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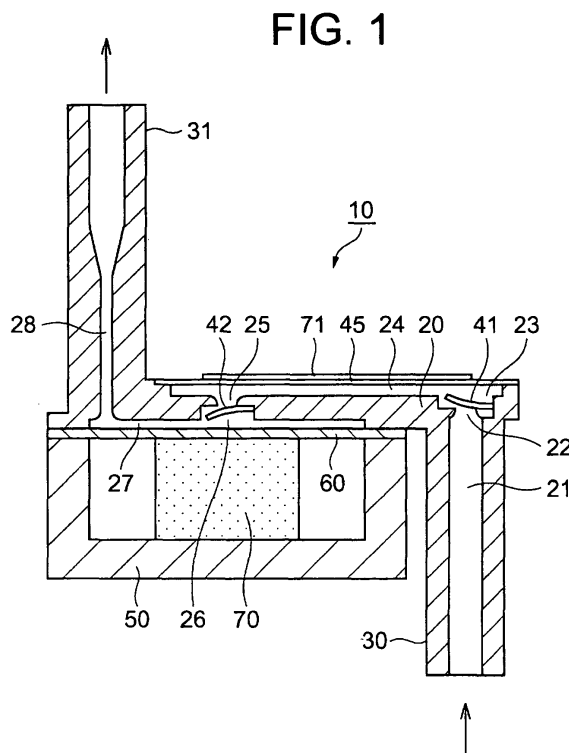
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(54) **Pump**

(57) A pump (10) comprises a primary pump chamber (27) whose volume can be varied by driving a diaphragm (60), an inlet passage for allowing a working fluid to flow into the primary pump chamber (27), an outlet passage for allowing the working fluid to flow out of the primary pump chamber (27), and check valves (41, 42) for opening and closing at least the inlet passage, wherein the total inertance value of the inlet passage is set to be smaller than the total inertance value of the outlet passage, and bubble discharging means for discharging gas bubbles remaining in the primary pump chamber (27) is further provided. As a result, it is possible to provide a pump capable of discharging gas bubbles with the bubble discharging means and thus maintaining a discharging ability, even when the gas bubbles stay in the primary pump chamber (27).



Description

[0001] The present invention relates to a pump for moving a working fluid by varying the volume of a pump chamber by means of a piston or a movable wall such as a diaphragm; more specifically the invention relates to a small high-power pump.

[0002] Conventionally, in such kind of pump check valves are provided between an inlet passage and a pump chamber having a variable volume and between an outlet passage and the pump chamber, respectively. Furthermore, a pump for transferring liquid is known, in which a thin wall portion is provided at an upstream side or downstream side passage of a pump chamber and thus pulsation due to the liquid being intermittently driven is reduced through deformation of the passage (see, for example, JP-A- 2000-265963).

[0003] Furthermore, a high-power pump with high reliability has been suggested, that is capable of coping with a high load pressure and a high frequency driving by employing a passage structure having a large inductance value in place of a valve in an outlet passage and thus by using a force of fluid inertia. In this pump, for preventing the suction efficiency of the pump from being decreased due to pulsation in an inlet passage, a deformable structure is used in the inlet passage (see, for example, JP-A- 2002-322986).

[0004] Furthermore, JP-A-61-171891 discloses a volume pump comprising a diaphragm driven by a piezoelectric element such as PZT, a pump chamber whose volume can be varied by means of the diaphragm, a hole for allowing a fluid to flow into the pump chamber, and a hole for allowing the fluid to flow out of the pump chamber, wherein check valves are provided in the respective holes.

[0005] However, in the construction of JP-A-2000-265963, there is a problem that it is not possible to cope with a high load pressure or a high frequency driving, because the inlet passage and the outlet passage require the check valve serving as a fluid resistance element and thus the pressure loss of the fluid is large through the two check valves. In addition, in a case where gas bubbles stay in the pump chamber, it is not possible to obtain a predetermined amount of discharge, because the pressure of the liquid in the pump chamber is not raised enough in the course of reducing the volume of the pump chamber.

[0006] Furthermore, with the pumps of JP-A-2002-322986 and JP-A-61-171891, since the variation in volume of the pump chamber due to the deformation of the diaphragm is small, the pressure of the liquid in the pump chamber is not raised enough in the course of reducing the volume of the pump chamber when gas bubbles stay in the pump chamber. As a result, the flow characteristics of the pump are largely deteriorated, and in the worst case, it may be impossible to discharge the liquid.

[0007] It is an object of the present invention to provide a pump capable of discharging gas bubbles and thus maintaining a discharging ability, even when gas bubbles stay inside a pump chamber.

[0008] This object is achieved by a pump as claimed in claim 1. Preferred embodiments of the invention are subject-matter of the dependent claims.

[0009] A diaphragm, which is driven with an actuator such as a piezoelectric element, may be used as the movable wall. A check valve may be used as the fluid resistance element.

[0010] Furthermore, as the bubble discharging means, details of which will be described later, for example, a secondary pump chamber, a pressurizing mechanism, a heating section, etc., which is used to apply a pressure to the pump chamber, may be used.

[0011] According to this construction, since the pump comprises the bubble discharging means, the pump can be started even when gas bubbles stay in the pump chamber, that is, even when the working fluid is not filled in the pump chamber. Further, when gas bubbles stay in the pump chamber, although it is considered that the pressure in the pump chamber is not sufficiently raised, the gas bubbles can be discharged in driving the pump due to the aforementioned bubble discharging means, so that it is possible to maintain performance of the pump, specifically, the discharge amount of the working fluid.

[0012] Now, embodiments of the present invention will be described with reference to the accompanying drawings.

Fig. 1 is a vertical cross-sectional view illustrating a pump according to a first embodiment of the present invention;

Fig. 2 is a graph illustrating inner states of the pump according to the first embodiment of the present invention;

Fig. 3 is a block diagram illustrating a driving circuit of the pump according to the first embodiment of the present invention;

Fig. 4 is a plan view illustrating a diaphragm for a secondary pump chamber of a pump according to a second embodiment of the present invention;

Fig. 5 is a vertical cross-sectional view illustrating a part of a pump according to a third embodiment of the present invention;

Fig. 6 is a block diagram illustrating a driving circuit of the pump according to the third embodiment of the present invention;

Fig. 7 is a vertical cross-sectional view illustrating a pump according to a fourth embodiment of

the present invention;

- Fig. 8 is a block diagram illustrating a driving circuit of the pump according to the fourth embodiment of the present invention;
- Fig. 9 is a vertical cross-sectional view illustrating a pump according to a fifth embodiment of the present invention;
- Fig. 10 is a vertical cross-sectional view illustrating a pressurizing mechanism according to a sixth embodiment of the present invention;
- Fig. 11 is a vertical cross-sectional view illustrating a part of a pump according to the sixth embodiment of the present invention;
- Fig. 12 is a vertical cross-sectional view illustrating a part of a pump according to a seventh embodiment of the present invention;
- Fig. 13 is a plan view illustrating a heater according to the seventh embodiment of the present invention;
- Fig. 14 is a plan view illustrating a modified example of the heater according to the seventh embodiment of the present invention;
- Fig. 15 is a block diagram illustrating a driving circuit of the pump of the seventh embodiment of the present invention;
- Fig. 16 is a plan view illustrating another modified example of the heater according to the seventh embodiment of the present invention; and
- Fig. 17 is a vertical cross-sectional view illustrating a pump according to another embodiment of the present invention.

First Embodiment

[0013] Figs. 1 to 3 show a pump 10 according to a first embodiment.

[0014] Fig. 1 is a vertical cross-sectional view illustrating a structure of the pump 10. In Fig. 1, the pump 10 basically comprises a cup-shaped case 50 to which a laminated piezoelectric element 70 is fixed, an inflow passage 21 for introducing a working fluid, an outflow passage 28 for discharging the working fluid, and a pump case 20 having a secondary pump chamber 24 and a primary pump chamber 27.

[0015] One end of the piezoelectric element 70 is fixed to an inside bottom portion of the case 50 through fixing means such as an adhesive, and a primary pump chamber diaphragm 60 is closely fixed to both of a top

surface of an edge portion of the case 50 and a top surface of the other end of the piezoelectric element 70. The pump case 20 is fixed to the circumferential edge portion of the top surface of the diaphragm 60 such that the airtightness of the fixed portions is maintained. The primary pump chamber 27 is formed in a space between the diaphragm 60 and a first concave portion formed in a lower portion of the pump case 20.

[0016] A second concave portion is provided in an upper portion of the pump case 20, and a secondary pump chamber diaphragm 45 is airtightly fixed to a top surface of an edge portion of this second concave portion, thereby forming the secondary pump chamber 24. The diaphragm 45 is formed out of a plate member thinner than the diaphragm 60, and is deformable with the inside pressure of the secondary pump chamber 24. A plate-shaped piezoelectric element 71 is fixed to the top surface of the diaphragm 45. The diaphragm 45 and the piezoelectric element 71 form a unimorph actuator.

[0017] A respective piezoelectric element 71 may be attached to both surfaces of the diaphragm 45 to form a bimorph actuator, and in this case, the close attachment of the piezoelectric element 71 in contact with the working fluid should be noted, while an actuator having a larger displacement can be formed.

[0018] Next, the construction along the flow passage of the working fluid will be described. The inflow passage 21 is formed in an inlet connection tube 30 protruded from the pump case 20, and communicates with the secondary pump chamber 24 through an inlet valve hole 22 for the secondary pump chamber and an inlet valve fitting hole 23 for the secondary pump chamber. An inlet check valve 41 for the secondary pump chamber as a fluid resistance element for opening and closing the inlet valve hole 22 is fixed to the edge of the inlet valve fitting hole 23. An inlet valve hole 25 for the primary pump chamber and an inlet valve fitting hole 26 for the primary pump chamber are provided between the secondary pump chamber 24 and the primary pump chamber 27. An inlet check valve 42 for the primary pump chamber as a fluid resistance element, including an opening and closing member which can open and close the inlet valve hole 25, is fixed to the edge of the inlet valve fitting hole 26.

[0019] The primary pump chamber 27 communicates with the outflow passage 28. The outflow passage 28 has a narrow tube portion connected to the primary pump chamber 27 and a wide tube portion whose sectional area is larger than that of the narrow tube portion with an intermediate portion connecting the narrow tube portion to the wide tube portion. An outer circumferential portion of the outlet passage constitutes the outlet connection tube 31.

[0020] Although not shown, when the pump is used tubes made of silicon rubber having elasticity are connected to the inlet connection tube 30 and the outlet connection tube 31.

[0021] Next, an inertance value L of a flow passage

is defined. Supposing that the sectional area of a flow passage is S , the length of the flow passage is r , and the density of the working fluid is ρ , the following equation is obtained: $L = \rho \times r/S$. Supposing further that the pressure difference over the flow passage is ΔP and the flow volume of the working fluid flowing in the flow passage is Q , the following equation is obtained by deforming a dynamic equation of the fluid in the flow passage using the inertance value L : $\Delta P = L \times dQ/dt$.

[0022] That is, the inertance value L indicates a degree of influence of a unit pressure on the variation of flow volume per unit time, where the variation of flow volume per unit time becomes smaller with increase of the inertance value L and the variation of flow volume per unit time becomes larger with decrease of the inertance value L .

[0023] The total inertance value of a parallel connection of a plurality of flow passages or a serial connection of a plurality of flow passages having different shapes may be calculated by total inertance values of the respective flow passages similarly to the parallel connection or the serial connection, respectively, of inductances in electric circuits. For example, when two flow passages having inertance values of L_1 and L_2 , respectively, are connected in series, the total inertance value is given as $L_1 + L_2$.

[0024] The inlet passage described hereinafter means a flow passage extending from the inside of the primary pump chamber 27 to an inlet end surface of the inlet valve hole 25. In the first embodiment of the present invention, since the secondary pump chamber 24 having the diaphragm 45 as pulsation absorbing means is connected to an intermediate portion of the flow passage, the inlet passage means a flow passage extending from the inside of the primary pump chamber 27 to a connection portion of the pulsation absorbing means.

[0025] Therefore, when the diaphragm 45 has a high rigidity and thus a small pulsation absorbing effect, it is necessary to calculate the total inertance value of the primary pump chamber inlet passage up to the position of the pulsation absorbing means such as a tube at the upstream of the secondary pump chamber 24.

[0026] The outlet passage means a flow passage extending up to an outlet end surface of the outflow passage 28, because the tube serving as the pulsation absorbing means is connected to the outlet connection tube 31.

[0027] Next, the inertance value of an opening and closing member of the check valve is defined. The inertance value of the opening and closing member is associated with the mass of the opening and closing member and the sectional area of the flow passage (a valve hole) which is closed by the opening and closing member, and is given as (inertance value of the opening and closing member) = ((mass of the opening and closing member) / (sectional area of the flow passage which is closed by the opening and closing member)²). For a time when the flow volume is small by opening the flow

passage from a state where the opening and closing member closes the flow passage entirely, the inertance value of the opening and closing member indicates a degree of influence of a unit pressure on the variation of flow volume per unit time, similarly to the inertance value of the flow passage, where the variation of flow volume per unit time becomes smaller with increase of the inertance value and the variation of flow volume per unit time becomes larger with decrease of the inertance value.

[0028] Next, an internal state of the pump according to the first embodiment when the pump operates will be described with reference to Fig. 2. Fig. 1 will be also referred to.

[0029] Fig. 2 is a graph illustrating as waveforms relations of a driving voltage (V) of the piezoelectric element 70 and a pressure (MPa) of the primary pump chamber 27 expressed as an absolute pressure with respect to time (ms), when the primary pump chamber 27 and the secondary pump chamber 24 are filled with the working fluid which is a liquid (water) in the pump 10 according to the first embodiment. In Fig. 2, since the piezoelectric element 70 is expanded with increase of the driving voltage, the diaphragm 60 is raised, thereby compressing the volume of the primary pump chamber 27. In Fig. 2, it can be seen that the pressure starts its increase due to the compression of the primary pump chamber 27 after passing through a valley of the driving voltage, and the inside pressure of the primary pump chamber 27 is rapidly decreased after passing through the point of largest upward slope of the driving voltage, and drops down substantially to an absolute pressure of 0.

