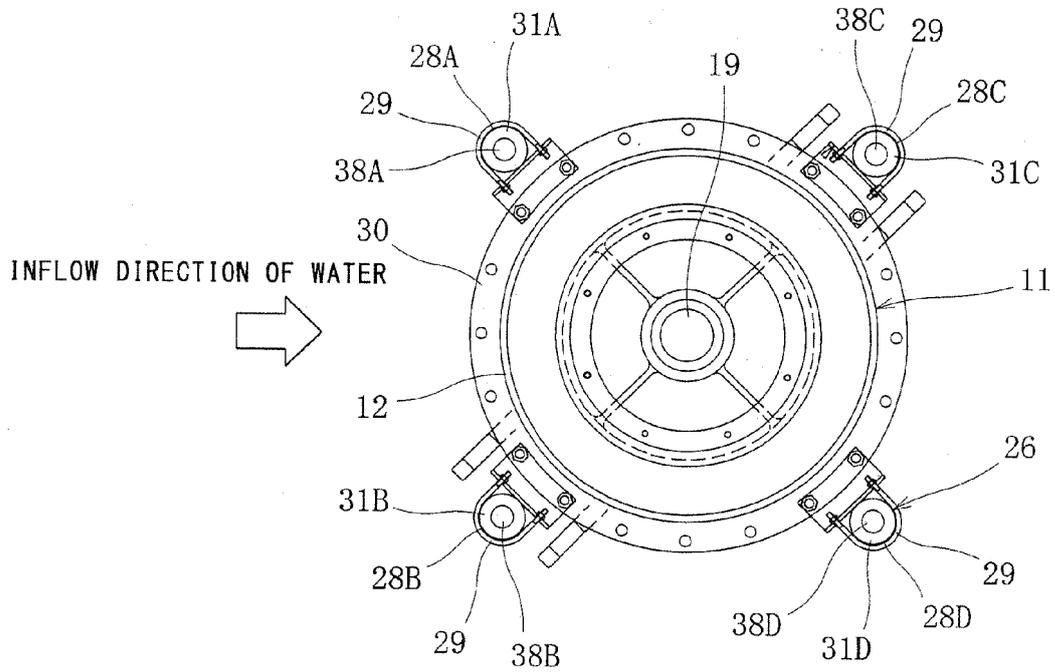


Fig. 3B

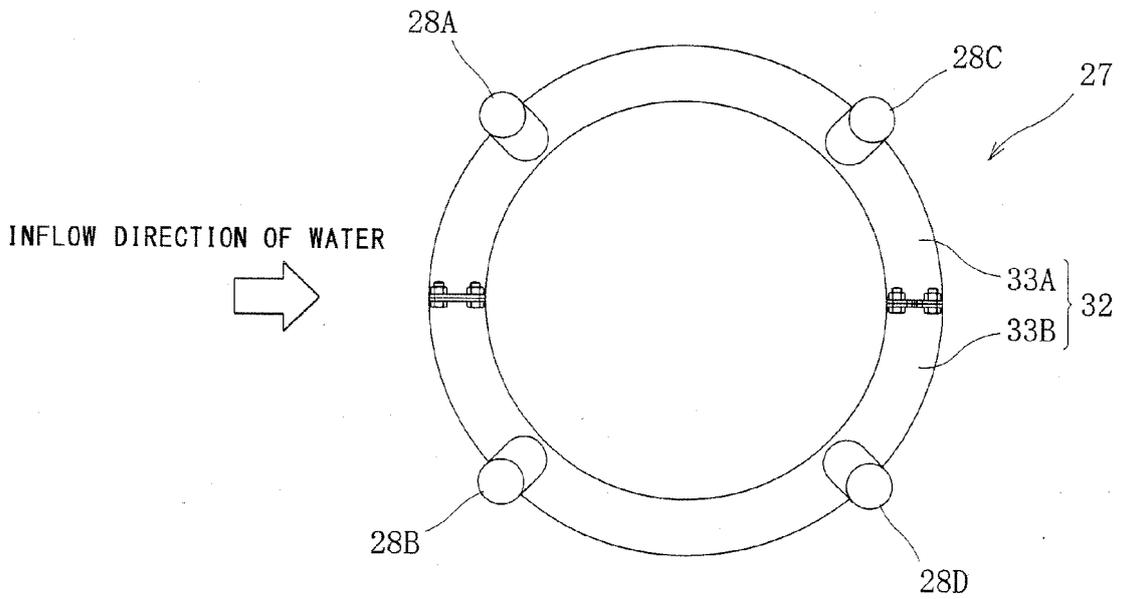


