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(54) Liquid injection apparatus

(57) A liquid injection apparatus includes a plurality of liquid droplet injectors arranged on a suction pipe of an internal combustion engine and adapted to eject liquid droplets into the suction pipe by pressurizing liquid contained in pressurizing chambers through operation of corresponding piezoelectric/electrostrictive elements. One group of liquid droplet injectors are mounted on the suction pipe in such a manner as to eject liquid droplets into a space located above a horizontal plane including the center axis of the suction pipe. The other group of liquid droplet injectors are mounted on the suction pipe in such a manner as to eject liquid droplets into a space located under the horizontal plane.

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Description

BACKGROUND OF THE INVENTION

Field of the Invention:

[0001] The present invention relates to a liquid injection apparatus including a plurality of liquid droplet injectors for ejecting, in the form of liquid droplets, liquid such as liquid material or fuel from outlets through pressurization of the liquid contained in pressurizing chambers.

Description of the Related Art:

[0002] A liquid injection apparatus of this type, particularly a fuel feed apparatus for an internal combustion engine, includes a plurality of liquid droplet injectors for ejecting liquid in the form of liquid droplets by pressurizing the liquid contained in pressurizing chambers through change of the volume of the pressurizing chambers effected by operation of piezoelectric/electrostrictive elements, as disclosed in Japanese Patent Application Laid-Open (*kokai*) No. S54-90416. The plurality of liquid droplet injectors are arranged on the wall of the intake manifold of an engine such that fuel can be ejected dispersively from a wide region of the intake system of the engine, thereby improving atomization of fuel.

[0003] However, the above-described conventional liquid injection apparatus involves a problem in that, since a plurality of liquid droplet injectors are arranged without consideration for mutual interference in injection, an injection flow of liquid droplets ejected from an outlet of any one liquid droplet injector directly reaches an outlet of another liquid droplet injector and thus hinder ejection of liquid droplets from the outlet of the other liquid droplet injector.

SUMMARY OF THE INVENTION

[0004] In one form, the present invention liquid injection apparatus including a plurality of liquid droplet injectors arranged such that injection flows of liquid droplets ejected from one liquid droplet injector do not hinder ejection of liquid droplets from any other liquid droplet injector.

[0005] To achieve the above object, the present invention provides a liquid injection apparatus comprising a plurality of liquid droplet injectors, the liquid droplet injectors being arranged on the wall of a member defining a predetermined space and each comprising a pressurizing chamber communicating with a liquid feed passage via a liquid introduction hole; a nozzle connected to the pressurizing chamber; and a piezoelectric/electrostrictive element for changing volume of the pressurizing chamber so as to pressurize liquid introduced into the pressurizing chamber through the liquid introduction hole, thereby ejecting the liquid from an outlet of the nozzle in the form of liquid droplets. The plurality of liquid droplet injectors are arranged such that an injection flow of liquid droplets ejected from an outlet of any one liquid droplet injector does not reach an outlet of any other liquid droplet injector.

[0006] According to this configuration, an injection flow of liquid droplets ejected from an outlet of any one liquid droplet injector does not reach an outlet of any other liquid droplet injector and thus does not hinder ejection of liquid droplets from the outlet of the other liquid droplet injector.

[0007] Preferably, the plurality of liquid droplet injectors are arranged such that the direction of an injection flow of liquid droplets ejected from an outlet of one liquid droplet injector crosses the direction of an injection flow of liquid droplets ejected from an outlet of another liquid droplet injector.

[0008] This configuration allows a reduction in space for mounting the liquid droplet injectors, and thus the liquid injection apparatus of the present invention is applicable to a case where mounting space is limited, as in the case of a suction pipe of an internal combustion engine.

[0009] Preferably, when the plurality of liquid droplet injectors are to be arranged such that an injection flow of liquid droplets is ejected from an outlet of one liquid droplet injector in parallel with and in opposition to that ejected from an outlet of another liquid droplet injector, the liquid droplet injectors are arranged such that opposed injection flows of liquid droplets do not collide with one another.

[0010] This configuration does not involve collision between injection flows of liquid droplets, thereby maintaining good atomization of liquid.

[0011] Preferably, when an air flow is formed within the aforementioned predetermined space such as an intake passage of an internal combustion engine, the plurality of liquid droplet injectors are arranged such that injection flows of liquid droplets ejected from outlets thereof cross the air flow.

[0012] This configuration yields the following advantages. When injection flows of liquid droplets are directed obliquely downstream in relation to the air flow, the injection flows are unlikely to disturb the air flow, whereby good atomization of liquid can be maintained. When injection flows of liquid droplets are directed obliquely upstream in relation to the air flow, the injection flows are fanned out by the air flow, whereby atomization of liquid can be maintained at higher degree of homogeneity.

[0013] The present invention provides another liquid injection apparatus comprising a plurality of liquid droplet injectors, the liquid droplet injectors being arranged on a wall of a member defining a predetermined space and each comprising a pressurizing chamber communicating with a liquid feed passage via a liquid introduction hole; a nozzle connected to the pressurizing chamber; and a piezoelectric/electrostrictive element for changing volume of the pressurizing chamber so as to pressurize liquid introduced into the pressurizing chamber through the liquid introduction hole, thereby ejecting the liquid from an outlet of the nozzle in the form of liquid droplets. The liquid injection apparatus further comprises a partition provided within the space between outlets of opposed liquid droplet injectors.

[0014] This partition provides a space into which the liquid droplet injectors eject liquid droplets, such that an injection flow of liquid droplets ejected from an outlet of any one liquid droplet injector does not reach an outlet of any other liquid droplet injector and thus does not hinder ejection of liquid droplets from the outlet of the other liquid droplet injector.

[0015] Preferably, the liquid droplet injectors are arranged such that injection flows of droplets ejected from outlets thereof form a predetermined angle with respect to a vertical line. Preferably, the predetermined angle is 75° to 105°.