[0030] Specifically, first, when the primary pump chamber 27 is compressed in a state where the inlet check valve 42 is closed, the inside pressure of the primary pump chamber 27 is largely increased due to the large inertance of the outflow passage (outlet passage) 28. With the increase of the inside pressure of the primary pump chamber 27, the working fluid in the small tube portion is accelerated, and thus the kinetic energy generating an inertia effect is accumulated. When the slope of the expansion and contraction speed of the piezoelectric element 70 is decreased, the working fluid tends to continuously flow due to the inertia effect from the kinetic energy of the working fluid in the outlet passage accumulated in the meantime, so that the inside pressure of the primary pump chamber 27 is rapidly dropped, and thus becomes smaller than the inside pressure of the secondary pump chamber 24.

[0031] At this time point, the inlet check valve 42 is opened due to the pressure difference, so that the working fluid flows in the primary pump chamber 27 from the secondary pump chamber 24. At that time, since the sum of the total inertance value of the inlet passage of the primary pump chamber 27 and the inlet check valve 42 serving as the opening and closing member is smaller enough than the inertance value of the outlet passage

described above, an efficient inflow of the working fluid is caused.

[0032] This state where the outflow and inflow to the primary pump chamber 27 occur simultaneously is continued until the piezoelectric element 70 is compressed and then is expanded again. This denotes the flat portion of the inside pressure of the primary pump chamber 27 in Fig. 2.

[0033] That is, in the pump 10 according to the first embodiment, since the discharge and suction are continued for a long time, it is possible to allow a large flow volume to flow, and since the inside of the pump chamber has a very high pressure, it is possible to cope with a high load pressure.

[0034] At that time, in the secondary pump chamber 24, the diaphragm 45 absorbs the pulsation through deformation by the inside pressure of the secondary pump chamber 24. As a result, the inflow of the working fluid from the inflow passage 21 having a large inertance value to the secondary pump chamber 24 is a static flow having a small pulsation, and the inlet check valve 41 is continuously opened. In this way, the diaphragm 45 has an effect of suppressing the pulsation of the inflow passage 21 while keeping the inertance value of the inlet passage of the primary pump chamber 27 small through its deformation. At that time, since the opened state of the inlet check valve 41 is continued, a problem such as generation of fluid resistance or fatigue failure does not occur.

[0035] Next, a priming action when the pump 10 starts its operation will be described with reference to Figs. 1 and 3.

[0036] Fig. 3 is a block diagram of a driving circuit system according to the first embodiment. A priming action is an action where, in a case where gas bubbles stay in the pump, a liquid is filled using another pump when the primary pump chamber 27 not having an ability of voluntarily absorbing the liquid is started. In Fig. 3, the driving circuit system of the pump 10 comprises the piezoelectric element 70 for driving the diaphragm 60, the piezoelectric element 71 for driving the diaphragm 45, a switching circuit 85 serving as a driving switch control unit for switching the driving between the piezoelectric element 70 and the piezoelectric element 71, and a pump driving control circuit 80 for controlling the driving of the pump 10.

[0037] In a case where the working fluid is not filled in the primary pump chamber 27, a driving voltage generated by the pump driving control circuit 80 is applied to the piezoelectric element 71 attached to the diaphragm 45 by means of the switching circuit 85 at an initial stage of the pump operation. The driving voltage has, for example, a sine waveform. Since the secondary pump chamber diaphragm 45 is formed out of a thin plate member and, together with the piezoelectric element 71, constitutes a unimorph actuator having a large amount of displacement, the second pump chamber 24 causes large variation in volume with the driving voltage. The

inlet check valve 41 is arranged at the inlet side of the secondary pump chamber 24, and the inlet check valve 42 is arranged at the outlet side thereof. The inlet check valve 42 functions as the outlet check valve of the secondary pump chamber 24.

[0038] As a result, since the secondary pump chamber 24 comprises the check valves at both of the inlet and outlet and thus has a large amount of variation in volume, the secondary pump chamber functions as a pump capable of transferring both gas and liquid, and since the secondary pump chamber 24 and the primary pump chamber 27 discharge the gas and thus are filled with the liquid which is the working fluid, the pump can operate through variation in volume of the primary pump chamber 27. The switching circuit 85 is switched to apply the driving voltage to the piezoelectric element 70 after sufficient time has passed as determined by a timer (not shown), thereby automatically enabling high-power operation.

[0039] Furthermore, during operation of the primary pump chamber 27, it is possible to detect the operating condition of the diaphragm 45 by detecting a terminal voltage of the piezoelectric element 71. In a case where gas bubbles in the working fluid stay in the primary pump chamber 27 to deteriorate the pump ability, the amount of operation of the diaphragm 45 is decreased. At that time, by allowing the diaphragm 45 to operate by means of the piezoelectric element 71, thus discharging the gas bubbles, and then switching the driving voltage such that the diaphragm 60 is driven by means of the piezoelectric element 70, the pump ability can be recovered. The priming action is executed by performing the aforementioned driving control.

[0040] Furthermore, since the primary pump chamber inlet passage is the secondary pump chamber outlet passage and the fluid resistance element (the check valve 42) for opening and closing the primary pump chamber inlet passage is the fluid resistance element for opening and closing the secondary pump chamber outlet passage, the flow passage of the working fluid is shortened, so that it is possible to reduce the fluid resistance of the flow passage. As a result, it is possible to simplify the structure of the pump 10 and to reduce the number of components, thereby realizing low cost.

[0041] In the first embodiment described above, a case where the diaphragm 60 is used as the means for causing the variation in volume of the primary pump chamber 27 has been described, but the object of the present invention can be also accomplished by using a piston instead.

Second Embodiment

[0042] Next, a second embodiment will be described with reference to Fig. 4.

[0043] The pump according to the second embodiment has a basic structure similar to the aforementioned first embodiment, but is different from the first embodi-

ment in that a part of a driving electrode 52 attached to the piezoelectric element 71 of the secondary pump chamber 24 is separated and forms a detecting electrode 53.

[0044] Fig. 4 is a plan view of the pump according to the second embodiment as seen from the secondary pump chamber diaphragm side. In Fig. 4, a part of the electrode 52 formed on the piezoelectric element 71 attached to the top surface of the diaphragm 45 is separated to form the detecting electrode 53.

[0045] Next, the function of the detecting electrode will be described. During the priming action such as the time of starting the pump, the driving voltage is applied to the piezoelectric element 71 in the aforementioned first embodiment. However, in the second embodiment, since the detecting electrode 53 is isolated, it is possible to detect movement of the diaphragm 45 even during the priming action (when the driving voltage is applied to the piezoelectric element 71). When gas in the secondary pump chamber 24 is discharged through the operation of the diaphragm 45 and thus liquid is filled in the secondary pump chamber 24, the movement of the diaphragm 45 is decreased due to difference in compression rate thereof, and shortly thereafter the primary pump chamber 27 is thus filled with the working fluid. Therefore, when a long tube is connected to the inflow side, timing when the priming action is completed can be detected more accurately than in a case where time management is performed, so that it is possible to switch the driving voltage toward the piezoelectric element 70 attached to the diaphragm 60 for a short time.

[0046] Furthermore, by independently connecting the driving circuits to the respective piezoelectric elements of the diaphragm 60 and the second pump chamber diaphragm 45, and always monitoring the detecting electrode 53, it is possible to right perform the priming action without switching the circuits even in a case of operation failure due to interfusion of gas bubbles, etc. during operation of the pump.

[0047] Therefore, according to the second embodiment described above, since the detecting electrode 53 is isolated, it is possible to detect the movement of the diaphragm 45 during the priming action, and to accurately detect the timing when the priming action is completed, so that it is possible to switch the driving voltage toward the piezoelectric element 70 of the diaphragm 60 for a short time.

Third Embodiment

[0048] Next, a third embodiment will be described with reference to Figs. 5 and 6. The pump according to the third embodiment has a basic structure similar to the aforementioned first embodiment, but is different from the first embodiment in that the pump comprises a pressure sensor 90 in the primary pump chamber 27. A description of constituent elements common to the first embodiment will be omitted.

[0049] Fig. 5 is a vertical cross-sectional view of the pump according to the third embodiment, and Fig. 6 is a block diagram of the driving circuit of the pump according to the third embodiment. In Fig. 5, two-stepped concave portion 35 is formed in an inside top wall of the primary pump chamber 27. The pressure sensor 90 made of the same material as the aforementioned piezoelectric element 71 is fixed to the step of the concave portion 35 toward the primary pump chamber 27. An electrode not shown is formed on the surface of the pressure sensor 90, and the pressure sensor is connected to the pump driving control circuit 80 (see Fig. 6) described later. The concave portion 35 has a gap so that the pressure sensor 90 does not come in contact with the wall when it is bent.

[0050] In Fig. 6, the driving circuit system of the pump 10 comprises the piezoelectric element 70 for driving the diaphragm 60, the piezoelectric element 71 for driving the diaphragm 45, the pressure sensor 90 for detecting the inside pressure of the primary pump chamber 27, and the pump driving control circuit 80 for controlling the driving of the pump 10.

[0051] In Figs. 5 and 6, when gas bubbles stay in the primary pump chamber 27, the inside pressure of the primary pump chamber 27 is decreased. This state is detected by the pressure sensor 90, and a driving signal is output to the piezoelectric element 71 from the pump driving control circuit 80, so that the diaphragm 45 is driven to increase the inside pressure of the secondary pump chamber 24.

[0052] Accordingly, the gas bubbles staying in the primary pump chamber 27 are discharged from the pump chamber. That is, the piezoelectric element 71 of the diaphragm 45 is driven in synchronism with variation of the inside pressure of the primary pump chamber 27.

[0053] In the first to third embodiments, the pump not comprising a check valve at the side of the outflow passage 28 of the primary pump chamber 27 has been constructed, but with a pump comprising the check valve and requiring the priming action, similar advantages can be obtained.

[0054] Therefore, according to the third embodiment, since the pressure sensor 90 is provided in the primary pump chamber 27, it is possible to accurately detect an operation failure due to interfusion of gas bubbles into the primary pump chamber 27. Furthermore, in the third embodiment, since the piezoelectric element 71 of the diaphragm 45 can be driven in synchronism with the diaphragm 60, it is possible to further improve the suction efficiency of the primary pump chamber 27, so that it is possible provide a higher-power pump.

Fourth Embodiment

[0055] Next, a pump according to a fourth embodiment will be described with reference to Figs. 7 and 8. The fourth embodiment basically has the technical spirit of the first embodiment, but is different from the first em-

bodiment in that a pressurizing mechanism 150 is provided as a bubble removing unit in place of the secondary pump chamber 24 (see Fig. 1).

[0056] Fig. 7 is a vertical cross-sectional view of the pump according to the fourth embodiment. In Fig. 7, the pump 100 basically comprises the cup-shaped case 50 to which the piezoelectric element 70 is fixed, an inflow passage 121 for introducing the working fluid, an outflow passage 128 for discharging the working fluid, a pump case 120 having a pump chamber 127, and a pressurizing mechanism 150 (surrounded with a broken line in the figure) for applying pressure to the pump chamber 127.

[0057] In the cup-shaped case 50, one end of the piezoelectric element 70 is fixed to an inside bottom portion thereof, and the diaphragm 60 is fixed to the edge portion of the case 50 and a top surface of the other end of the piezoelectric element 70. A pump case 120 is airtightly fixed to the top surface of the diaphragm 60, and the pump chamber 127 is formed in a space between the diaphragm 60 and the bottom of the pump case 120.

[0058] The inflow passage 121 and the outflow passage 128 are formed toward the pump chamber 127. In the inflow passage 121, a check valve 122 as a fluid resistance element for opening and closing the inflow passage 121 is provided at a connection portion with the pump chamber 127. A part of the outer circumference of a cylindrical portion constituting the inflow passage 121 functions as an inlet connection tube 130 to be connected to an external tube not shown. The outflow passage 128 comprises a narrow tube portion connected to the pump chamber 127 and a wide tube portion whose sectional area is larger than that of the narrow tube portion. Both tube portions are connected by a continuously formed intermediate portion whose sectional area changes gradually from that of the narrow tube portion to that of the wide tube portion. The outer circumference of a cylindrical portion constituting the outflow passage 128 functions as an outlet connection tube 131 to be connected to an external tube not shown. Tubes made of silicon rubber, for example, can be used as the external tubes.

[0059] The pressure sensor 90 as the pressure detecting section for detecting the inside pressure of the pump chamber 127 is fixed to the inside top wall of the pump chamber 127.

[0060] The pressurizing mechanism 150 comprises a metallic bellows 151, which is an elastic member, an actuator 170 formed out of a piezoelectric element as a volume varying mechanism of the bellows 151, and an shutoff valve 140 for shutting off the movement of the working fluid in the outflow passage 128. The bellows 151 is closely fixed to a side surface of the outlet connection tube 131, and its opening portion 152 is connected to the flow passage 132 communicating with the outflow passage 128.

[0061] A variable-volume chamber is formed inside the bellows 151, and a pressure sensor 91 as the pres-

sure detecting section for detecting the inside pressure of the bellows 151 is provided inside the bellows. The volume of the bellows 151 is varied by means of the actuator 170.

[0062] In the fourth embodiment, an end of the actuator 170 opposite to the bellows 151 is fixed to the side of the inlet connection tube 130, and the actuator is reciprocated by means of a driving section not shown. The actuator comprises a pressing section 171 for compressing the bellows 151, and the pressing section is driven by means of the pump driving control circuit 180 (see Fig. 8).