Fig. 4

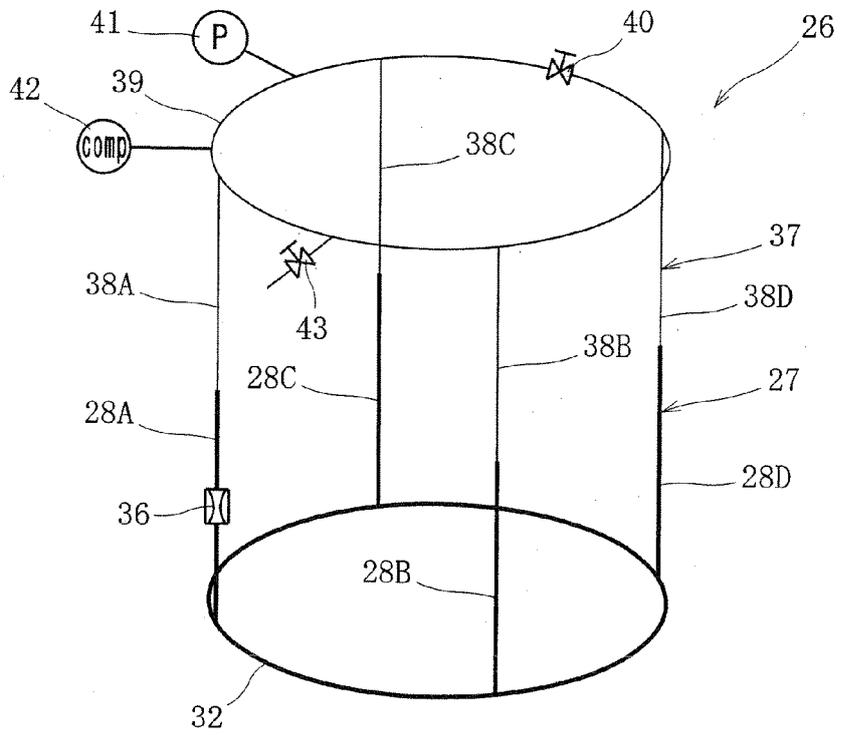


Fig. 5

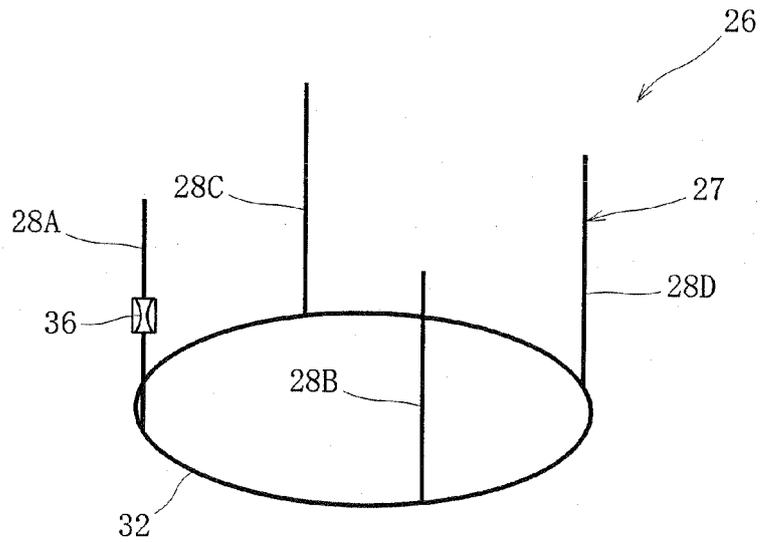