[0016] In order for the liquid droplet injectors to carry out initial injection, the respective pressurizing chambers must be charged with liquid. This charging is carried out by, for example, increasing a difference in pressure between outside of the outlets and inside of the outlets or by introducing liquid forcibly into the pressurizing chambers from the liquid feed passage by use of a pump or a like device. In this case, excess liquid from the pressurizing chambers may remain in the form of film around the outlets. When such liquid film is of a large amount, subsequent ejection may be adversely affected.

[0017] In this connection, when the liquid droplet injectors are arranged such that injection flows of droplets ejected from outlets thereof form a predetermined angle with respect to a vertical line, the end face of each outlet includes a vertical component; thus, the adhering liquid film drops off, thereby ensuring subsequent ejection in good condition.

[0018] When the predetermined angle assumes 75° to 105°, the liquid film can be eliminated within a short period of time.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] Various other objects, features and many of the attendant advantages of the present invention will be readily appreciated as the same becomes better understood by reference to the following detailed description of the preferred embodiment when considered in connection with the accompanying drawings, in which:

FIG. 1 is a schematic plan view showing a fuel injection system for a fuel-injection-type internal combustion engine which employs a liquid injection apparatus according to a first embodiment of the present invention;

FIG. 2 is a sectional view of a suction pipe taken along line II-II of FIG. 1;

FIG. 3 is a front view of a liquid droplet injection portion of a first liquid droplet injector shown in FIG. 1;

FIG. 4 is a plan view of a liquid droplet injection element which partially constitutes the liquid droplet injection portion shown in FIG. 3;

FIG. 5 is a sectional view of the liquid droplet injection element taken along line V-V of FIG. 4;

FIG. 6 is a block diagram showing electrical connections of the liquid injection apparatus shown in FIG. 1;

FIG. 7 is a schematic, partially sectional view showing a suction pipe and a liquid injection apparatus according to a second embodiment of the present invention;

FIG. 8 is a schematic, partially sectional view showing a suction pipe and a liquid injection apparatus according to a modification of the second embodiment;

FIG. 9 is a partial plan view showing a suction pipe and a liquid injection apparatus according to a third embodiment of the present invention;

FIG. 10 is a schematic, partially sectional view showing a suction pipe and a liquid injection apparatus according to a fourth embodiment of the present invention;

FIG. 11 is a partial sectional view showing a modified embodiment of the liquid injection apparatus of the present invention;

FIG. 12 is a schematic plan view showing a fuel injection system for a gasoline-injection-type internal combustion engine which employs another modified embodiment of the liquid injection apparatus of the present invention; and

FIG. 13 is a schematic, partially sectional view showing a modification of the second embodiment of FIG. 7.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0020] Embodiments of the present invention will next be described in detail with reference to the drawings.

(First Embodiment)

[0021] FIG. 1 schematically shows, in a plan view, a fuel injection system for a fuel-injection-type internal combustion engine 10 which employs as a fuel injection apparatus a liquid injection apparatus 20 according to a first embodiment of the present invention.

[0022] The fuel injection system of the internal combustion engine 10 includes an air introduction section 11, which accommodates an air cleaner; a suction pipe 12 connected to the air introduction section 11 and forming a predetermined space (fuel injection space); intake manifold pipes 13 branching off from the suction pipe 12 and connected to corresponding cylinders of the internal combustion engine 10; and a throttle valve 14 provided within the suction pipe 12 and adapted to change the area of a cross-sectional opening of the suction pipe 12 under operation of a driver.

[0023] The liquid injection apparatus 20 includes eight (a plurality of) liquid droplet injectors (fuel injectors); i. e., first to eighth liquid droplet injectors 21 to 28, mounted on the wall of a straight portion of the suction pipe 12 (on the wall of a member defining a predetermined space). In the plan view of FIG. 1, the first to fourth liquid droplet injectors 21 to 24 are disposed on one side of the suction pipe 12, whereas the fifth to eighth liquid droplet injectors 25 to 28 are disposed on the opposite side of the suction pipe 12 and in opposition to the first to fourth liquid droplet injectors 21 to 24, respectively. The first to eight liquid droplet injectors 21 to 28 are adapted to eject liquid droplets into the suction pipe 12 and assume identical structures except for mounting position and a fuel feed pipe. Therefore, the description below discusses, as representative liquid droplet injectors, the second and sixth liquid droplet injectors 22 and 26 shown in FIG. 1 and FIG. 2, which is a sectional view of the suction pipe 12 taken along line II-II of FIG. 1.

[0024] The second liquid droplet injector 22 includes a liquid droplet injection portion 22a having a plurality of outlets, which will be described later in detail; an injection pipe 22b connecting the liquid droplet injection portion 22a and the suction pipe 12; and a pair of fuel filters 22c. As shown in FIG. 2, the liquid droplet injection portion 22a is located above a plane that includes a longitudinal center axis CL of the suction pipe 12 (hereinafter called the "center axis CL") and is perpendicular to a vertical plane including the center axis CL (hereinafter called the "vertical plane"), and is adapted to eject liquid droplets in the direction of arrow A perpendicular to the vertical plane (horizontally when the center axis CL is horizontal). The fuel filters 22c are connected to a near bottom portion of a float chamber 31 via a fuel feed pipe 22d and a common fuel feed pipe 31a and are adapted to filter out foreign matter from liquid fuel fed from the float chamber 31 before feeding to the liquid droplet injection portion 22a.

[0025] The sixth liquid droplet injector 26 includes a liquid droplet injection portion 26a having a plurality of outlets, which will be described later in detail; an injection pipe 26b connecting the liquid droplet injection portion 26a and the suction pipe 12; and a pair of fuel filters 26c. As shown in FIG. 2, the liquid droplet injection portion 26a is located under a plane that includes the center axis CL of the suction pipe 12 and is perpendicular to the vertical plane including the center axis CL, and is adapted to eject liquid droplets in the direction of arrow B perpendicular to the vertical plane (horizontally when the center axis CL is horizontal).