[0063] In addition, the sectional area of the wide tube portion of the outflow passage 128 at a position connected to the bellows 151 is double the sectional area of the narrow tube portion. For this reason, the flow rate of the fluid passing through the flow passage 132 connected to the bellows 151 is decreased, so that the energy loss of the fluid during passing the flow passage can be reduced.

[0064] The inertance value relation important in driving the pump according to the present invention has been described in the first embodiment, and thus its description is omitted. The inlet passage and the outlet passage in the fourth embodiment will be defined.

[0065] In the flow passage for allowing the working fluid to flow into the pump chamber 127, the flow passage extending from the opening portion of the pump chamber 127 to the connection with pulsation absorbing means is defined as the inlet passage. Here, the pulsation absorbing means is the means for sufficiently reducing the variation in the inside pressure of the flow passage. In addition, a flow passage made of a material such as silicon rubber, resin, thin metal, etc. which can be easily deformed with the inside pressure, an accumulator connected to the flow passage, a composition flow passage for composing pressure variations having a plurality of different phases, etc. correspond to the pulsation absorbing means.

[0066] In the fourth embodiment, since the external tube such as a silicon rubber tube is connected to the inlet connection tube 130, the flow passage extending from the opening portion of the pump chamber 127 to the end surface of the connection side of the silicon rubber tube in the inflow passage 121, that is, the inflow passage 121 itself is defined as the inlet passage.

[0067] In addition, the outlet passage is defined similarly to the inlet passage. That is, in the flow passage to which the working fluid is discharged from the pump chamber 127, a flow passage extending from the opening portion of the pump chamber 127 to a connection portion with the pulsation absorbing means is defined as the outlet passage. In the fourth embodiment, since the bellows 151 in the way of the outflow passage 128 has a function of absorbing the pressure pulsation in a discharge mode to be described later, the outflow passage 128 extending from the opening portion of the pump chamber 127 to the connection portion with the

bellows 151 is defined as the outlet passage.

[0068] Next, a case where the pump 100 according to the fourth embodiment is driven in the discharge mode will be described.

[0069] The discharge mode means an operation mode in which the working fluid is allowed to flow out toward the downstream of the outflow passage 128, and is performed in a case where the working fluid is filled in the pump chamber 127 and thus gas bubbles do not stay therein. At that time, the shutoff valve 140 does not shut off the outflow passage 128. The pressing section 171 of the actuator 170 is separated from the bellows 151, as shown in Fig. 7. As a result, the bellows 151 can be freely deformed elastically with the inside pressure, and the bellows 151 functions as reducing the pressure pulsation in the outflow passage 128. Accordingly, even if an external tube made of any material is connected to the outlet connection tube 131, the inertance value of the outlet passage is not influenced, so that it is possible to prevent change in the pump ability due to the external tube. Only if a variable-volume chamber is formed of an elastic member in place of the bellows 151, the same advantage can be obtained.

[0070] Next, the internal state of the pump 100 according to the fourth embodiment when it is driven will be described. The internal state of the pump 100 is similar to that of the above first embodiment (see Fig. 2), the description thereof having been omitted, and thus features of the fourth embodiment will be described in detail.

[0071] The features are described with reference to Figs. 2 and 7. In Fig. 2, as can be seen from the fact that the inside pressure of the pump chamber 127 is raised up to about 2 MPa, the pump 100 according to the fourth embodiment causes a high pressure in the pump chamber 127, thereby obtaining a high power. For this reason, specifically when gas bubbles stay in the pump chamber 127, the variation in volume (hereinafter, referred to as exclusion volume) of the pump chamber 127 generated due to the deformation of the diaphragm 60 is used to compress the gas bubbles during the time when the piezoelectric element 70 turns to the state where it is most expanded from the state where it is most contracted, and thus does not contribute to increase of the inside pressure of the pump chamber 127, so that the pump cannot operate properly. For this reason, it is important to remove the gas bubbles rapidly.

[0072] Subsequently, a case where the pump 100 according to the fourth embodiment is driven in a bubble discharge mode will be described with reference to Figs. 7 and 8.

[0073] Fig. 8 is a block diagram of the driving circuit of the pump 100 according to the fourth embodiment. Here, the bubble discharge mode means an operation mode to be performed when gas bubbles stay in the pump chamber 127. In Fig. 8, the driving circuit system of the pump 100 comprises the pressure sensor 90 (see Fig. 7) for detecting the inside pressure of the pump

chamber 127, the pressure sensor 91 for detecting the inside pressure of the bellows 151, the pressurizing mechanism 150, and a pump driving control circuit 180 for controlling them.

[0074] Next, the discharge of gas bubbles by means of the pressurizing mechanism 150 when the pump is driven in the bubble discharge mode will be described.

[0075] When the maximum inside pressure of the pump chamber detected by the pressure sensor 90 is smaller than, specifically a half or less of, the maximum inside pressure of the pump chamber in the normal driving under the driving condition, the pump driving control circuit 180 determines that gas bubbles stay in the pump chamber 127. Then, the pump driving control circuit 180 gives an instruction to the pressurizing mechanism 150. In response to that instruction, first, the shutoff valve 140 is switched not to shut off the outflow passage 128. Next, the actuator 170 in Fig. 7 allows the pressing section 171 to extend to the left and to come into contact with the bellows 151, and then compresses the bellows 151 in the left direction, so that the volume of the chamber formed by the bellows 151 is largely reduced. As a result, gas bubbles staying in the chamber formed by the bellows 151 can be allowed to flow out to the downstream from the shutoff valve 140.

[0076] Next, the shutoff valve 140 shuts off the outflow passage 128, and the actuator 170 allows the pressing section 171 to be contracted and separated from the bellows 151. Since the bellows 151 is formed of an elastic member, it recovers to the original state by its own elastic force. In this way, the working fluid is filled in the bellows 151. Subsequently, the actuator 170 is allowed to compress the bellows 151 again. As a result, the pressure of the working fluid existing from the inside of the bellows 151 to the pump chamber 127 can be raised.

[0077] The volume of the gas bubbles staying in the pump chamber 127 is decreased through the pressing, and the volume of the gas bubbles can be made to be sufficiently smaller than the exclusion volume. At that time, it is necessary to set the chamber of the bellows 151 to about one atmosphere (101.325 kPa) or more of gauge pressure, preferably a pressure between about one atmosphere (101.325 kPa) and five atmospheres (506.625 kPa). By allowing the pump driving control circuit 180 to control the actuator 170 for compressing the bellows 151 on the basis of the detected value by the pressure sensor 91 for detecting the pressure of the chamber formed out of the bellows 151, it is possible to raise the inside pressure of the bellows 151 up to a proper pressure.

[0078] Subsequently, when the piezoelectric element 70 is driven, like in the discharge mode, the inside pressure of the pump chamber 127 is raised enough and the working fluid is discharged from the pump chamber 127 to the outflow passage 128. The gas bubbles staying in the pump chamber 127 flow in the bellows 151 with the flow of the working fluid in the pump chamber 127.

[0079] The pump driving control circuit 180 comprises

a timer (not shown) for counting the time while the piezoelectric element 70 is driven after the shutoff valve 140 shuts off the outflow passage 128. After a predetermined time interval sufficient to discharge the gas bubbles staying in the pump chamber 127 has been counted by the timer, the shutoff valve 140 releases the shutoff of the outflow passage 128 and the actuator 170 is contracted up to the position where it is separated from the bellows 151. Thereafter, the bubble discharge mode is finished.

[0080] At that time, the inside pressure of the bellows 151 is raised due to the working fluid discharged from the pump chamber 127, but the bellows is designed such that the deformation due to the pressure is suppressed within an allowable range of elastic deformation. In this way, by forming the variable-volume chamber out of an elastic member, the pressure can be made to be smoothly raised due to the introduction of the working fluid, so that it is possible to prevent destruction of the constituent elements of the pump 100.

[0081] In addition, the pump driving control circuit 180 may be allowed to control the actuator 170 by using values detected by the pressure sensor 91 provided in the bellows 151, so that it may be possible to surely suppress the inside pressure of the bellows 151 from being raised.

[0082] The pump may be constructed so that a relief valve is provided in the bellows 151, and it is possible to surely suppress the inside pressure of the bellows 151 from being raised by opening the relief valve when the inside pressure of the bellows 151 gets too high.

[0083] Therefore, in the fourth embodiment, since the pressurizing mechanism 150 for raising and maintaining the pressure of the working fluid existing in the pump chamber 127 is provided, it is possible to raise and maintain the pressure of the working fluid existing in the pump chamber 127, when gas bubbles stay in the pump chamber 127, the inside pressure of the pump chamber 127 is reduced, and thus it is not possible to discharge the working fluid. As a result, the volume of the gas bubbles is decreased, so that it is possible to discharge the gas bubbles in the pump chamber by compressing the volume of the pump chamber 127 through the operation of the diaphragm 60.

[0084] The pressurizing mechanism 150 presses the bellows 151, but since the variable-volume chamber of the bellows 151 communicates with the outflow passage 128, it is possible to simply generate a high pressure in the pump chamber 127 communicating with the outflow passage 128.

[0085] Furthermore, by forming the variable-volume chamber out of an elastic member, the increase in pressure due to introduction of the working fluid into the variable-volume chamber is smoothed, so that it is possible to prevent the constituent elements of the pump from being damaged due to the pressure. Furthermore, by forming the variable-volume chamber out of an elastic member, the variable-volume chamber can be allowed

to have a function of reducing the pressure pulsation in the outlet passage. As a result, it is possible to prevent the pump ability from being varied due to influence of the external tube connected to the outlet passage.

First Modification of Fourth Embodiment

[0086] In a modification of the fourth embodiment described above, the detected value of the pressure sensor 90 in the pump chamber 127 may be checked, for example, by arbitrarily setting the time interval to be counted by the timer of the pump driving control circuit 180 and allowing the pump to operate in the discharge mode after the bubble discharge mode is finished.

[0087] According to this modification, by repeatedly performing the operation of the bubble discharge mode until the gas bubbles are discharged, it is possible to surely discharge the gas bubbles.

[0088] In the fourth embodiment described above, since the operation of the bubble discharge mode is executed when it is determined by means of the pressure sensor 90 in the pump chamber 127 that there are gas bubbles, the operation of the bubble discharge mode is not executed wastefully, but the operation of the bubble discharge mode may instead be executed at proper time intervals. In this case, the pressure sensor 90 can be omitted, so that it is possible to simplify the structure.

[0089] Furthermore, when the inflow passage 121 and the outflow passage 128 are connected to the external tubes, it is possible to raise and maintain the inside pressure of the pump chamber 127 by pressing the bellows 151 with the actuator 170 without the shutoff valve 140, thereby obtaining the same advantage. Furthermore, although the actuator 170 is provided to press the bellows 151, the same advantage can be obtained, even when a display means through which a user can view an output of the pressure sensor 91 is provided and the user manipulates the shutoff valve 140 to press the bellows 151.

Second Modification of Fourth Embodiment

[0090] In the fourth embodiment, the pressure sensor 90 has been provided as the pressure detecting means for the pump chamber in the pump chamber 127, but a different means may be employed.

[0091] For example, the inside pressure of the pump chamber 127 may be calculated by measuring the deformation of the diaphragm 60 with a strain gauge or a displacement sensor.

[0092] Further, the inside pressure of the pump chamber 127 may be calculated by measuring the deformation of the case 50 with a strain gauge.

[0093] Furthermore, the inside pressure of the pump chamber 127 may be calculated by measuring the deformation of the opening and closing member in a state where the check valve 122 is closed, with a strain gauge or a displacement sensor.

[0094] Furthermore, the inside pressure of the pump chamber 127 may be calculated by measuring current for driving the piezoelectric element 70 with a current sensor. Furthermore, by providing a strain gauge in the piezoelectric element 70, the inside pressure of the pump chamber 127 may be calculated on the basis of a voltage applied to the piezoelectric element 70 and the measured value by the strain gauge. At that time, any type of strain gauge which detects the quantity of deformation by using variation in resistance, variation in capacitance, or variation in voltage may be used as the strain gauge. As the inside pressure detecting means of the bellows 151, a structure of calculating the pressure by detecting the deformation of the bellows 151 with a strain gauge may be used.

Third Modification of Fourth Embodiment

[0095] In the fourth embodiment described above, a piezoelectric element has been employed as the actuator 170, but an electromagnetic type actuator, a shape-memory alloy type actuator, etc. may be employed instead of the piezoelectric element. Since the shape-memory alloy type actuator can realize a large quantity of deformation with a simple structure, it is preferable.

[0096] Furthermore, the elastic member forming the variable-volume chamber may be made of rubber or resin material, but the elastic member made of metal is specifically preferable because it can prevent vaporization of the working fluid. Furthermore, the variable-volume chamber may have a film shape or a diaphragm shape, but since the bellows shape described in the fourth embodiment allows a large quantity of deformation and the piezoelectric element 70 can be driven in the bubble discharge mode continuously for a long time, it is preferable in that the gas bubbles can be easily discharged.

[0097] Therefore, according to the construction of the modifications of the fourth embodiment, it is possible to obtain an advantage similar to that of the fourth embodiment.

Fifth Embodiment

[0098] Next, a pump according to a fifth embodiment will be described with reference to Fig. 9.

[0099] The pump according to the fifth embodiment has a basic structure similar to that of the fourth embodiment (see Fig. 7), but is different from the fourth embodiment in that the pump has a structure of switching between a first mode where the working fluid flowing out of the pump chamber 127 is introduced into the chamber formed out of the bellows 151 and a second mode where the chamber formed out of the bellows 151 is shut off from the flow of the working fluid flowing out of the pump chamber 127. Therefore, the difference will be paid attention to. The same functional members are denoted by the same reference numerals as in the fourth embodiment (see Fig. 7).