Fig. 6

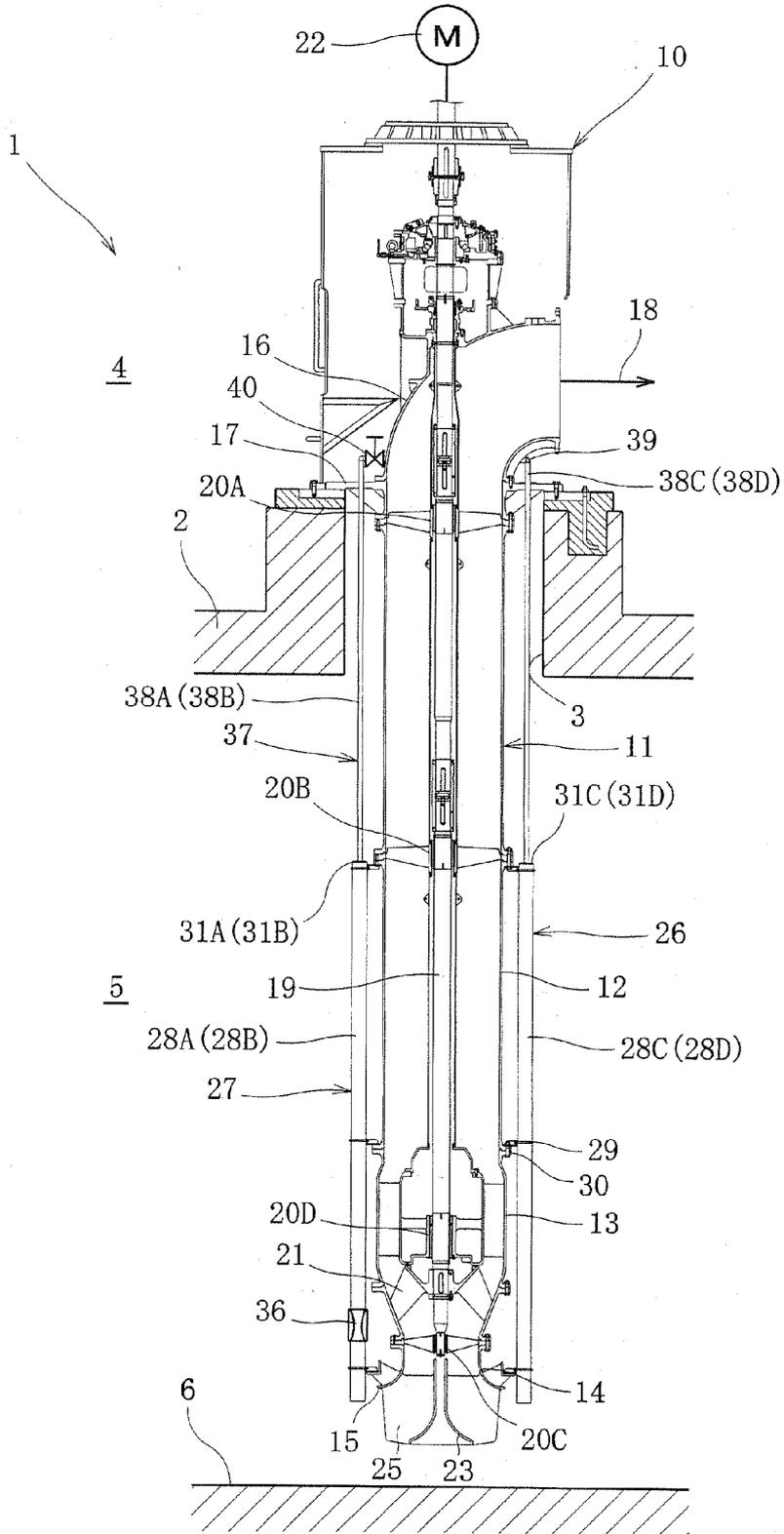


Fig. 7

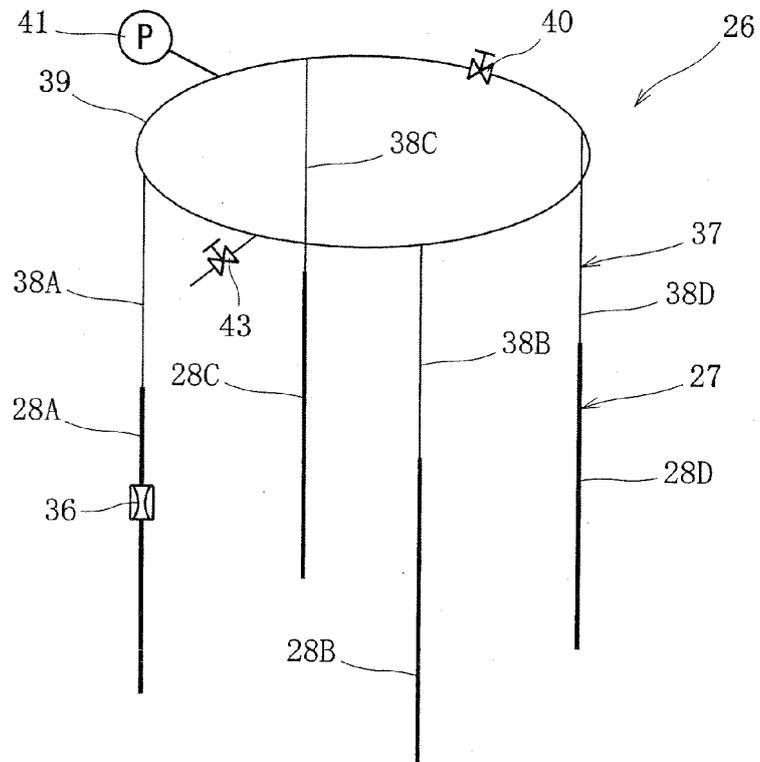