[0026] Since the second liquid droplet injector 22 and the sixth liquid droplet injector 26 are mounted on the suction pipe 12 as described above, an injection flow of liquid droplets ejected from any one outlet provided on the liquid droplet injection portion 26a of the sixth liquid droplet injector 26 does not reach any outlet provided on the liquid droplet injection portion 22a of the second liquid droplet injector 22; and an injection flow of liquid droplets ejected from any one outlet provided on the liquid droplet injection portion 22a of the second liquid droplet injector 22 does not reach any outlet provided on the liquid droplet injection portion 26a of the sixth liquid droplet injector 26.

[0027] The fuel filters 26c are connected to the near bottom portion of the float chamber 31 via a fuel feed pipe 26d connected to the common fuel feed pipe 31a, and are adapted to filter out foreign matter from liquid fuel fed from the float chamber 31 before feeding to the liquid droplet injection portion 26a.

[0028] The float chamber 31 stores fuel under predetermined back pressure (pressure of an upper space of the float chamber 31), is connected, at an upper portion thereof, to one end of a connection pipe 31b and to one end of a fuel pipe 31c, and has a float valve 31d provided therein.

[0029] The other end of the connection pipe 31b is connected to the suction pipe 12, and a solenoid on-off valve for regulating pressure (pressure-regulating on-off valve) 31b1 is installed on the connection pipe 31b. The pressure-regulating on-off valve 31b1 establishes selectively a state of introduction of the atmosphere into the float chamber 31 or a state of introduction of the internal pressure of the suction pipe 12 into the float chamber 31. Usually, the internal pressure of the suction pipe 12 is introduced into the float chamber 31; i.e., the back pressure of the float chamber 31 is held identical to the internal pressure of the suction pipe 12 (the differential pressure is held zero).

[0030] One end of the fuel pipe 31c is opened/closed by means of the float valve 31d, and the other end of the fuel pipe 31c extends to a bottom portion of the fuel tank 15. The float valve 31d moves vertically according to the fuel level within the float chamber 31. Therefore, the fuel level within the float chamber 31 is held substantially constant by means of the float valve 31d and the fuel pipe 31c.

[0031] A check valve 31a1 is installed in the common fuel feed pipe 31a so as to permit flow of liquid fuel only from the float chamber 31 toward the first, second, fifth, and sixth liquid droplet injection portions 21a, 22a, 25a, and 26a. The common fuel feed pipe 31a has a bypass pipe 31a2 for bypassing the check valve 31a1. A motor-driven pump P1, which serves as pressurizing means, is installed in the bypass pipe 31a2. The pump P1, when driven, pressurizes fuel contained in the float chamber 31 to thereby feed liquid fuel from the float chamber 31 to the first, second, fifth, and sixth liquid droplet injection portions 21a, 22a, 25a, and 26a.

[0032] Similarly, the liquid droplet injection portion 21a of the first liquid droplet injector 21 is connected to the fuel feed pipe 22d via a pair of filters 21c, so that liquid fuel is fed thereto from the float chamber 31. Also, the liquid droplet injection portion 25a of the fifth liquid droplet injector 25 is connected to the fuel feed pipe 26d via a pair of filters 25c, so that liquid fuel is fed thereto from the float chamber 31. The third liquid droplet injector 23, the fourth liquid droplet injector 24, the seventh liquid droplet injector 27, the eighth liquid droplet injector 28, and a float chamber 32 are configured in a manner similar to that described above.

[0033] As in the case of the liquid droplet injection portion 22a of the second liquid droplet injector 22, the liquid droplet injection portion 21a of the first liquid droplet injector 21, a liquid droplet injection portion 23a of the third liquid droplet injector 23, and a liquid droplet injection portion 24a of the fourth liquid droplet injector 24 are located above a plane that includes the center axis CL of the suction pipe 12 and is perpendicular to the vertical plane including the center axis CL, and are adapted to eject liquid droplets in a direction perpendicular to the vertical plane (horizontally when the center axis CL is horizontal). As in the case of the liquid droplet injection portion 26a of the sixth liquid droplet injector 26, the liquid droplet injection portion 25a of the fifth liquid droplet injector 25, a liquid droplet injection portion 27a of the seventh liquid droplet injector 27, and a liquid droplet injection portion 28a of the eighth liquid droplet injector 28 are located under the plane that includes the center axis CL and is perpendicular to the vertical plane including the center axis CL, and are adapted to eject liquid droplets in a direction perpendicular to the vertical plane (horizontally when the center axis CL is horizontal).

[0034] Since the first to eighth liquid droplet injectors 21 to 28 are in opposed arranged as described above, injection flows of liquid droplets ejected from outlets of any one of the liquid droplet injection portions 21a to 28a of the first to eighth liquid droplet injectors 21 to 28 do not reach outlets of any other liquid droplet injection portions 21a to 28a.

[0035] Next, the structure of the liquid droplet injection portion 21a of the first liquid droplet injector 21 will be described. This structure is also assumed by the liquid droplet injection portions 22a to 28a of the second to eighth liquid droplet injectors 22 to 28.

[0036] The liquid droplet injection portion 21a includes two (a pair of) metal plates 21a1 as shown in FIG. 3. Each of the metal plates 21a1 includes four liquid droplet injection elements 21-1 to 21-4. The liquid droplet injection elements 21-1 to 21-4 include columns of outlets 21-1a to 21-4a, respectively. The liquid droplet injection elements 21-1 and 21-2 and the liquid droplet injection elements 21-3 and 21-4 are fixedly attached to the metal plate 21a1 while being arranged such that the outlets 21-1a and 21-2a are aligned longitudinally, and the outlets 21-3a and 21-4a are aligned longitudinally. The outlets 21-1a and 21-2a and the outlets 21-3a and 21-4a are exposed through substantially rectangular cutouts (windows) 21a2 and 21a3, respectively, formed in the metal plate 21a1.