[0100] Fig. 9 shows a vertical cross-sectional view of the pump 100 according to the fifth embodiment. In Fig. 9, the pressurizing mechanism 150 surrounded with a broken line is provided in the outflow passage 128. The pressurizing mechanism 150 comprises the metallic bellows 151 formed of an elastic member, and a switching valve 190 (surrounded with a two-dot chain line in the drawing) as passage switching means. The switching valve 190 comprises a switching valve 182 for opening and closing the flow passage 132 communicating with the outflow passage 128 at the opening portion 152 of the chamber formed out of the bellows 151, and a switching valve 183 for opening and closing the outflow passage 128.

[0101] The switching valve 190 functions to switch between a first connection state where the outflow passage 128 extending from the pump chamber 127 to the switching valve 182 and the outflow passage 128 at the downstream side thereof communicate with each other by opening the switching valve 183 and the chamber formed out of the bellows 151 is shut off from the outflow passage 128 by closing the switching valve 182, and a second connection state where the outflow passage 128 extending from the pump chamber 127 to the switching valve 182 and the chamber formed out of the bellows 151 communicate with each other and the outflow passage 128 at the more downstream side than the switching valve 183 is shut off by closing the switching valve 183.

[0102] In the outflow passage 128, the sectional area of the outflow passage 128 at the position at which the switching valve 183 is arranged is double the sectional area of the narrow flow passage portion of the outflow passage 128 connected to the pump chamber 127. The reason has been described in the fourth embodiment. The pressure sensor 91 as an inside pressure detecting means of the bellows for detecting the pressure of the chamber formed out of the bellows 151 is provided in the bellows 151.

[0103] Definitions of the inlet passage and the outlet passage, and relations of the inertance values in the fifth embodiment are similar to the fourth embodiment.

[0104] Next, a case where the pump 100 according to the fifth embodiment is driven in the discharge mode will be described. In the fifth embodiment, in the discharge mode, the switching valve 190 is switched into the first connection state to allow the working fluid to flow out toward the downstream side of the outflow passage 128. At that time, the pressure waveform in the pump chamber 127 when the piezoelectric element 70 is driven is similar to that in the first embodiment (see Fig. 2). For this reason, similarly to the first embodiment, since the discharge and the absorption occur simultaneously, a large flow volume can be transferred, and since the pump chamber has a very high inside pressure, it is possible to cope with a high load pressure. On the other hand, when gas bubbles stay in the pump chamber 127, it has been already described in the first embodiment that the pump does not operate properly.

[0105] Next, the bubble discharge mode, which is executed when gas bubbles stay in the pump chamber, will be described. Further, although not shown, in the switching valve control system, if the pump driving control circuit determines that gas bubbles stay in the pump chamber 127, the pump driving control circuit gives an instruction to the switching valve 190, and thus the switching valve 190 is switched into the second connection state from the first connection state.

[0106] At that time, since the inside of the bellows 151 is pressurized up to about one atmosphere (101.325 kPa) or more of gauge pressure, preferably to a pressure between about one atmosphere (101.325 kPa) and five atmospheres (506.625 kPa), the pump chamber 127 is almost pressurized up to the above pressure. In this way, by forming the variable-volume chamber out of an elastic member, it is possible to apply the pressure only with the elastic force of the elastic member.

[0107] Since the volume of the gas bubbles staying in the pump chamber 127 becomes smaller than the exclusion volume of the pump chamber 127 through the pressing, the gas bubbles are discharged into the bellows 151 through the driving of the piezoelectric element 70, as described in the fourth embodiment. Since the pump driving control circuit comprises a timer (not shown) for counting the time interval when the piezoelectric element 70 is driven after the switching valve 190 is switched into the second connection state, a predetermined time interval is counted sufficient to discharge the gas bubbles staying in the pump chamber 127 by using the timer, the switching valve 190 is then switched into the first connection state, and then the bubble discharge mode is finished.

[0108] At that time, the inside pressure of the bellows 151 is raised by the working fluid discharged from the pump chamber 127, but the bellows is designed so that the deformation due to the inside pressure is suppressed within an allowable range for elastic deformation. Further, the pump may be constructed so that a relief valve not shown is provided in the bellows 151, and it is possible to suppress the inside pressure of the bellows 151 from being raised by opening the relief valve when the inside pressure of the bellows 151 is too raised, and it is thus possible to maintain the inside pressure at a constant value of about one atmosphere (101.325 kPa) or more of gauge pressure and preferably a constant value between about one atmosphere (101.325 kPa) and five atmospheres (506.625 kPa). In the bubble discharge mode, the gas bubbles are removed, so that it is possible to recover the pump ability.

[0109] Next, a bellows pressing mode, which is performed to maintain the inside pressure of the bellows 151 to about one atmosphere (101.325 kPa) or more of gauge pressure and preferably a value between about one atmosphere (101.325 kPa) and five atmospheres (506.625 kPa), will be described with reference to Fig. 8.

[0110] The inside pressure of the bellows 151 is detected by the pressure sensor 91 provided in the bellows

151. When the detected pressure is smaller than about one atmosphere (101.325 kPa) of gauge pressure, an instruction is given to the pressurizing mechanism 150 from the pump driving control circuit 180, so that the switching valve 190 is switched to the second connection state. Next, the diaphragm 60 is driven by means of the piezoelectric element 70, so that the fluid is allowed to flow out of the pump chamber 127 to the outflow passage 128, similarly to the discharge mode.

[0111] Then, the working fluid flows in the bellows 151 through the switching valve 182, so that the inside of the chamber formed out of the bellows 151 is compressed. When the pump driving control circuit 180 confirms on the basis of the detected value of the pressure sensor 91 that the inside pressure of the bellows 151 reaches about one atmosphere (101.325 kPa) or more of gauge pressure and preferably a value between about one atmosphere (101.325 kPa) and five atmospheres (506.625 kPa), an instruction is given to the pressurizing mechanism 150 from the pump driving control circuit 180, the switching valve 190 is thus switched to the first connection state, and then the bellows pressing mode is finished. By performing this operation mode, even when leakage occurs in the switching valve 190, etc., the inside of the bellows 151 can be always maintained to the set pressure, so that it is possible to wait for the bubble discharge mode.

[0112] In the above fifth embodiment, the switching valve 190 comprises two valves, but an integrated three-way valve, etc. may be used. Since a hole (not shown in the figures), which can be airtightly closed, is provided in the bellows 151, it is possible to discharge the gas bubbles through the hole when too much gas bubbles are gathered in the bellows 151.

[0113] In a modification of the above fifth embodiment, in a case where the relationship between the time and the amount of leakage from the bellows 151 is known, the bellows pressing mode may be performed every predetermined time interval without providing the pressure sensor 91 in the bellows. In this case, by converting the amount of leakage from the time until the current bellows pressing mode is started after the previous bellows pressing mode is finished, it is possible to drive the piezoelectric element 70 for the time required for allowing the working fluid having the same volume as the amount of leakage to flow into the bellows 151 from the pump chamber 127.

[0114] Furthermore, by providing a relief valve not shown in the chamber formed out of the bellows 151 without providing the pressure sensor 91, the bellows pressing mode may be performed every predetermined time interval. As a result, if the inside of the bellows 151 is compressed above the pressure set with the relief valve when the bellows pressing mode is performed, the relief valve is opened and thus the working fluid is leaked, so that it is possible to maintain the inside of the bellows 151 to a constant pressure.

[0115] In the above description, the pressure sensors

described in the fourth embodiment can be similarly used as the pressure sensor 90 in the pump chamber 127 for detecting the inside pressure of the pump chamber 127 and the pressure sensor 91 in the bellows 151.

[0116] Therefore, according to the fifth embodiment, the pressurizing mechanism 150 is provided with the passage switching means for switching between the first mode in which the working fluid flowing out of the pump chamber 127 is introduced into the chamber of the bellows 151 and the second mode in which the chamber of the bellows 151 is shut off from the flow of the working fluid flowing out of the pump chamber 127. As a result, it is possible to surely compress the working fluid in the pump chamber 127 with the elastic force of the elastic member constituting the variable-volume chamber.

[0117] Furthermore, since the pressure sensor 91 for detecting the inside pressure of the variable-volume chamber is provided, it is possible to control the inside pressure of the variable-volume chamber within a proper pressure range. Furthermore, since the pressure sensor 90 is provided in the pump chamber 127, it is possible to determine whether gas bubbles stay in the pump chamber 127.

[0118] Furthermore, since the pressure applied from the pressurizing mechanism 150 is set to a value between about one atmosphere (101.325 kPa) and five atmospheres (506.625 kPa) of gauge pressure, it is possible to reduce the volume of the gas bubbles staying in the pump chamber as much as possible to discharge, without damaging the constituent components of the pump due to the pressure.

Sixth Embodiment

[0119] Next, a pump according to a sixth embodiment will be described with reference to Figs. 10 and 11.

[0120] The sixth embodiment has a basic structure similar to that of the above fourth embodiment except for the pressurizing mechanism, and thus differences therebetween will be described in detail. The pump according to the sixth embodiment is used without connecting an external tube to the outflow passage 128, has a structure not requiring the switching valve (see Figs. 7 and 9) described in the fourth and fifth embodiments, and is characterized in that the pressurizing mechanism 150 is provided detachably from the outflow passage 128.

[0121] Fig. 10 shows a vertical cross-sectional view of the independent pressurizing mechanism according to the sixth embodiment. In Fig. 10, the pressurizing mechanism 150 comprises the bellows 151 and a valve case 153 to which the bellows 151 is fixed and receives a valve 156.

[0122] As described in the above fourth embodiment, the variable-volume chamber in which the working fluid stays and an opening portion 152 are formed in the bellows 151, which is closely fixed to an end of the valve case 153.

[0123] The valve case 153 comprises the opening portion 152 communicating with the bellows 151, an entry hole 155 into which the outlet connection tube 131 (see Fig. 11) of the pump 100 is inserted, a valve fitting hole 154 which communicates with the opening portion 152 and an entry hole 155 and to which the valve 156 is fitted, and a rod inserting hole 160 into which a rod 159 of the valve 156 is inserted. A seal member 165 for preventing the working fluid from leaking from the connected portion of the outlet connection tube 131 and the entry hole 155 is fitted into an intermediate portion of the entry hole 155.

[0124] The valve 156 is connected to the rod 159 with the rod inserting hole 160 therebetween and a washer 157 for fixing the rod 159. Through-holes 158 through which the working fluid passes are formed in the washer 157. In addition, a coil spring 161 for applying force to the valve 156 in order to seal the rod inserting hole 160 is provided between the washer 157 and the inside wall of the entry hole 155.

[0125] The variable-volume chamber of the bellows 151 is compressed within a range of about one atmosphere (101.325 kPa) to five atmospheres (506.625 kPa) of gauge pressure by means of the elastic force of the bellows 151, similarly to the fourth and fifth embodiments.

[0126] Fig. 11 is a partially vertical cross-sectional view illustrating a state where the above pressurizing mechanism 150 is fitted onto the outlet connection tube 131 of the pump 100. In Fig. 11, the entry hole 155 of the pressurizing mechanism 150 is inserted onto the outlet connection tube 131. At that time, the front end portion of the outlet connection tube 131 comes into contact with the washer 157 and compresses the coil spring 161, so that the valve 156 is moved to a position for opening the rod inserting hole 160. At that time, the outflow passage 128 and the chamber surrounded with the bellows 151 communicate with each other, so that the working fluid can flow through the through-holes 158 therebetween.

[0127] Next, a case where gas bubbles do not stay in the pump 100 according to the sixth embodiment will be described. This case will be described with reference to Figs. 10 and 11.

[0128] In a normal state where gas bubbles do not stay in the pump 100 according to the sixth embodiment, the pressurizing mechanism 150 is separated from the outflow passage 128 to discharge the working fluid from the outflow passage 128. In this case, the principle of discharging the working fluid to the outflow passage 128 is similar to that of the first embodiment. Therefore, when gas bubbles stay in the pump chamber 127, increase in pressure of the pump chamber is hindered and the pump ability is thus deteriorated largely, so that it is important to rapidly remove the gas bubbles.

[0129] Next, a case where gas bubbles stay in the pump chamber 127 will be described.

[0130] When there are gas bubbles, the outflow

amount of the working fluid from the outflow passage 128 is decreased largely. Therefore, when a user observes the decrease of the outflow amount from the outflow passage 128, the user fits the pressurizing mechanism 150 onto the outlet connection tube 131 (see Fig. 11). In Fig. 11, by pressing the washer 157 with the end portion of the outlet connection tube 131 by means of a force larger than the elastic force of the coil spring 161, the coil spring 161 is compressed, the valve 156 is thus opened, and the through-holes 158 for the working fluid provided in the washer 157 and the opened valve 156 communicate with each other, so that the outflow passage 128 is connected to the inside (the chamber) of the bellows 151.

[0131] In this way, since the volume of the gas bubbles staying in the pump chamber 127 is reduced by means of compression of the inside of the pump chamber 127, the gas bubbles can be discharged into the bellows 151 from the outflow passage 128, as described in the fourth and fifth embodiments. At that time, a lock mechanism for preventing the connection of the outflow passage 128 and the bellows 151 from going amiss may be provided.

[0132] In this embodiment, the inside pressure of the bellows may be suppressed from being raised by providing a relief valve in the bellows 151. Furthermore, by providing a hole that can be airtightly closed in the bellows 151, the gas bubbles staying in the bellows can be discharged.

[0133] Therefore, according to the sixth embodiment, since the pressurizing mechanism is freely detachable, when the pressurizing mechanism is fitted into the outlet passage, the outlet passage and the pressurizing mechanism communicate with each other, and the inside pressure of the variable-volume chamber is raised, thereby discharging the gas bubbles in the pump chamber. When there are no gas bubbles in the pump chamber, by separating the pressurizing mechanism, it is possible to realize a small and light pump.