Fig. 8

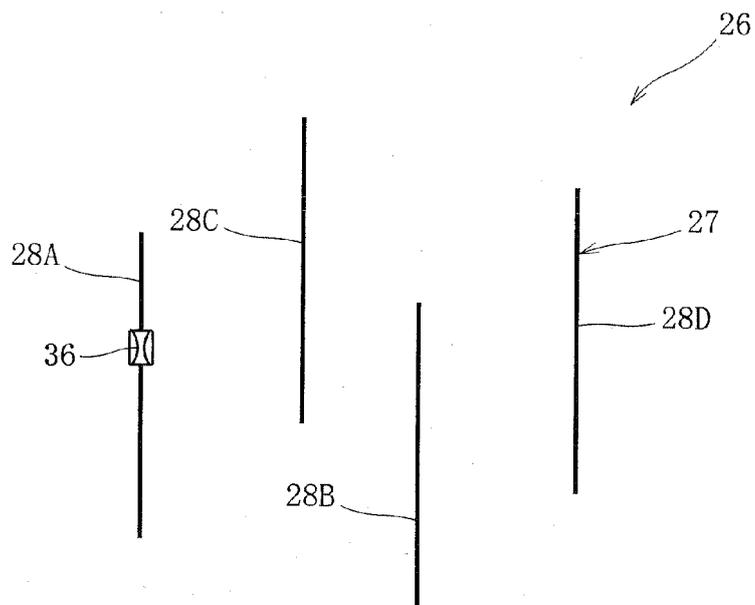


Fig. 10