[0037] As shown in FIG. 4, which is a plan view of the liquid droplet injection element 21-1, and FIG. 5, which is a sectional view of the liquid droplet injection element 21-1 taken along line V-V of FIG. 4, the liquid droplet injection element 21-1 substantially assumes the form of a rectangular parallelepiped whose sides extend in parallel with the corresponding orthogonal X, Y, and Z axes, and is configured such that a plurality of ceramic sheets 41 to 46 are arranged and pressed in layers, and piezoelectric/electrostrictive elements 47 are fixedly arranged on the exterior surface of the ceramic sheet 46. The liquid droplet injection element 21-1 includes a liquid feed passage 21-1b; a plurality of (herein seven) mutually independent pressurizing chambers 21-1c; a plurality of liquid introduction holes 21-1d for allowing the corresponding pressurizing chambers 21-1c to communicate with the liquid feed passage 21-1b; and a plurality of nozzles 21-1e for allowing the corresponding pressurizing chambers 21-1c to communicate with the exterior of the liquid droplet injection element 21-1.

[0038] The liquid feed passage 21-1b is a cutout space formed in the ceramic sheet 43, assuming, as viewed from above, the form of an elongated circle whose major and minor axes are in parallel with the X and Y axes, respectively, and defined by a cutout wall in the ceramic sheet 43, the upper surface of the ceramic sheet 42, and the lower surface of the ceramic sheet 44. The liquid feed passage 21-1b communicates with the float chamber 31 via the filter 22c, the fuel feed pipe 22d, and the common fuel feed pipe 31a, and is filled with liquid fuel to be ejected.

[0039] Each of the pressurizing chambers 21-1c is a cutout space formed in the ceramic sheet 45, assuming, as viewed from above, the form of an elongated circle whose major and minor axes are in parallel with the Y and X axes, respectively, and defined by a cutout wall in the ceramic sheet 45, the upper surface of the ceramic sheet 44, and the lower surface of the ceramic sheet 46. Each pressurizing chamber 21-1c extends in the positive direction of the Y axis such that an end portion thereof is located above the liquid feed passage 21-1b, and communicates, at the end portion, with the liquid feed passage 21-1b via the corresponding cylindrical liquid introduction hole 21-1d formed in the ceramic sheet 44.

[0040] The piezoelectric/electrostrictive elements 47 are slightly smaller than the pressurizing chambers 21-1c as viewed from above and are fixed to the upper surface of the ceramic sheet 46 in such a manner as to be disposed within the corresponding pressurizing chambers 21-1c as viewed from above. A potential difference is established between unillustrated electrodes provided on the upper and lower surfaces of each piezoelectric/electrostrictive element 47 to thereby deform the ceramic sheet 46 (the upper wall of the pressurizing chambers 21-1c), whereby the volume of the pressurizing chambers 21-1c is changed by ΔV.

[0041] Each of the nozzles 21-1e is a through-hole assuming substantially the form of a truncated cone (circular cross section) and extending through the ceramic sheets 41 to 44, and communicates, at the bottom thereof, with the corresponding pressurizing chamber 21-1c.

An annular liquid-repellent-treated layer 48 is formed on the exterior surface (lower surface in FIG. 5) of the ceramic sheet 41 around an end opening (i.e., an ejection end opening) of each nozzle 21-1e. The annular liquid-repellent-treated layer 48 provides a cylindrical hole formed therein, and the exterior end of the cylindrical hole serves as an outlet 48a (21-1a) for ejecting liquid droplets to the exterior of the liquid droplet injection element 21-1.

[0042] Next, an electric diagram of the liquid injection apparatus 20 will be described. As shown in FIG. 6, an electric controller 50 composed primarily of a microcomputer is connected to piezoelectric/electrostrictive elements of the first to eighth liquid droplet injectors 21 to 28 (e.g., in the case of the first liquid droplet injector 21, the piezoelectric/electrostrictive elements 47 of the liquid droplet injection elements 21-1 to 21-4), the motor-driven pumps P1 and P2, and the pressure-regulating on-off valves 31b1 and 32b1, in order to send independent drive signals to these components.

[0043] In operation of the thus-configured liquid injection apparatus 20, when the internal combustion engine 10 is in a predetermined state (e.g., in a start-up state), the motor-driven pumps P1 and P2 are operated for predetermined time. As a result, fuel from the float chambers 31 and 32 is fed into the pressurizing chambers and nozzles of the liquid droplet injection elements of the first to eighth liquid droplet injectors 21 to 28, whereby the pressurizing chambers and the nozzles are filled with an initial charge of liquid. For example, in the case of the first liquid droplet injector 21, liquid fuel is fed from the float chamber 31 into the pressurizing chambers 21-1c to 21-4c and the nozzles 21-1e to 21-4e via the bypass pipe 31a2, the fuel feed pipe 22d, the filters 22c, the liquid feed passages 21-1b to 21-4b of the liquid droplet injection elements 21-1 to 21-4, and the liquid introduction holes 21-1d to 21-4d. Next, the electric controller 50 applies a predetermined potential difference to piezoelectric/electrostrictive elements of the liquid droplet injection elements. Since the first to eighth liquid droplet injectors 21 to 28 operate in the same manner, the operation of a liquid droplet injection element of the first liquid droplet injector 21 will next be described by way of example.

[0044] In the liquid droplet injection element 21-1 (the operation of the other liquid droplet injection elements 21-2 to 21-4 is identical to that of the liquid droplet injection element 21-1), shown in FIGS. 4 and 5, of the first liquid droplet injector 21, when a predetermined potential difference is applied to the piezoelectric/electrostrictive elements 47, the piezoelectric/electrostrictive elements 47 attempt to contract in the X-Y plane, thereby generating a force of contraction in the X-Y plane. The force of contraction is transmitted to the upper surface of the ceramic sheet 46, on which the piezoelectric/electrostrictive elements 47 are fixed. As a result, the ceramic sheet 46 is deformed such that the volume of the pressurizing chambers 21-1c is reduced by ΔV. Thus, liquid (fuel) contained in the pressurizing chambers 21-1c is pressurized and thus ejected in the form of liquid droplets from the outlets 48a via the nozzles 21-1e. Notably, an injection flow of liquid droplets to be ejected is substantially linear and slightly cones to thereby assume the form of a truncated cone with the outlet 48a serving as a top face thereof (see FIG. 11).