Seventh Embodiment

[0134] Next, a pump according to a seventh embodiment will be described with reference to Figs. 12 to 14. The seventh embodiment has the same basic structure and discharge operation of working fluid as the first to sixth embodiments described above, but is different from them in that a heating section is provided as the bubble discharging means of the pump chamber.

[0135] Therefore, a relationship between the heating section and the bubble discharge will be described in detail.

[0136] Fig. 12 shows a vertical cross-section of the pump 200 according to the seventh embodiment. In Fig. 12, the pump 200 basically comprises a cup-shaped case 50 to which a piezoelectric element 70 is fixed, an inflow passage 221 for introducing a working fluid, an outflow passage 228 for discharging the working fluid,

a pump case 220 having a pump chamber 227, and a ring-shaped heater 212 provided in the pump chamber 227.

[0137] In the case 50, one end portion of the piezoelectric element 70 is fixed to the inside bottom portion, and a diaphragm 60 is fixed to both of the edge portion of the case 50 and the other end portion of the piezoelectric element 70. The pump case 220 is airtightly fixed to the top surface of the diaphragm 60, and the pump chamber 227 is formed in a space between the diaphragm 60 and the bottom portion of the pump case 220.

[0138] The inflow passage 221 and the outflow passage 228 are formed toward the pump chamber 227. In the inflow passage 221, a check valve 222 as a fluid resistance element for opening and closing the inflow passage 221 is provided at a connecting portion with the pump chamber 127. A part of the outer circumference of a cylindrical portion constituting the inflow passage 221 functions as an inlet connection tube 230 to be connected to an external tube not shown. A part of the outer circumference of a cylindrical portion constituting the outflow passage 228 functions as an outlet connection tube 231 to be connected to an external tube not shown. As the external tube not shown, for example, tubes made of silicon rubber can be used.

[0139] The inflow passage 221 itself is defined as an inlet passage, and the outflow passage 228 itself is defined as an outlet passage. In a relationship of inertance values, as described above, the total inertance value of the inlet passage side is set to be smaller than the inertance value of the outlet passage side.

[0140] In addition, the ring-shaped heater 212 is fixed to the outer circumferential corner portion of the inside top wall of the pump chamber 227. The heater 212 is airtightly inserted and fixed to that corner portion, so that the heater does not protrude from the top wall surface of the pump chamber 227 toward the pump chamber.

[0141] Fig. 13 is a plan view of the pump case 220 shown in Fig. 12 as seen from the pump chamber side.

[0142] In Fig. 13, the heater 212 is arranged at a position in the corner portion of the pump chamber 227 where gas bubbles easily stay. The heater 212 is formed by fixing a resistance member to a ceramics substrate of alumina, etc., and then coating an insulating film thereon. Various members may be used as the resistance member, but members having a high melting point, specifically, platinum or a platinum alloy, can be preferably used. Although not shown, a lead wire for supplying power to the heater 212 is drawn out through the pump case 220.

[0143] The inside of the pump chamber 227 is provided with a pressure sensor 90 not shown (see Fig. 15).

[0144] Next, a modified example of the heater 212 according to the seventh embodiment will be described with reference to Fig. 14.

[0145] In Fig. 14, the heater 212 is formed as a thin plate having a circular plate shape, and is fixed to a wide range of the top wall surface of the pump chamber 227

other than the circumferential portion of the inflow passage 221 and outflow passage 228. The heater 212 is inserted into the top wall of the pump chamber 227 so that it does not protrude from the top wall surface.

[0146] Next, a case where the pump 200 according to the seventh embodiment is driven in a discharge mode of the working fluid will be described.

[0147] The discharge mode is a mode in which power is not supplied to the heater 212 and a voltage is applied only to the piezoelectric element 70. Since the discharge mode has been described in the first to sixth embodiments described above, the description thereof will be omitted here. At that time, as described above, when gas bubbles stay in the pump chamber 227, the inside pressure of the pump chamber is decreased and the pump ability is deteriorated, so that a bubble discharge mode is performed.

[0148] Next, a case where the pump 200 according to the seventh embodiment is driven in the bubble discharge mode will be described with reference to Fig. 15 (also, see Fig. 12).

[0149] Fig. 15 is a block diagram of a driving circuit system of the pump 200. In Fig. 15, the driving circuit system of the pump 200 comprises the pressure sensor 90 as pressure detecting means in the pump chamber 227, the heater 212, a power distribution circuit 265 for controlling the heater 212, and a pump driving control circuit 280 for controlling the driving of the pump 200.

[0150] In a case where the maximum inside pressure of the pump chamber detected by the pressure sensor 90 when the pump 200 is driven in the discharge mode is smaller, specifically by 50% or less, than the maximum inside pressure of the pump chamber when the pump is normally driven, the pump driving control circuit 280 determines that gas bubbles stay in the pump chamber 227, and thus switches the driving mode to the bubble discharge mode from the discharge mode. Then, the pump driving control circuit 280 sends a signal to the power distribution circuit 265, and then the power distribution circuit 265 starts the power distribution to the heater 212 in response to the signal.

[0151] Since the heater 212 is arranged at the corner portion in which the flow is stagnant and the gas bubbles easily stay as described above, the gas bubbles existing in the vicinity thereof are heated by means of the heater 212, so that it is possible to expand the volume of the gas bubbles. As a result, if the size of the gas bubbles grows such that the gas bubbles can no longer be received completely in the stagnant area, the gas bubbles are moved along the flow inside the pump chamber 227 due to the driving of the diaphragm 60 and thus can be discharged out of the outflow passage 128. The bubble discharge mode is set to be finished after a predetermined time interval.

[0152] At that time, in a case where a plurality of heaters 212 are provided, by constructing the power distribution circuit 265 to sequentially switch the power distribution to the respective heaters with time, the distrib-

uted current can be reduced without change of the heat quantity of the heaters supplied with electricity, so that the power distribution circuit 265 can be miniaturized.

[0153] On the other hand, by generating a heat quantity with which the working fluid existing on the surface of the heaters 212 changes its phase, gas bubbles may be generated due to the phase change from the respective surface portions of the heaters 212. In this method, the working fluid corresponding to the volume of the generated gas bubbles is discharged to the outflow passage 228. When the power distribution to the heaters 212 is stopped and the change of phase is finished, the working fluid having an amount corresponding to the volume of the discharged working fluid is introduced into the pump chamber 227 through the check valve 222 from the inflow passage 221. At that time, since the gas bubbles due to the change of phase are generated from the respective surface portions of the heaters 212, the flow inside the pump chamber 227 is complex and not stagnant, so that it is possible to discharge the gas bubbles gathered at the corner portions of the pump chamber which is the stagnant area in the discharge mode.

[0154] Furthermore, by generating a heat quantity enough to allow the working fluid existing on the surface of the heater 212 to reach an overheated state through the power distribution from the power distribution circuit 265, a film boiling, i.e., generation of film-shaped gas bubbles from the whole surface of the heater 212, may be caused. This method is preferable in that since the volume of the gas bubbles generated due to the change of phase is increased and the volume of the working fluid discharged to the outflow passage 228 from the pump chamber 227 with one power distribution is increased, it is easy to discharge the gas bubbles.

[0155] Fig. 16 shows another modified example of the heater 212. In Fig. 16, the heater 212 comprises two heaters, a heater 213 arranged at the inflow passage 221 side and a heater 214 arranged at the outflow passage 228 side.

[0156] In this case, the phases of the distributed current to the respective heaters are deviated by using the power distribution circuit 265 (see Fig. 15). As a result, after the inside pressure of the gas bubbles generated through the film boiling on the surface of one heater exceeds the maximum value, the inside pressure of the gas bubbles generated through the film boiling on the surface of the other heater reaches the maximum value.

[0157] Furthermore, it is preferable that the heater 213 close to and the heater 214 far from the opening portion of the pump chamber 227 of the outflow passage 228 are provided, the power distribution to the far heater 214 is first started, and the power distribution to the heater 213 is started later, so that the flow from the corner portion of the pump chamber 227 toward the outflow passage 228 can be easily generated. Of course, the number of heaters 212 may be two or more.

[0158] When the phase of the working fluid on the surface of the heater 212 is changed, the diaphragm 60

may have any one of the stopped state and the driven state, but it is preferable that the diaphragm 60 is driven, so that the flow inside the pump chamber becomes complex and thus the gas bubbles can be easily discharged.

[0159] In the seventh embodiment, the pump driving control circuit 280 and the power distribution circuit 265 may be controlled so that the heater 212 is allowed to emit heat in a pulse shape by performing the power distribution to the heater 212 using a pulse current and the diaphragm 60 is driven in a direction in which the volume of the pump chamber 227 is reduced in synchronism with the heat emitting.

[0160] As a result, it is possible to effectively discharge the gas bubbles staying in the pump chamber while reducing the energy consumption of the heating section.

[0161] Furthermore, it is preferable that when the start and stop of the power distribution to the heater 212 are repeated several times during one bubble discharge mode, a more complex flow is generated inside the pump chamber and thus the gas bubbles are more easily discharged. Furthermore, it is preferable that the value detected by the pressure sensor 91 is checked by driving the pump in the discharge mode after the bubble discharge mode is finished, so that it is possible to repeat the driving of the bubble discharge mode until the gas bubbles are surely discharged.

[0162] Therefore, according to the seventh embodiment, since the inside pressure of the pump chamber 227 is raised by providing the heater 212 inside the pump chamber 227 and thus the volume of the gas bubbles is compressed, it is possible to discharge the gas bubbles in the pump chamber 227.

[0163] Furthermore, since the heater 212 is fitted into the wall of the pump chamber 227 so that the heater does not protrude from the wall, and the heater is arranged at least at the corner portion of the pump chamber 227, the gas bubbles can be prevented from staying in a protruded portion in which the gas bubbles become easily stagnant, and it is also possible to discharge the gas bubbles at the corner portion of the pump chamber 227.

[0164] Furthermore, when a plurality of heaters 212 are provided, it is possible to reduce the quantity of energy per unit time to be supplied to the heaters 212, and to rapidly discharge the gas bubbles while preventing a destruction of the pump.

[0165] Furthermore, since the pressure sensor 90 is provided in the pump chamber 227, it is possible to surely determine whether gas bubbles stay in the pump chamber 227, and to discharge the gas bubbles in the pump chamber 227 as described above.

[0166] Furthermore, since the heater 212 emits heat in a pulse shape and the diaphragm 60 is driven in synchronism with the pulse, it is possible to effectively discharge the gas bubbles staying in the pump chamber 227 while reducing the energy consumption of the heater 212.

[0167] Furthermore, by performing the heating process to generate the heat quantity with which the working fluid in contact with the heater 212 changes its phase, gas bubbles due to the change of phase are generated in the pump chamber 227, so that a complex and non-stagnant flow flowing toward the outflow passage 228 can be caused in the pump chamber 227. As a result, it is possible to discharge the gas bubbles staying in the pump chamber 227.

[0168] Furthermore, in the above description, since the bubble discharge mode is performed when it is determined by means of the pressure sensor 91 that there are gas bubbles, the bubble discharge mode is not performed wastefully, but the bubble discharge mode may be performed every predetermined time interval instead. In this case, since the pressure sensor 91 can be omitted, it is possible to simplify the structure.

[0169] Furthermore, in the above description, a construction where the pressure sensor as the pressure detecting means for the pump chamber is provided in the pump chamber 227 has been described, but different constructions may be employed. In one different construction, for example, the inside pressure of the pump chamber 227 may be calculated by measuring the deformation of the diaphragm 60 with a strain gauge or a displacement sensor. Further, the inside pressure of the pump chamber 227 may be calculated by measuring the deformation of the valve member in a state where the check valve 222 is closed, with a strain gauge or a displacement sensor. Furthermore, the inside pressure of the pump chamber 227 may be calculated by measuring current for driving the piezoelectric element 70 with a current sensor. Furthermore, by providing a strain gauge in the piezoelectric element 70, the inside pressure of the pump chamber 227 may be calculated on the basis of the voltage applied to the piezoelectric element 70 and the measured value by the strain gauge. At that time, any type of strain gauges that detect the quantity of deformation by using variation in resistance, variation in capacitance, or variation in voltage may be used as the strain gauge.

[0170] In addition, the shape of the diaphragm 60 is not limited to the circular shape. Further, the check valve 222 is not limited to the passive valve which performs the opening and closing due to the pressure difference of the fluid, but an active valve which can control the opening and closing with different forces may be used as the check valve.

[0171] The present invention is not limited to the above embodiments, but the present invention includes modifications and improvements within a range in which the object of the present invention can be accomplished as determined by the claim.

[0172] In the seventh embodiment, for example, the total inertance value of the inlet passage side is smaller than the total inertance value of the outlet passage side, and the heater 212 as the bubble discharging means is employed in the small high-pressure pump having an

inertia effect of the working fluid. However, the bubble discharge means may be employed, for example, in a pump using a unimorph type diaphragm shown in Fig. 17.

[0173] Fig. 17 is a vertical cross-sectional view of the pump employing the unimorph type diaphragm. In Fig. 17, constituent elements different from the seventh embodiment will be described in detail. The pump 200 comprises a unimorph type diaphragm 260 as a diaphragm, and check valves 222, 242 as the fluid resistance elements provided in both of the inflow passage 221 and the outflow passage 228. In Fig. 17, the diaphragm 260 is airtightly fixed to the edge portion of the cup-shaped case 250, and the piezoelectric element 71 is fixed to the surface of the diaphragm 260 facing the case 250. The pump case 220 is airtightly fixed to the top of the diaphragm 260, and the pump chamber 227 is formed between the diaphragm 260 and the pump case 220.

[0174] The inflow passage 221 and the outflow passage 228 communicate with the pump chamber 227, the check valve 222 as the fluid resistance element is provided in the inflow passage 221, and the check valve 242 as the fluid resistance element is provided in the outflow passage 228. The plane-shaped heater 212 as the heating section is provided on the top wall surface constituting the pump chamber 227 of the pump case 220. The heater 212 is airtightly fitted into the pump case 220, so that the heater is not protruded from the pump case 220 toward the pump chamber.