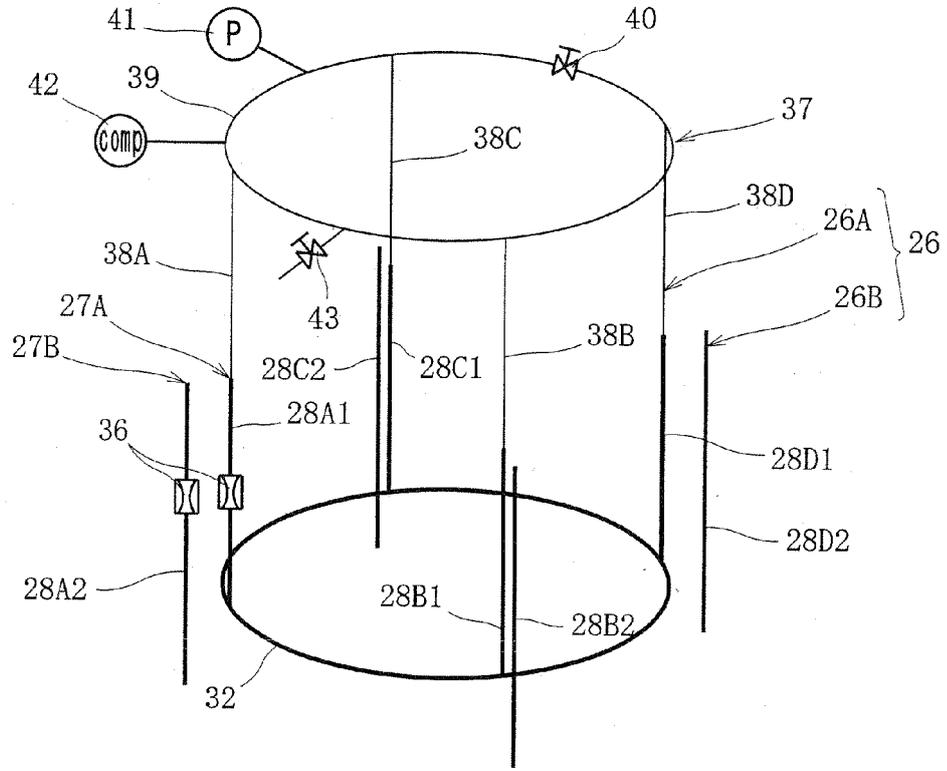


Fig. 11

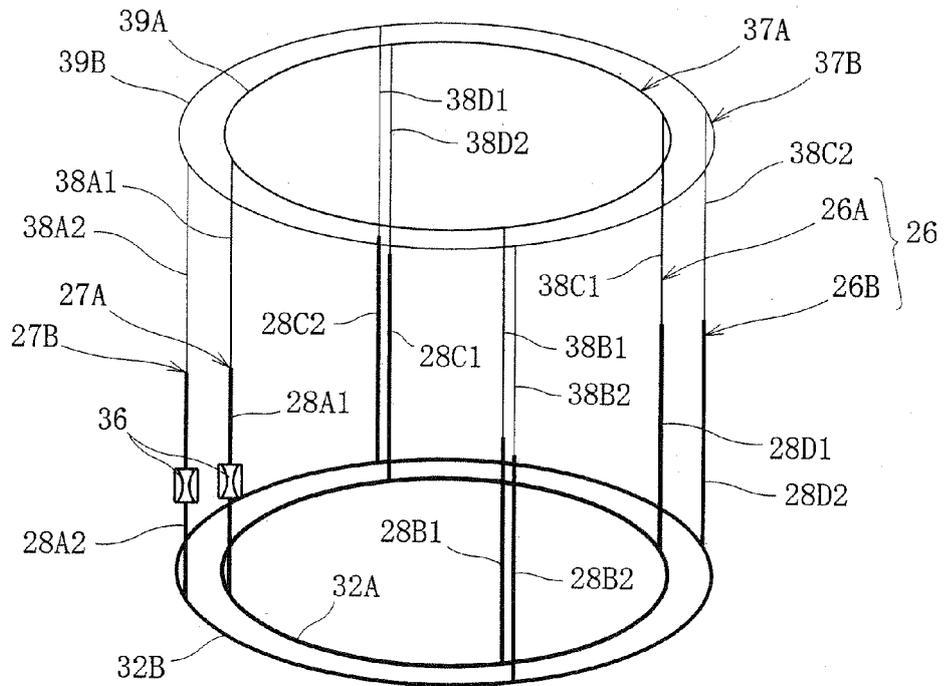


Fig. 12