[0045] Next, when the potential difference applied between opposite electrodes of the individual piezoelectric/electrostrictive elements 47 is eliminated, the ceramic sheet 46 is released from deformation which has been caused by the piezoelectric/electrostrictive elements 47; as a result, the original volume of the pressurizing chambers 21-1c is restored. At this time, since the pressure of liquid contained in the pressurizing chambers 21-1c decreases, liquid contained in the liquid feed passage 21-1b is sucked (introduced) into the pressurizing chambers 21-1c. The above-described operation is repeated to thereby eject liquid droplets continuously.

[0046] In the liquid injection apparatus 20, since the liquid droplet injectors 21 to 28 (liquid droplet injection portions 21a to 28a) are arranged such that injection flows of liquid droplets ejected from outlets of any one of the liquid droplet injection portions 21a to 28a of the first to eighth liquid droplet injectors 21 to 28 do not reach outlets of any other liquid droplet injection portions 21a to 28a, even when no air flows through the suction pipe 12, injection flows of liquid droplets ejected from outlets of any one of the liquid droplet injection portions 21a to 28a do not hinder ejection of liquid droplets from any other outlets. As a result, liquid droplets are ejected (injected) favorably in a homogeneously atomized condition from the first to eighth liquid droplet injectors 21 to 28.

[0047] The first to fourth liquid droplet injectors 21 to 24 are located above a plane PL that includes the longitudinal center axis CL of the suction pipe 12 and is perpendicular to the vertical plane including the center axis CL, and eject liquid droplets in parallel with the plane PL (in the leftward direction of arrows A in FIG. 2). The fifth to eighth liquid droplet injectors 25 to 28 are located under the plane PL and eject liquid droplets in parallel with the plane PL (in the rightward direction of arrows B in FIG. 2). Therefore, an injection flow of liquid droplets ejected from one outlet does not collide with that of liquid droplets ejected from any other outlet, thereby maintaining a favorably atomized condition of fuel. Further, the first to eighth liquid droplet injectors 21 to 28 are arranged such that, as represented by arrow C in FIG. 2 showing a view from the downstream side of the suction pipe 12 (the side toward the internal combustion engine 10) toward the upstream side of the suction pipe 12 (the side toward the air introduction section 11), injection flows of ejected liquid droplets generate a counterclockwise vortex. As a result, liquid fuel that is atomized homogeneously in a more favorable condition is fed to the internal combustion engine 10, thereby enhancing, for example, start-up performance of the internal combustion engine 10.

[0048] As shown in FIG. 1, a charge on-off valve 16 for varying the area of a cross-sectional opening of the suction pipe 12 may be provided downstream of the air introduction section 11 and upstream of the first and fifth liquid droplet injectors 21 and 25. The charge on-off valve 16 is opened/closed by a charge on-off valve drive motor 16a according to a signal from the electric controller 50.

[0049] This configuration allows the following operation. At the time of aforementioned initial charge of fuel, the back pressure of the float chambers 31 and 32 is set to the atmospheric pressure through operation of the pressure-regulating on-off valves 31b1 and 32b1, and the suction pipe 12 is closed by means of the charge on-off valve 16 through operation of the charge on-off valve drive motor 16a. Thus, when the internal pressure of the suction pipe 12, to which outlets of the first to eighth liquid droplet injectors 21 to 28 are exposed, becomes negative as a result of operation of, for example, a starter of the internal combustion engine 10, the difference between the negative pressure and the back pressure (the atmospheric pressure) of the float chambers 31 and 32 causes fuel to be fed from the float chambers 31 and 32 into the pressurizing chambers and nozzles of the liquid droplet injection elements, thereby filling the pressurizing chambers and nozzles with an initial charge of fuel.

[0050] The above-described operation regarding initial charge may be utilized in a different condition for increasing the amount of liquid droplets to be ejected. That is, negative pressure is generated in the interior of the suction pipe 12, to which outlets of the first to eighth liquid droplet injectors 21 to 28 are exposed, through operation of the charge on-off valve drive motor 16a, and the back pressure of the float chambers 31 and 32 is set to the atmospheric pressure through operation of the pressure-regulating on-off valves 31b1 and 32b1. The thus-generated differential pressure is utilized for boosting ejection of liquid droplets.

(Second Embodiment)

[0051] Next, a liquid injection apparatus 60 according to a second embodiment of the present invention will be described with reference to FIG. 7. The liquid injection apparatus 60 only differs from the liquid injection apparatus 20 of the first embodiment in the position (angle) of mounting the first to eighth liquid droplet injectors 21 to 28 onto the suction pipe 12.

[0052] Specifically, the second liquid droplet injector 22 is mounted on the suction pipe 12 such that a plane defined by outlets thereof (a metal plate 22a1, hereinafter called the "injection plane") is parallel with the longitudinal center axis CL of the suction pipe 12 and is inclined by a predetermined angle with respect to a vertical line extending upward from the longitudinal center axis CL (hereinafter referred to as the "upward vertical line"). In other words, the line normal to the injection plane of the second liquid droplet injector 22; i.e., injection flows (center axes of injection flows) of liquid droplets ejected from the liquid droplet injector 22 are inclined by angle $\theta 1$ with respect to the upward vertical line (by angle ($90° - \theta 1$) with respect to a horizontal line which extends from the center axis CL in a corresponding direction (hereinafter referred to as the "corresponding horizontal line")). Similarly, the sixth liquid droplet injector 26, which is located in opposition to the second liquid droplet injector 22 in a plan view, is mounted on the suction pipe 12 such that the injection plane (a metal plate 26a1) is parallel with the longitudinal center axis CL of the suction pipe 12 and is inclined by a predetermined angle with respect to the upward vertical line. In other words, the line normal to the injection plane of the sixth liquid droplet injector 26; i.e., injection flows of liquid droplets ejected from the liquid droplet injector 26 are inclined by angle $\theta 2$ with respect to the upward vertical line (by angle ($90° - \theta 2$) with respect to the corresponding horizontal line).