[0175] The shape and material of the heater 212, and the position in which the heater is fitted into the pump case 220 are similar to the seventh embodiment and the modified example of the seventh embodiment, and thus descriptions thereof will be omitted.

[0176] The discharge mode of the pump will be described.

[0177] If a voltage is applied to the piezoelectric element 71, the diaphragm 260 is deformed to have a convex surface toward the pump chamber 227 through the diametrical deformation of the piezoelectric element 71, and if the application of voltage is stopped, the diaphragm is restored to the original shape. In this pump, when the check valves 222 and 242 close the flow passage, the diaphragm 260 is deformed in the direction in which the volume of the pump chamber 227 is decreased by using the deformation of the diaphragm 226, thereby pressing the liquid inside the pump chamber 227. If the inside pressure of the pump chamber 227 becomes higher than the downstream pressure of the check valve 242, the check valve 222 is opened, and thus the liquid is discharged to the outflow passage 228.

[0178] Next, by deforming the diaphragm 260 in the direction in which the volume of the pump chamber 227 is increased, the inside pressure of the pump chamber 227 is decreased. Then, the check valve 242 is first closed, and if the inside pressure of the pump chamber 227 becomes lower than the upstream pressure of the check valve 222, the check valve 222 is opened, so that

the liquid is introduced into the pump chamber 227 from the inflow passage 221. By repeating the above actions, the working fluid is transferred.

[0179] By providing the heater 212 as the bubble discharge means in the pump having the above structure, it is possible to allow the gas bubbles inside the pump chamber to flow out, and to suitably maintain the inside pressure of the pump chamber, so that it is possible to secure the amount of working fluid to be discharged.

[0180] In the above embodiments, the diaphragms 60, 45 have a circular shape, but the shape is not limited to the circular shape. Further, the check valves 41, 42 are not limited to the passive valves that perform the opening and closing process due to the pressure difference of the fluid, but active valves that can control the opening and closing process with different forces may be used as the check valves. Furthermore, any element may be used as the piezoelectric element for driving the diaphragm 60, only if it can be contracted and expanded. However, in this pump structure, since the piezoelectric element and the diaphragm are connected to each other without a displacement enlarging mechanism and thus the diaphragm can be driven at a high frequency, it is possible to increase the flow volume with a high frequency driving by employing a piezoelectric element having a high response frequency as in the embodiments, so that it is possible to realize a small and high-power pump. Similarly, a super magnetic distortion element having a high frequency characteristic may be employed. Different liquid such as oil may be used as the working fluid, in addition to water.

[0181] Therefore, according to the first to seventh embodiments described above, since the bubble discharging means is provided, it is possible to provide a pump capable of discharging the gas bubbles and thus maintaining a discharging ability thereof, even when the gas bubbles stay in the pump chamber.

Claims

1. A pump comprising a pump chamber (24, 27) whose volume can be varied by driving a piston or a movable wall (45, 60), an inlet passage for allowing a working fluid to flow into the pump chamber, an outlet passage for allowing the working fluid to flow out of the pump chamber, and a fluid resistance element (41) for opening and closing at least the inlet passage,
 - wherein a total inertance value of the inlet passage is set to be smaller than a total inertance value of the outlet passage, and
 - wherein bubble discharging means for discharging gas bubbles remaining in the pump chamber is further provided.
2. The pump according to Claim 1, wherein the pump chamber comprises a primary pump chamber (27)

which communicates with the outlet passage and whose volume can be varied by driving a piston or a movable wall (60), and a secondary pump chamber (24) which communicates with the inlet passage and functions as the bubble discharging means and whose volume can be varied by driving a movable wall (45).

3. The pump according to Claim 2, comprising:

a primary pump chamber inlet passage for allowing the working fluid to flow into the primary pump chamber (27);
a primary pump chamber outlet passage for allowing the working fluid to flow out of the primary pump chamber (27);
a secondary pump chamber inlet passage for allowing the working fluid to flow into the secondary pump chamber (24); and
a secondary pump chamber outlet passage for allowing the working fluid to flow out of the secondary pump chamber (24),

wherein the primary pump chamber inlet passage also functions as the secondary pump chamber outlet passage.

4. The pump according to Claim 3, further comprising:

a fluid resistance element (42) for opening and closing the primary pump chamber inlet passage;
a fluid resistance element (41) for opening and closing the secondary pump chamber inlet passage; and
a fluid resistance element (42) for opening and closing the secondary pump chamber outlet passage,

wherein the fluid resistance element for opening and closing the primary pump chamber inlet passage also functions as the fluid resistance element for opening and closing the secondary pump chamber outlet passage.

5. The pump according to any one of Claims 2 to 4, wherein the movable wall (45) provided in the secondary pump chamber (24) is a diaphragm to which a piezoelectric element (71) is attached on at least one surface thereof, and the secondary pump chamber (24) and the diaphragm constitute a uni-morph pump or a bimorph pump.

6. The pump according to any one of Claims 2 to 5, further comprising a driving switch control unit (85) for switching the driving between the secondary pump chamber (24) and the primary pump chamber (27).

7. The pump according to Claim 5, wherein a driving electrode (52) and a detecting electrode (53) are formed on the piezoelectric element (71).

8. The pump according to any one of Claims 2 to 6, further comprising a pressure detecting section (90) for detecting an inside pressure of the primary pump chamber (127).

9. The pump according to Claim 1, further comprising a pressurizing mechanism (150) serving as the bubble discharging means for raising and maintaining the pressure of the working fluid existing in the pump chamber (127).

10. The pump according to Claim 9, wherein the pressurizing mechanism (150) comprises a variable-volume chamber (151) and a flow passage (132) for allowing the variable-volume chamber and the outlet passage (128) to communicate with each other.

11. The pump according to Claim 10, wherein the variable-volume chamber (151) is formed of an elastic member.

12. The pump according to Claim 10, wherein the pressurizing mechanism (150) further comprises a volume varying mechanism (170, 171) for applying a pressure to vary the volume of the variable-volume chamber.

13. The pump according to Claim 9, wherein the pressurizing mechanism (150) comprises a passage switching section (190) for switching between a first mode where the working fluid flowing out of the pump chamber (127) is introduced into the variable-volume chamber (151), and a second mode where the working fluid flowing out of the pump chamber (127) is isolated from the variable-volume chamber (151).

14. The pump according to Claim 10, further comprising a pressure detecting section (91) for detecting an inside pressure of the variable-volume chamber (151).

15. The pump according to Claim 9, wherein pressure detecting means (90) is provided in the pump chamber (127).

16. The pump according to Claim 12, wherein the inside pressure of the variable-volume chamber (151), which is pressurized by the pressurizing mechanism (150), ranges from about one atmosphere (101.325 kPa) to about five atmospheres (506.625 kPa) of gauge pressure.

17. The pump according to Claim 9,

wherein the pressurizing mechanism (150) comprises a variable-volume chamber (151), a flow passage communicating with the outlet passage (128), and an opening and closing member (156) for opening and closing the flow passage, and
wherein the pressurizing mechanism (150) is detachable from the outlet passage, and the variable-volume chamber and the outlet passage are allowed to communicate with each other by fitting the pressurizing mechanism (150) into the outlet passage.

18. The pump according to Claim 1, wherein a heating section (212) serving as the bubble discharging means is provided in the pump chamber (227).
19. The pump according to Claim 18, wherein the heating section (212) is received inside the wall of the pump chamber (227), or is arranged in a corner portion of the pump chamber (227).
20. The pump according to Claim 18, wherein a plurality of the heating sections (213, 214) are provided.
21. The pump according to Claim 18, further comprising a pressure detecting section for detecting an inner pressure of the pump chamber (227).
22. The pump according to Claim 18, wherein when the piston or the movable wall (60) is being driven, a heating signal is input to the heating section (212).
23. The pump according to Claim 18, wherein a pulse-shaped heating signal is input to the heating section (212), and the piston or the movable wall (60) is driven in synchronism with the heating signal.
24. The pump according to Claim 19, wherein the heating section (212) heats the working fluid to change the phase of the working fluid in contact with the heating section.