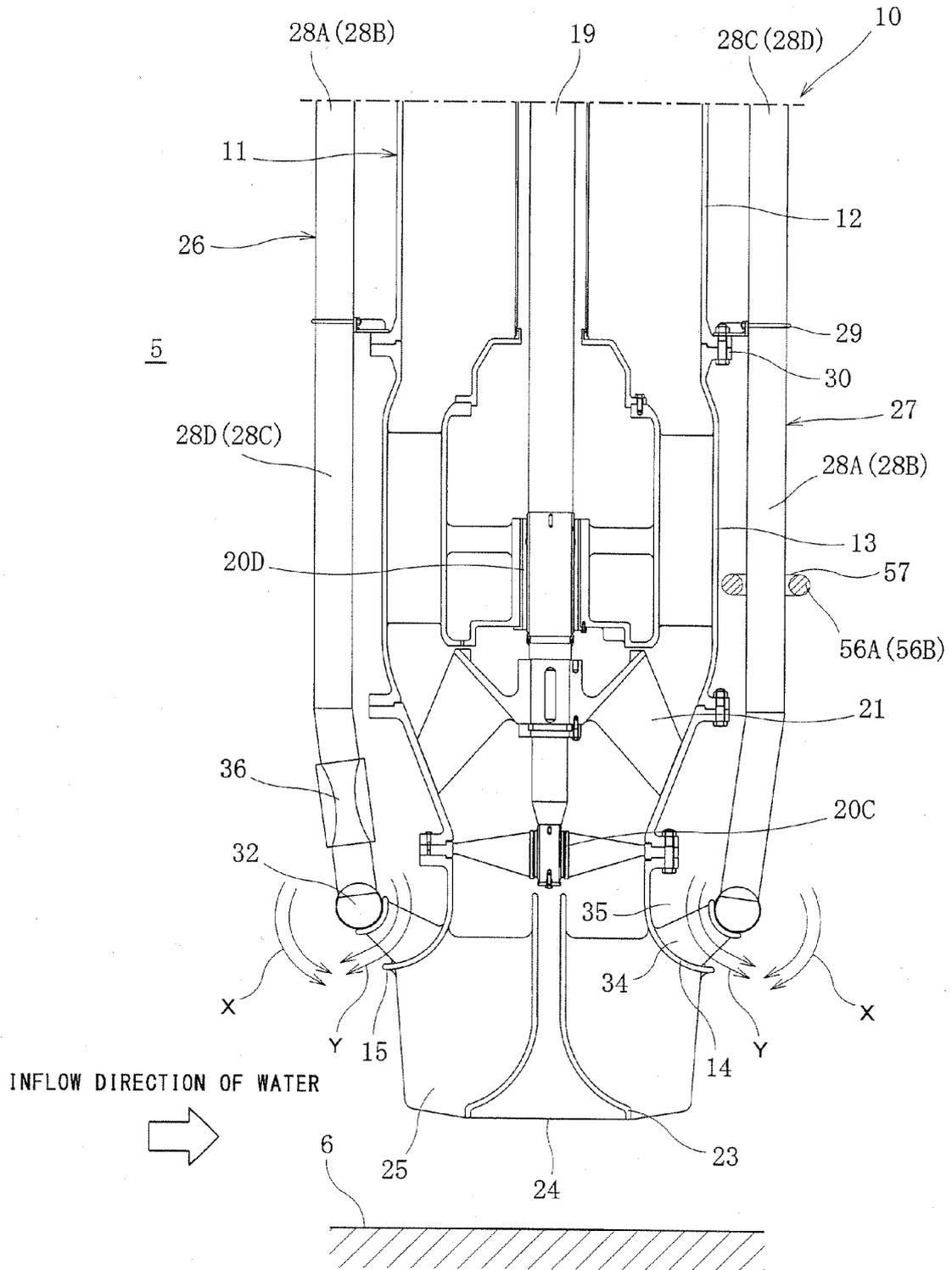
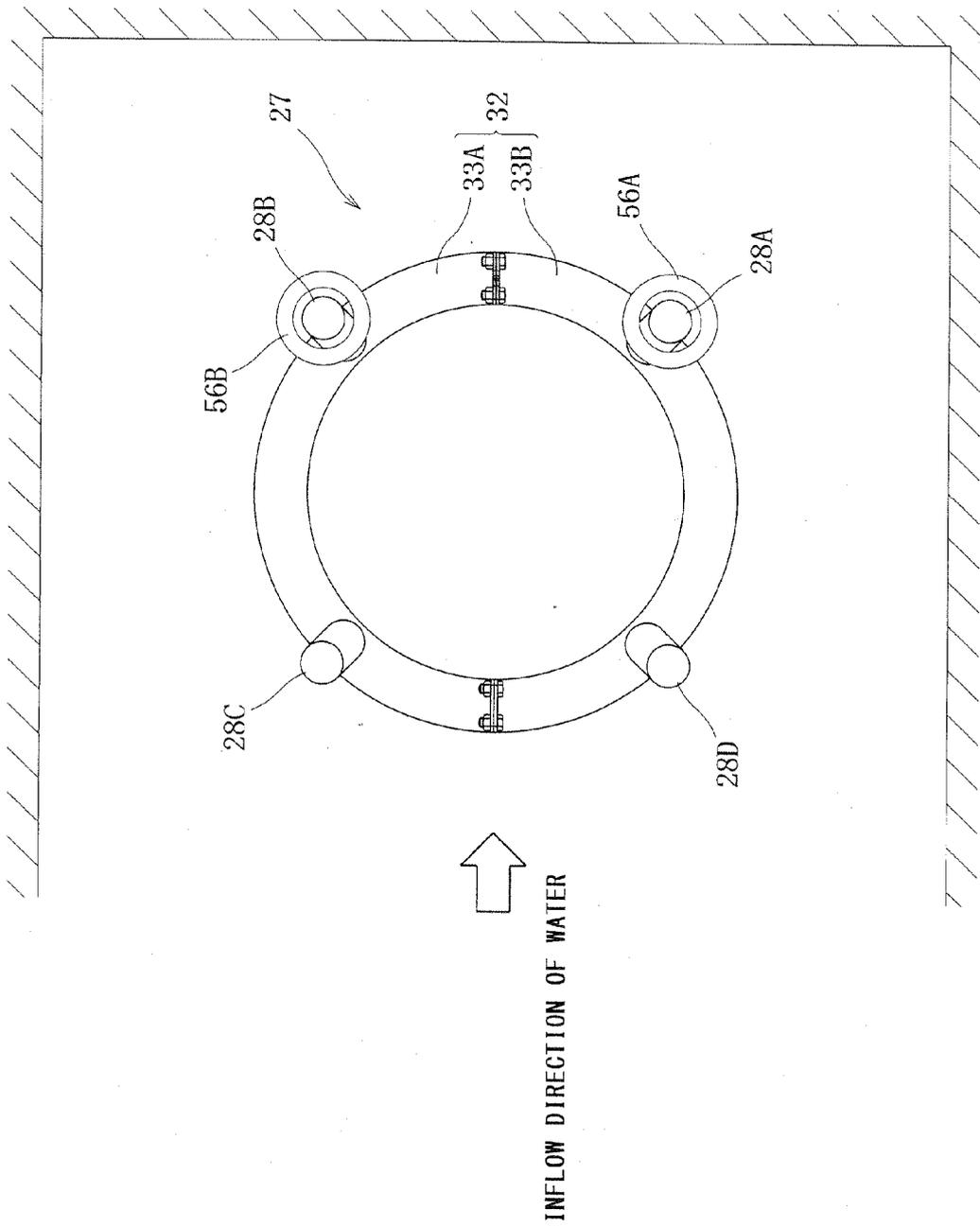


Fig. 13



REFERENCES CITED IN THE DESCRIPTION

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