[0053] The angle $\theta 1$ is selected such that, when no air flows through the suction pipe 12, injection flows from the second liquid droplet injector 22 do not reach outlets of the sixth liquid droplet injector 26. Similarly, the angle $\theta 2$ is identical to the angle $\theta 1$ and is selected such that, when no air flows through the suction pipe 12, injection flows from the sixth liquid droplet injector 26 do not reach outlets of the second liquid droplet injector 22. The angles $\theta 1$ and $\theta 2$ are preferably not less than 45° and less than 135°, particularly preferably 75° to 105°. FIG. 8 shows a modified example in which the angles $\theta 1$ and $\theta 2$ are set to a predetermined angle (e.g., 100°) not less than 90°.

[0054] The above-described positional relationship is also applicable to the other liquid droplet injectors. Specifically, the first, third, and fourth liquid droplet injectors 21, 23, and 24 are mounted on the suction pipe 12 such that injection flows therefrom are inclined by the angle $\theta 1$ with respect to the upward vertical line. The fifth, seventh, and eighth liquid droplet injectors 25, 27, and 28 are mounted on the suction pipe 12 such that injection flows therefrom are inclined by the angle $\theta 2$ with respect to the upward vertical line. As a result, the direction of injection flows of liquid droplets ejected from the first to fourth liquid droplet injectors 21 to 24 crosses the direction of injection flows of liquid droplets ejected from the fifth to eighth liquid droplet injectors 25 to 28.

[0055] The thus-configured liquid injection apparatus 60 operates similarly as does the liquid injection apparatus 20. In the liquid injection apparatus 60, the liquid droplet injectors are arranged in opposed array in a plan view. However, since the angle of mounting the liquid droplet injectors is selected such that injection flows of liquid droplets ejected from outlets of any one of the liquid droplet injection portions 21a to 28a of the first to eighth liquid droplet injectors 21 to 28 do not reach outlets of any other liquid droplet injection portions 21a to

28a, injection flows of liquid droplets ejected from outlets of any one of the liquid droplet injection portions 21a to 28a do not reach outlets of any other liquid droplet injection portions 21a to 28a and thus do not hinder ejection of liquid droplets from the other outlets. As a result, liquid droplets are ejected (injected) favorably from the liquid droplet injectors 21 to 28 in a homogeneously atomized condition. Also, in the liquid injection apparatus 60, any two of the liquid droplet injectors 21 to 28 can be arranged in opposition to each other in a plan view, space required for mounting the liquid droplet injectors 21 to 28 can be reduced. In other words, a large number of liquid droplet injectors can be mounted within a small mounting space, whereby a large amount of liquid droplets can be ejected (injected) into the suction pipe 12.

[0056] In the second embodiment, when the angles θ1 and θ2 are set to 75° to 105°, the injection planes (the planes of metal plates) of the liquid droplet injectors 21 to 28 include a large vertical component; thus, at the time of initial charge of fuel (liquid), excess fuel coming out from outlets can be eliminated within a short period of time by means of gravity, thereby eliminating liquid film formed in the vicinity of outlets. As a result, even immediately after initial charge of liquid, the liquid injection apparatus 60 can eject liquid droplets favorably.

[0057] According to the above-described second embodiment, the angles θ1 and θ2 assume an equal angle. However, the angles θ1 and θ2 may differ from each other. In this case, for example, as shown in FIG. 7, when the angle θ1 is set smaller than the angle θ2, a counterclockwise vortex of injected fuel can be formed, whereby, for example, start-up performance of the internal combustion engine 10 can be enhanced.

(Third Embodiment)

[0058] Next, a liquid injection apparatus 70 according to a third embodiment of the present invention will be described with reference to FIG. 9, which is a partial plan view showing a suction pipe 12-1. The liquid injection apparatus 70 includes liquid droplet injectors 71 and 72 similar to the first to eighth liquid droplet injectors 21 to 28. The suction pipe 12-1 includes a small cylindrical portion 12-1a located on the side toward the air introduction section 11 and having a small diameter; a large cylindrical portion 12-1b located on the side toward the internal combustion engine 10 and having a diameter greater than that of the small cylindrical portion 12-1a; and a transition portion 12-1c whose diameter increases gradually toward the large cylindrical portion 12-1b so as to connect the small cylindrical portion 12-1a and the large cylindrical portion 12-1b.

[0059] The liquid droplet injectors 71 and 72 are mounted on the transition portion 12-1c of the suction pipe 12-1 such that, as illustrated by dot-and-dash lines in FIG. 9, injection flows from the liquid droplet injectors 71 and 72 are in parallel with the plane that includes the longitudinal center axis CL of the suction pipe 12-1 and is perpendicular to the vertical plane including the center axis CL, and cross lines parallel with the center axis CL (the injection flows cross an air flow within the suction pipe 12-1 in such a manner as to be directed obliquely downstream).

[0060] The liquid droplet injector 71 is fixed to the suction pipe 12-1 such that, when no air flows through the suction pipe 12-1, injection flows of liquid droplets ejected therefrom do not reach any outlets of the liquid droplet injector 72. Similarly, the liquid droplet injector 72 is fixed to the suction pipe 12-1 such that, when no air flows through the suction pipe 12-1, injection flows of liquid droplets ejected therefrom do not reach any outlets of the liquid droplet injector 71.

[0061] According to the third embodiment, as in the case of the first and second embodiments, liquid droplets ejected from either one of the liquid droplet injectors 71 and 72 do not reach outlets of the other one, and thus liquid droplets can be ejected favorably. Since injection flows of liquid droplets are directed obliquely downstream in relation to the air flow, the injection flows are unlikely to disturb the air flow. Therefore, air-fuel mixture in a favorably atomized condition can be fed to the internal combustion engine 10.