45

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FIG. 1

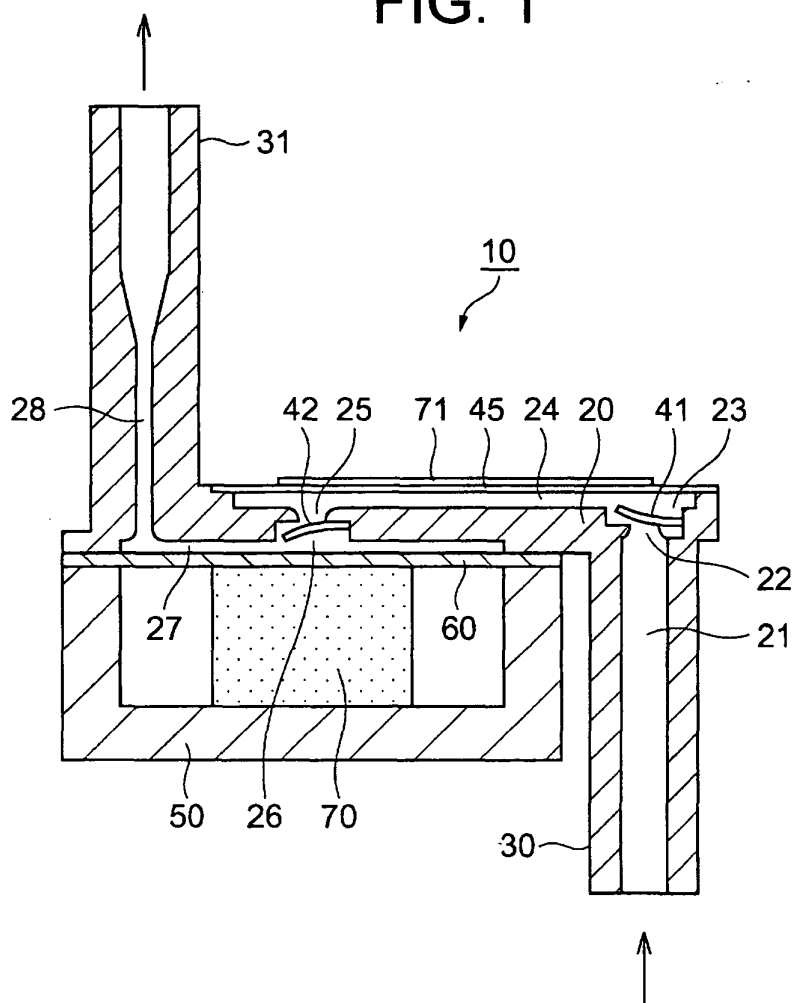


FIG. 2

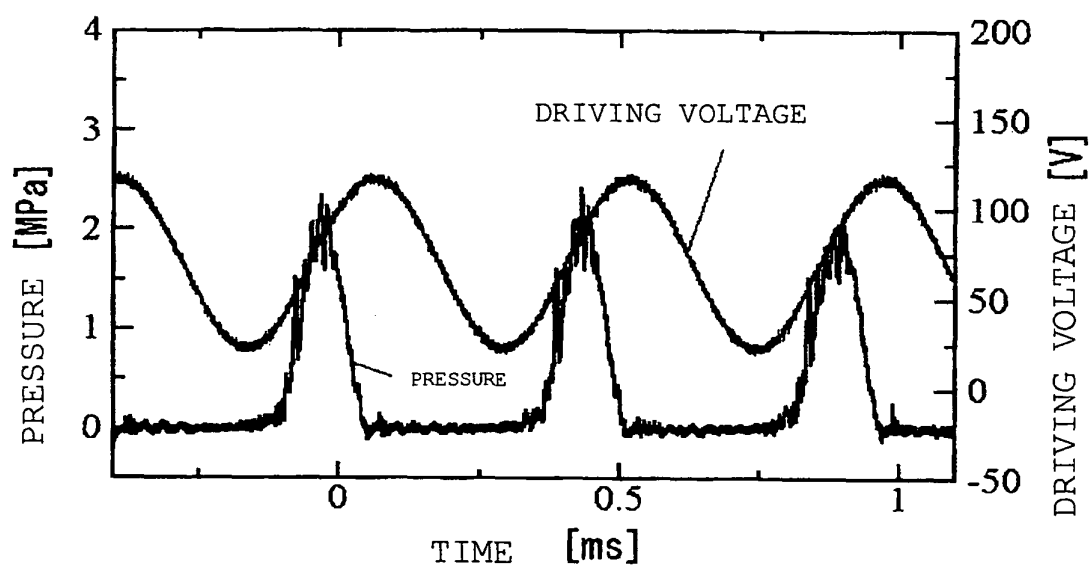


FIG. 3

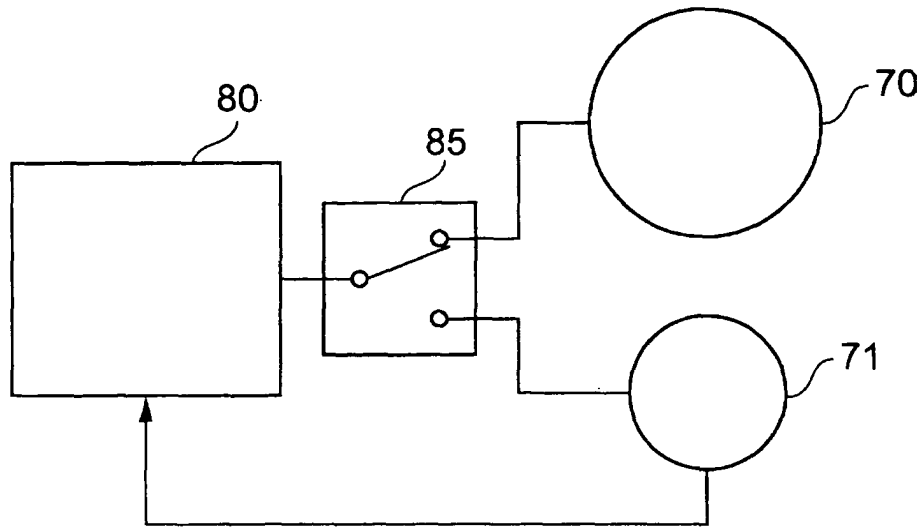


FIG. 4

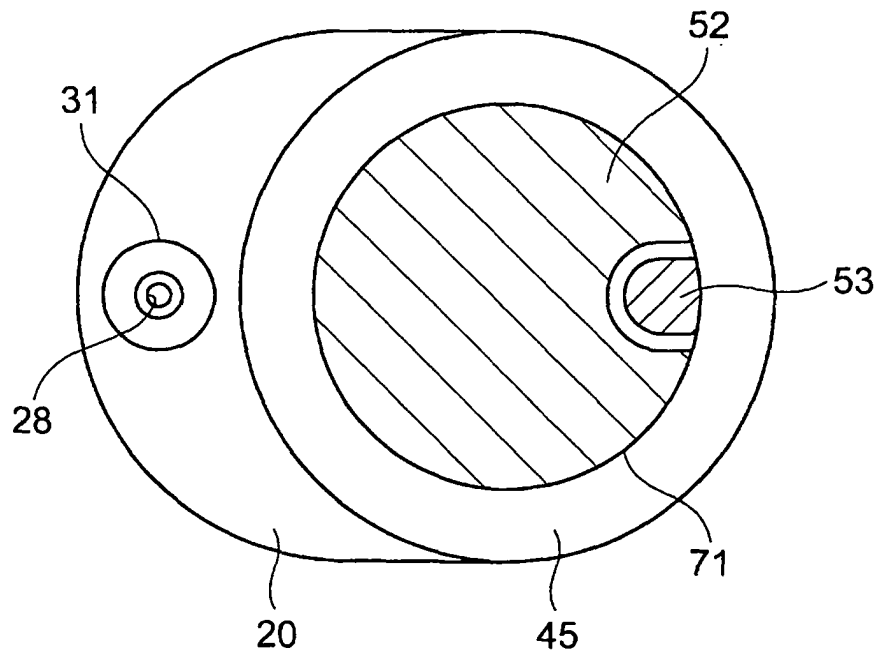


FIG. 5

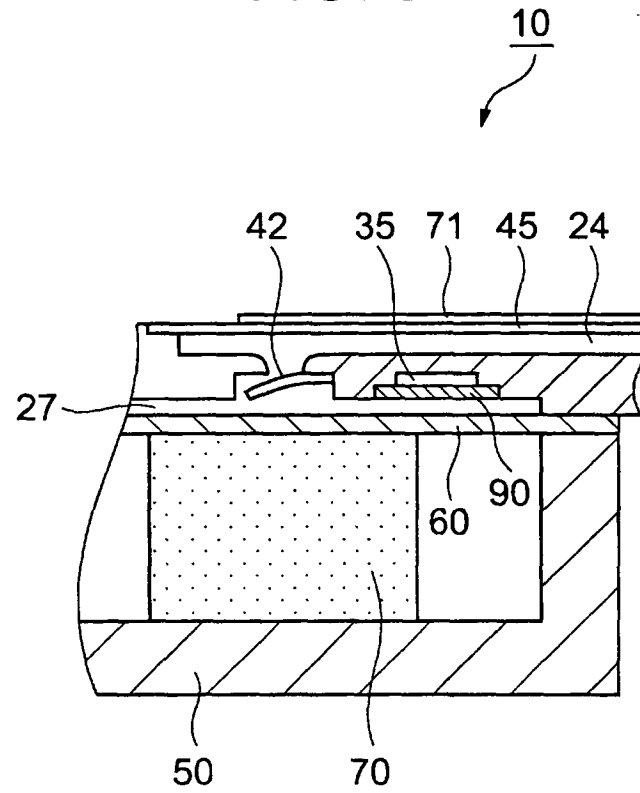


FIG. 6

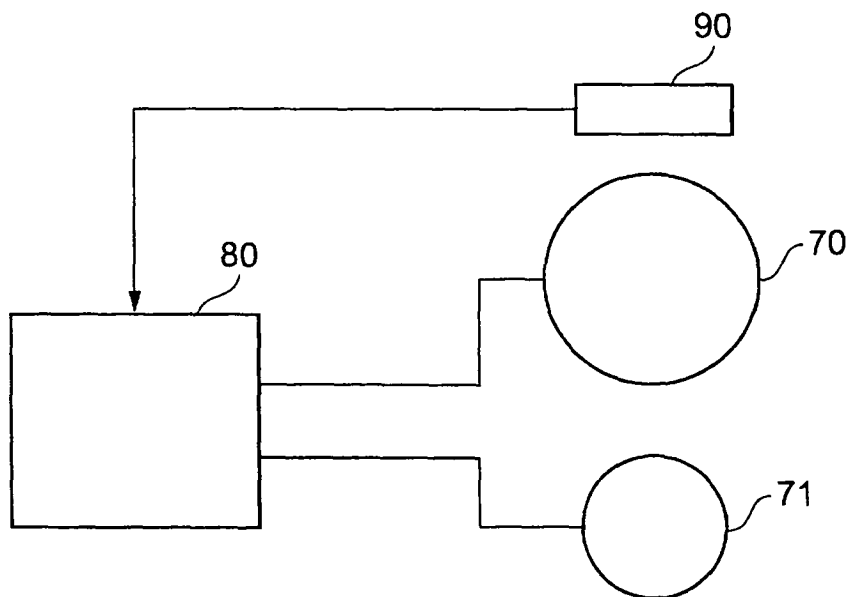


FIG. 7

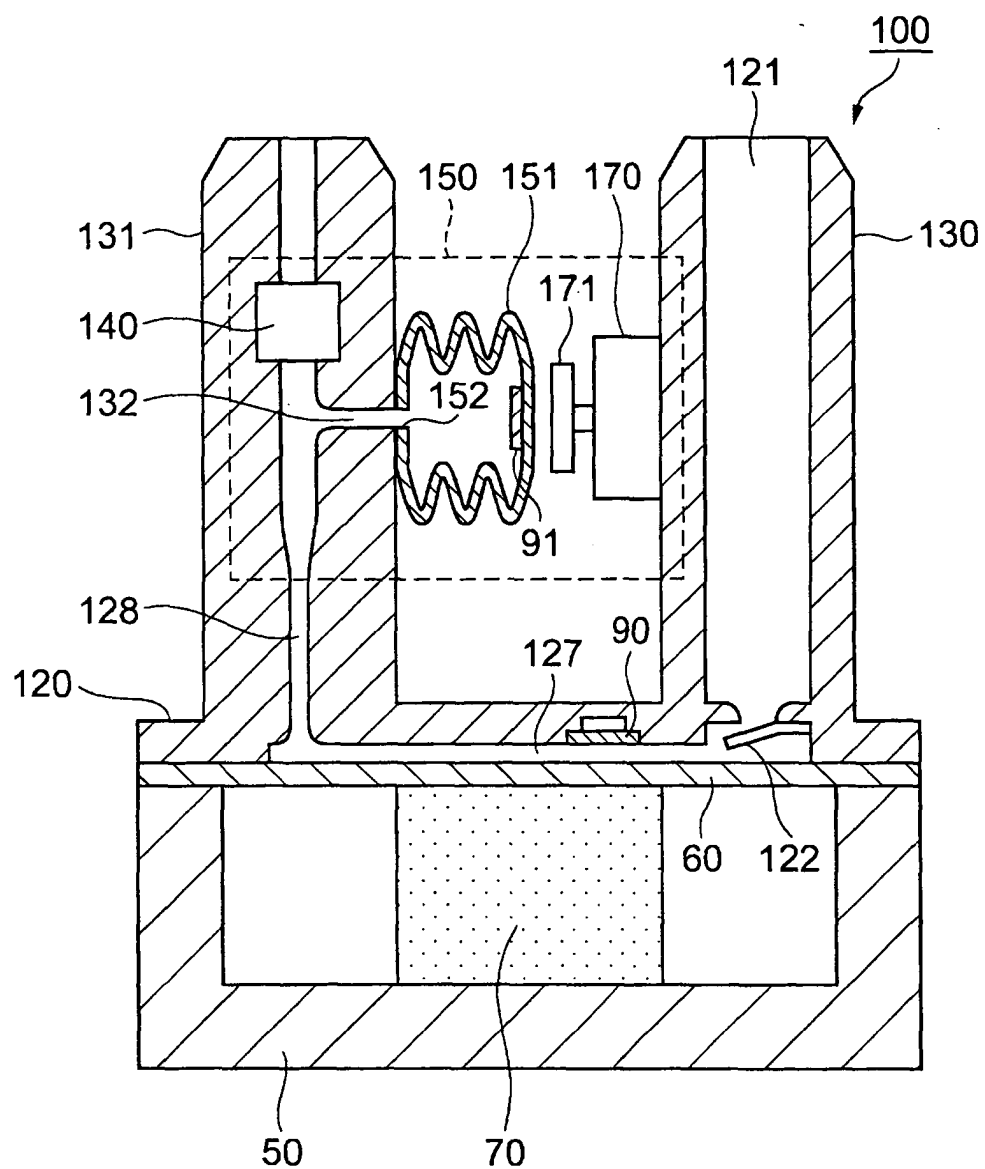


FIG. 8

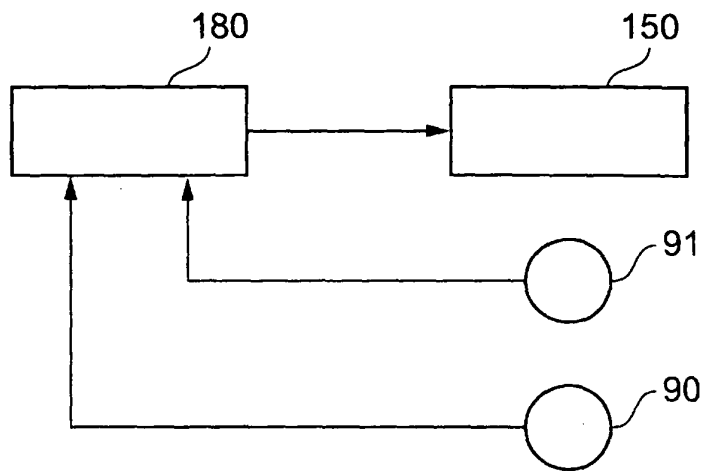