[0062] The third embodiment can be combined with the method for mounting the liquid droplet injectors on the suction pipe 12 according to the first or second embodiment. Also, in the third embodiment, injection flows of liquid droplets can be directed obliquely upstream in relation to the air flow. In this case, the injection flows are fanned out by the air flow, whereby atomization of liquid can be maintained at higher degree of homogeneity.

(Fourth Embodiment)

[0063] Next, a liquid injection apparatus 80 according to a fourth embodiment of the present invention will be described with reference to FIG. 10. The liquid injection apparatus 80 only differs from the liquid injection apparatus 20 of the first embodiment in the position (angle) of mounting the first to eighth liquid droplet injectors 21 to 28 onto the suction pipe 12 and in provision of a partition 17 within the suction pipe 12.

[0064] Specifically, the second liquid droplet injector 22 is mounted on the suction pipe 12 such that the injection plane thereof (the plane of the liquid droplet injection portion 22a) is parallel with the vertical plane including the longitudinal center axis CL of the suction pipe 12. The sixth liquid droplet injector 26 is mounted on the suction pipe 12 such that the injection plane thereof (the plane of the liquid droplet injection portion 26a) is parallel with the injection plane of the second liquid droplet injector 22. The positional relationship between the second liquid droplet injector 22 and the sixth liquid droplet injector 26 is applicable to that between the first liquid droplet injector 21 and the fifth liquid droplet injector 25, that between the third liquid droplet injector 23 and the seventh liquid droplet injector 27, and that between the fourth liquid droplet injector 24 and the eighth liquid droplet injector 28.

[0065] The partition 17 is a flat plate that stands from a bottom portion of the suction pipe 12 and extends along the center axis CL of the suction pipe 12 in parallel with the injection planes of the first to fourth liquid droplet injectors 21 to 24 and the injection planes of the fifth to eighth liquid droplet injectors 25 to 28 (i.e., in parallel with the vertical plane including the center axis CL), thereby separating the former injection planes and the latter injection planes. The height of the partition 17 is selected such that the partition 17 projects slightly above outlets located at the highest position on the injection planes of the first to eighth liquid droplet injectors 25 to 28. The partition 17 may extend between bottom and top portions of the suction pipe 12 so as to partition, into two parts, an interior portion of the suction pipe 12 extending between the air introduction section 11 and the throttle valve 14.

[0066] In the thus-configured liquid injection apparatus 80, injection flows of liquid droplets ejected from outlets of the first to fourth liquid droplet injectors 21 to 24 reach (impinge on) the partition 17, and thus do not reach outlets of the fifth to eighth liquid droplet injectors 25 to 28. Similarly, injection flows of liquid droplets ejected from outlets of the fifth to eighth liquid droplet injectors 25 to 28 reach the partition 17, and thus do not reach outlets of the first to fourth liquid droplet injectors 21 to 24. In other words, the partition 17 provides a space for the liquid droplet injectors 21 to 28 such that an injection flow of liquid droplets ejected from any one of the liquid droplet injectors 21 to 28 does not collide with an injection flow of liquid droplets ejected from any other liquid droplet injector. As a result, since injection flows from any one of the first to eighth liquid droplet injectors 21 to 28 do not hinder ejection of liquid droplets from outlets of any other liquid droplet injector, liquid droplets are ejected (injected) favorably in a homogeneously atomized condition. The idea (technique) of the fourth embodiment can be combined with the idea of another embodiment, for example, the second embodiment. In this case, the partition 17 may have a height such that an injection flow from any outlet is prevented from reaching any other outlet.

[0067] As described above, the liquid injection apparatus according to the embodiments of the present invention each include a plurality of liquid droplet injectors. The plurality of liquid droplet injectors are arranged so as to avoid interference among injection flows of liquid droplets, or a partition is provided for avoiding the interference. As a result, even when the liquid droplet injectors are arranged in opposed array in a plan view, and no air flows through a space where the liquid droplet injectors are arranged, an injection flow of liquid droplets ejected from any outlet does not reach any other outlet, whereby liquid droplets are ejected favorably from every outlet.

[0068] The present invention is not limited to the above-described embodiments, but may be modified as appropriate without departing from the spirit or scope of the invention. For example, as shown in FIG. 11, liquid droplet injectors 73 and 74 may be arranged in opposition to each other; i.e., such that a plane 73b defined by outlets 73a of the liquid droplet injector 73 is in parallel with a plane 74b defined by outlets 74a of the liquid droplet injector 74, while injection flows J1 of liquid droplets ejected from the outlets 73a do not reach the outlets 74a, and injection flows J2 of liquid droplets ejected from the outlets 74a do not reach the outlets 73a (i.e., the outlets 73a and 74a are arranged in a staggered condition).

[0069] As shown in FIG. 12, four liquid droplet injectors 91 to 94 may be mounted on the suction pipe 12 in opposed, staggered array along the center axis CL of the suction pipe 12 such that outlets of one liquid droplet injector do not directly face those of another liquid droplet injector. Further, as shown in FIG. 13, in the liquid injection apparatus 60 of the second embodiment, a potential difference to be applied to individual piezoelectric/electrostrictive elements may be adjusted so as to vary intensity of individual injection flows, whereby a vortex (a flow in the direction of a dotted line arrow in FIG. 13) can be generated within the suction pipe 12 to thereby acceleration homogenization of fuel.

Claims

1. A liquid injection apparatus comprising a plurality of liquid droplet injectors, the liquid droplet injectors being arranged on a wall of a member defining a predetermined space and each comprising:

   a pressurizing chamber communicating with a liquid feed passage via a liquid introduction hole;
   a nozzle connected to the pressurizing chamber; and
   a piezoelectric/electrostrictive element for changing volume of the pressurizing chamber so as to pressurize liquid introduced into the pressurizing chamber through the liquid introduction hole, thereby ejecting the liquid from an outlet of the nozzle in a form of liquid droplets;

   wherein the plurality of liquid droplet injectors are arranged such that an injection flow of liquid droplets ejected from an outlet of any one liquid droplet injector does not reach an outlet of any other liquid droplet injector.