FIG. 9

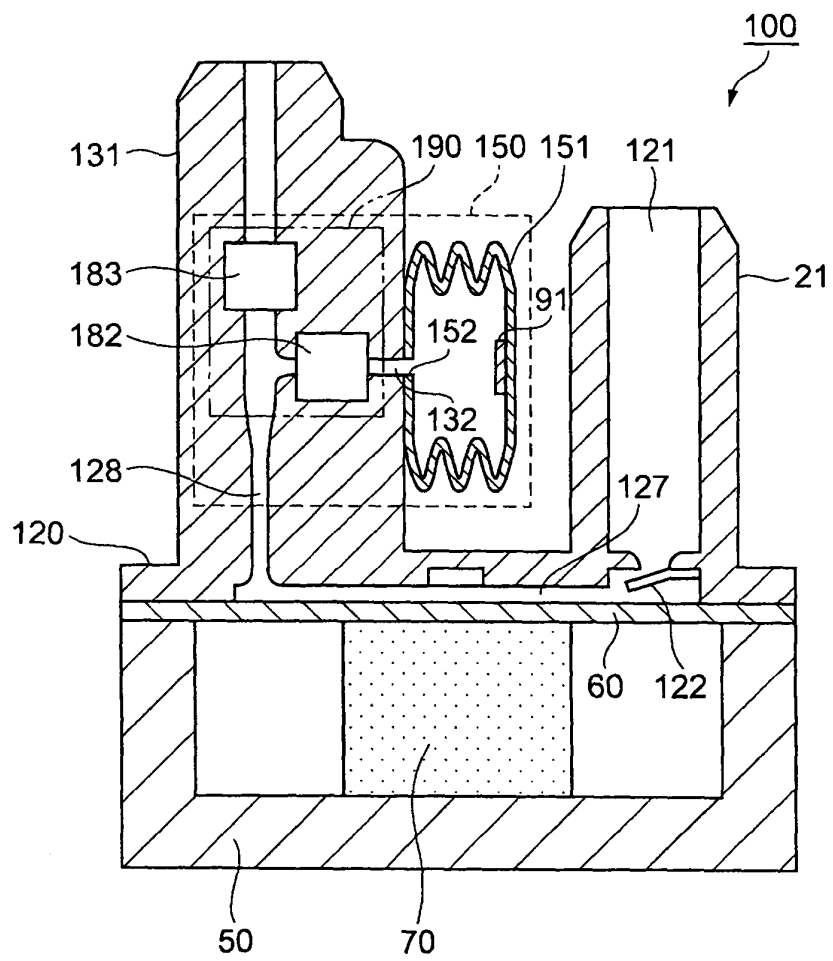


FIG .10

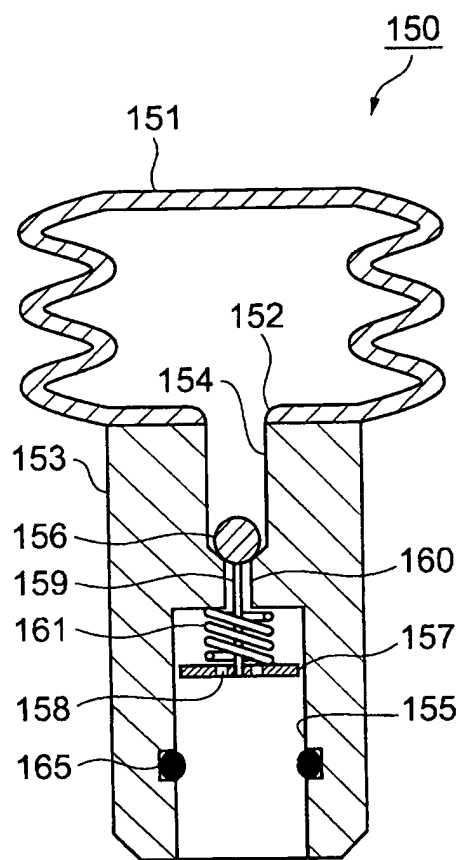


FIG. 11

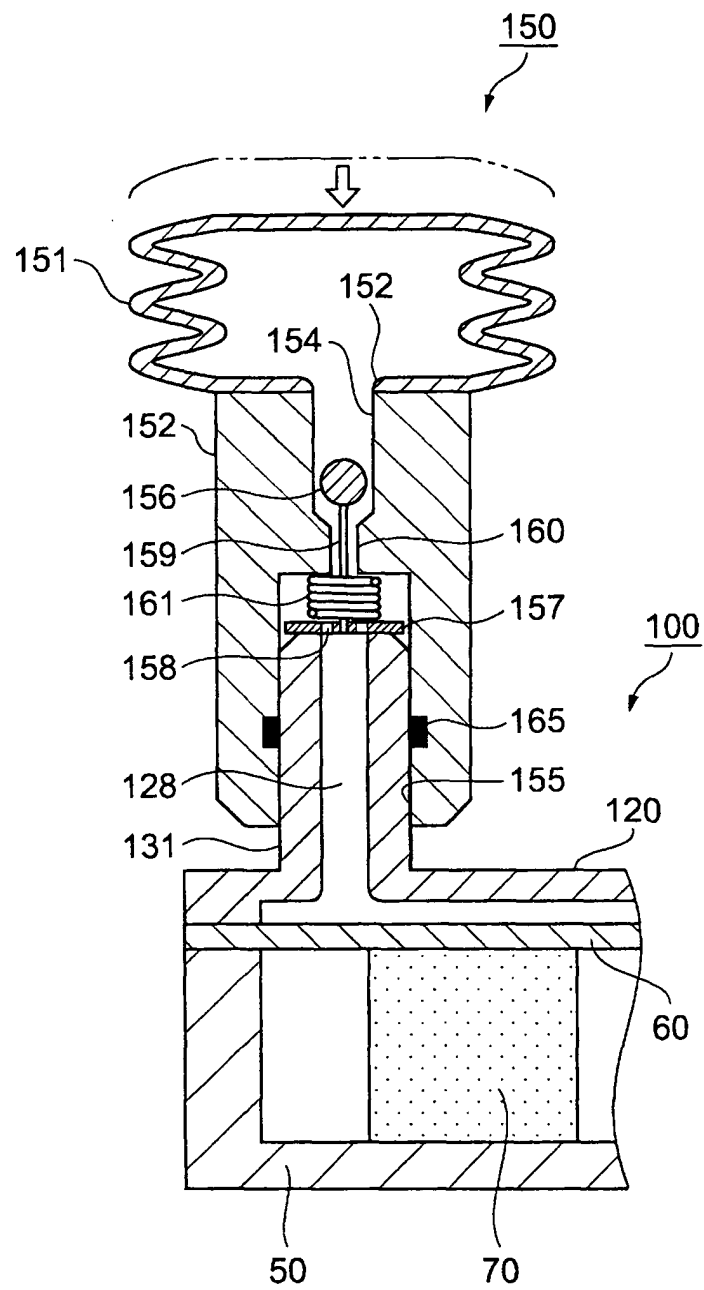


FIG. 12

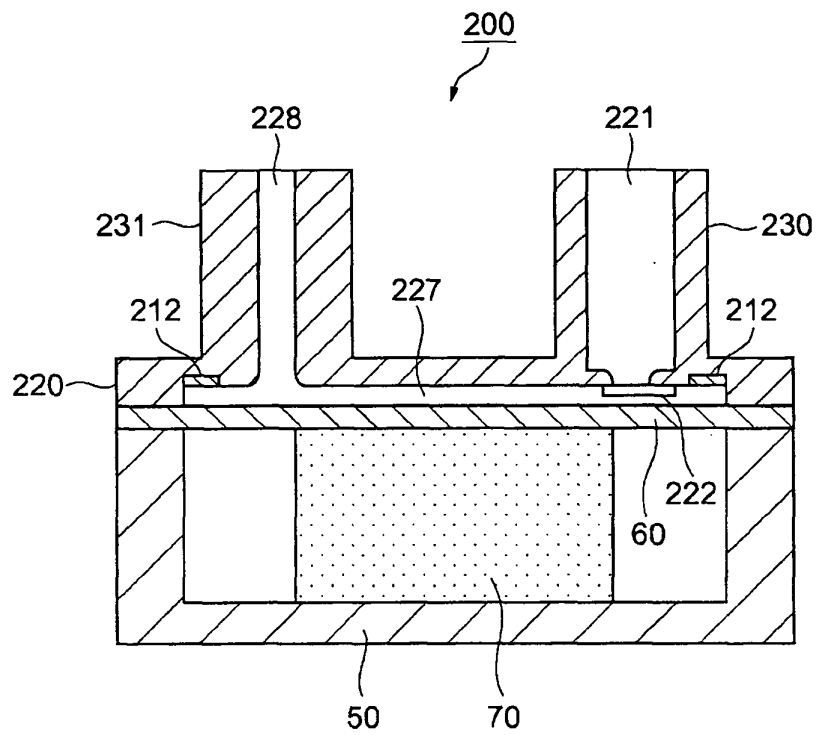


FIG. 13

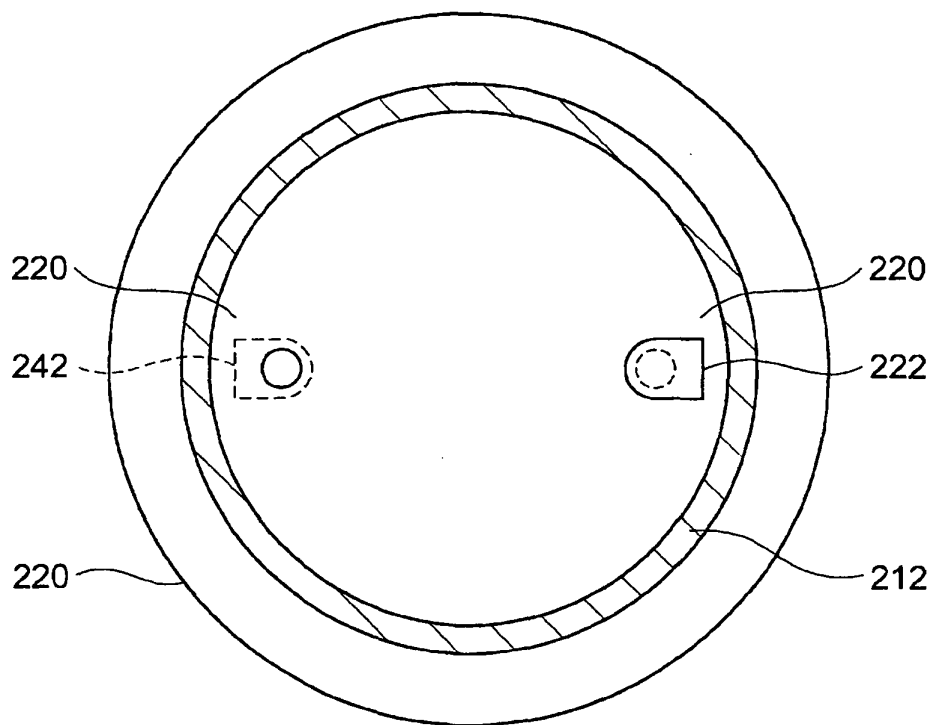


FIG. 14

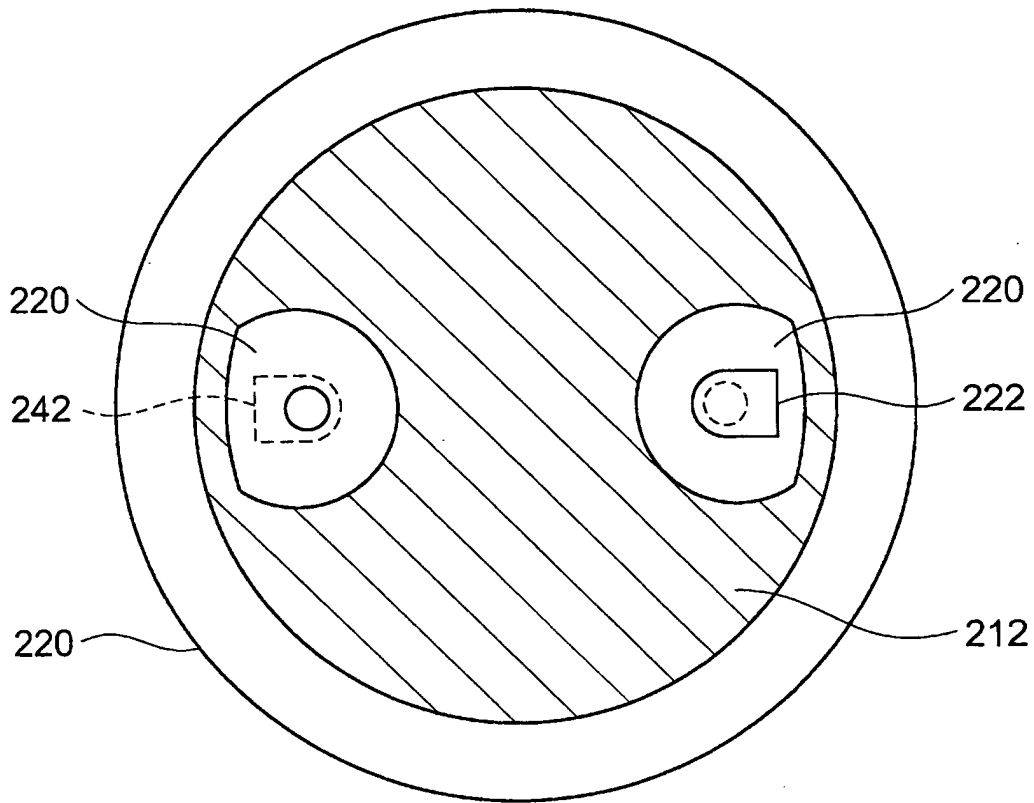


FIG. 15

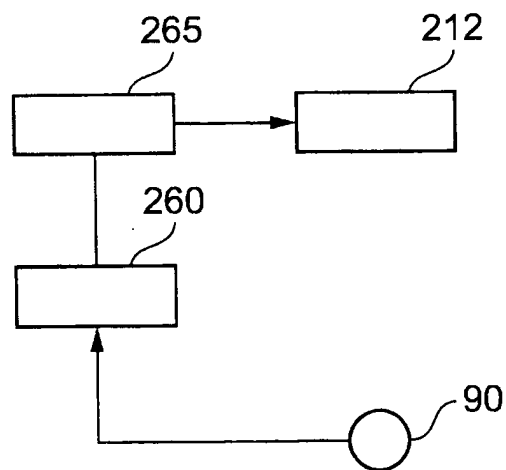


FIG .16

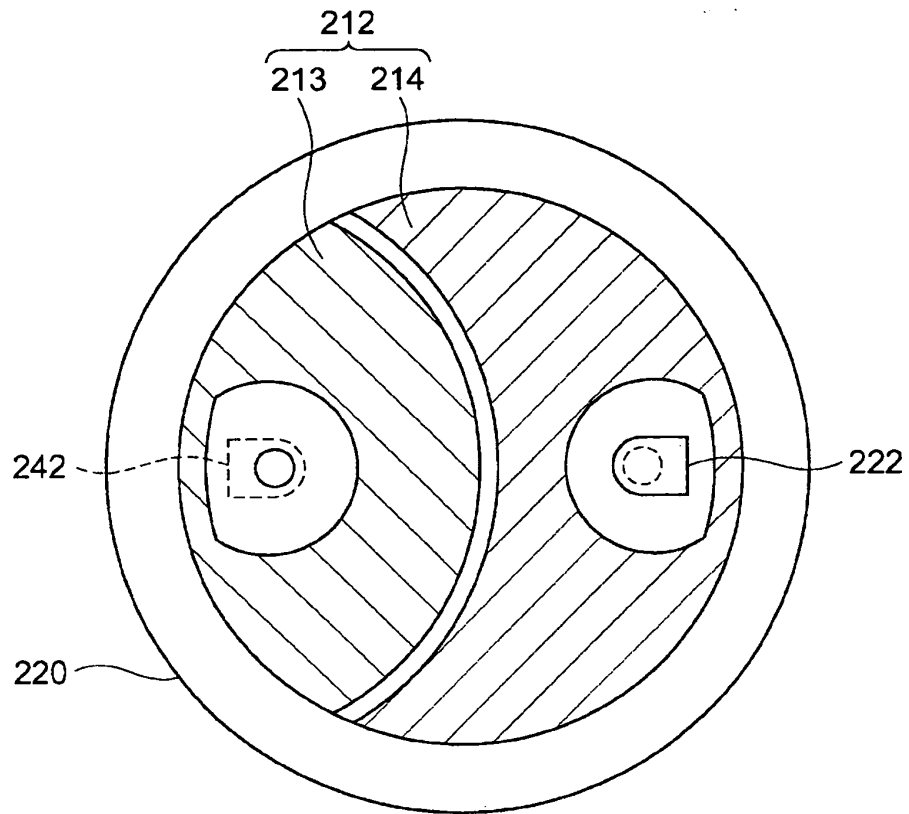


FIG. 17