2. A liquid injection apparatus according to claim 1, wherein the plurality of liquid droplet injectors are arranged such that a direction of an injection flow of liquid droplets ejected from an outlet of one liquid

droplet injector crosses a direction of an injection flow of liquid droplets ejected from an outlet of another liquid droplet injector.

3. A liquid injection apparatus according to claim 1, wherein the plurality of liquid droplet injectors are arranged such that an injection flow of liquid droplets is ejected from an outlet of one liquid droplet injector in parallel with and in opposition to an injection flow of liquid droplets ejected from an outlet of another liquid droplet injector and that the opposed injection flows of liquid droplets do not collide with one another.

4. A liquid injection apparatus according to claim 1 or 2, wherein air flows within the predetermined space; and

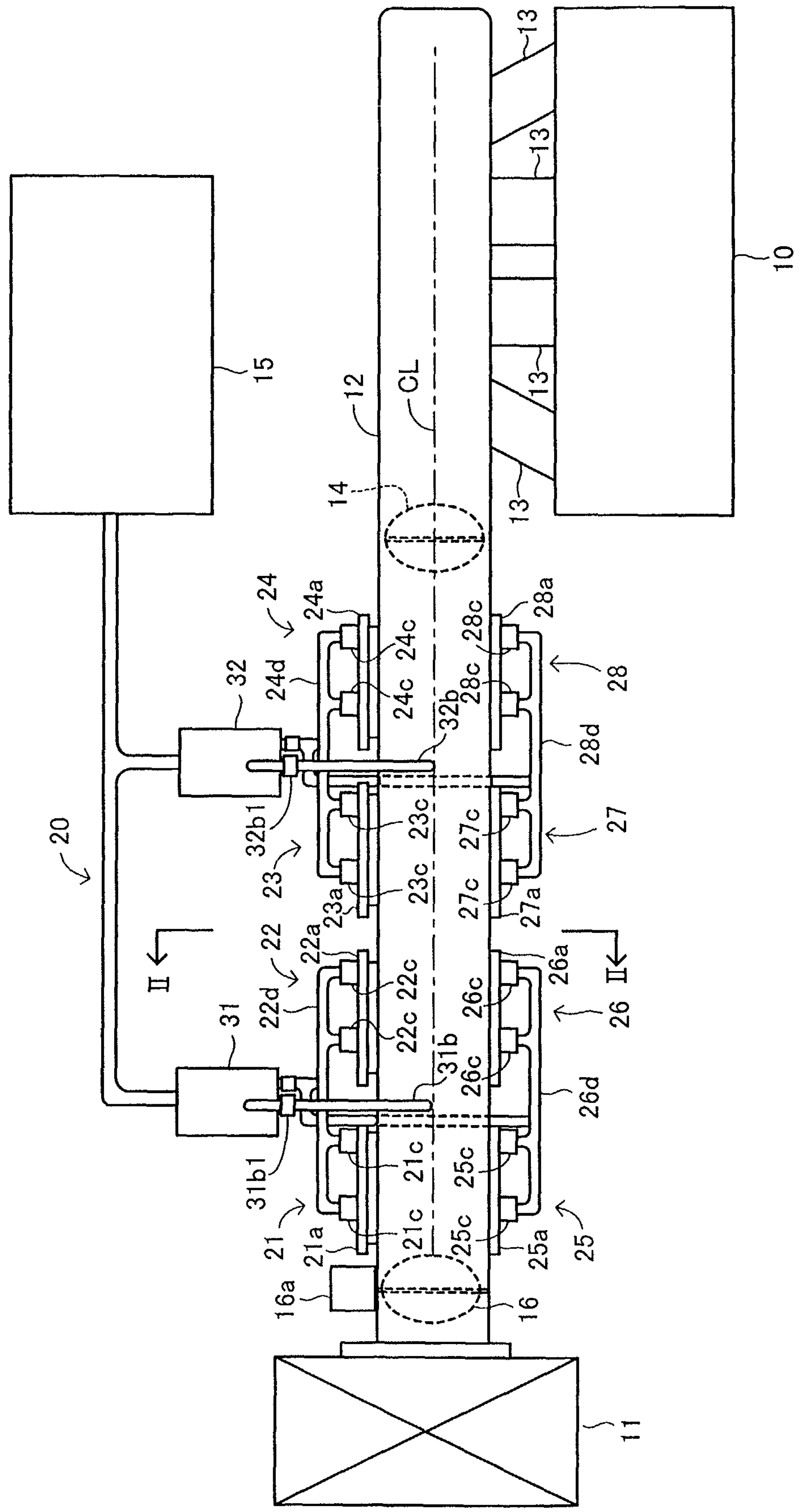
wherein the plurality of liquid droplet injectors are arranged such that injection flows of liquid droplets ejected from outlets thereof cross the air flow.

5. A liquid injection apparatus comprising a plurality of liquid droplet injectors, the liquid droplet injectors being arranged on a wall of a member defining a predetermined space and each comprising:

a pressurizing chamber communicating with a liquid feed passage via a liquid introduction hole;
a nozzle connected to the pressurizing chamber; and
a piezoelectric/electrostrictive element for changing volume of the pressurizing chamber so as to pressurize liquid introduced into the pressurizing chamber through the liquid introduction hole, thereby ejecting the liquid from an outlet of the nozzle in a form of liquid droplets; and
the liquid injection apparatus further comprising a partition provided within the space between outlets of opposed liquid droplet injectors.

6. A liquid injection apparatus according to any one of claims 1 to 5, wherein the liquid droplet injectors are arranged such that injection flows of droplets ejected from outlets thereof form a predetermined angle with respect to a vertical line.

7. A liquid injection apparatus according to claim 6, wherein the predetermined angle is 75° to 105°.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14
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16
16a
20
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21a
21c
22
22a
22c
22d
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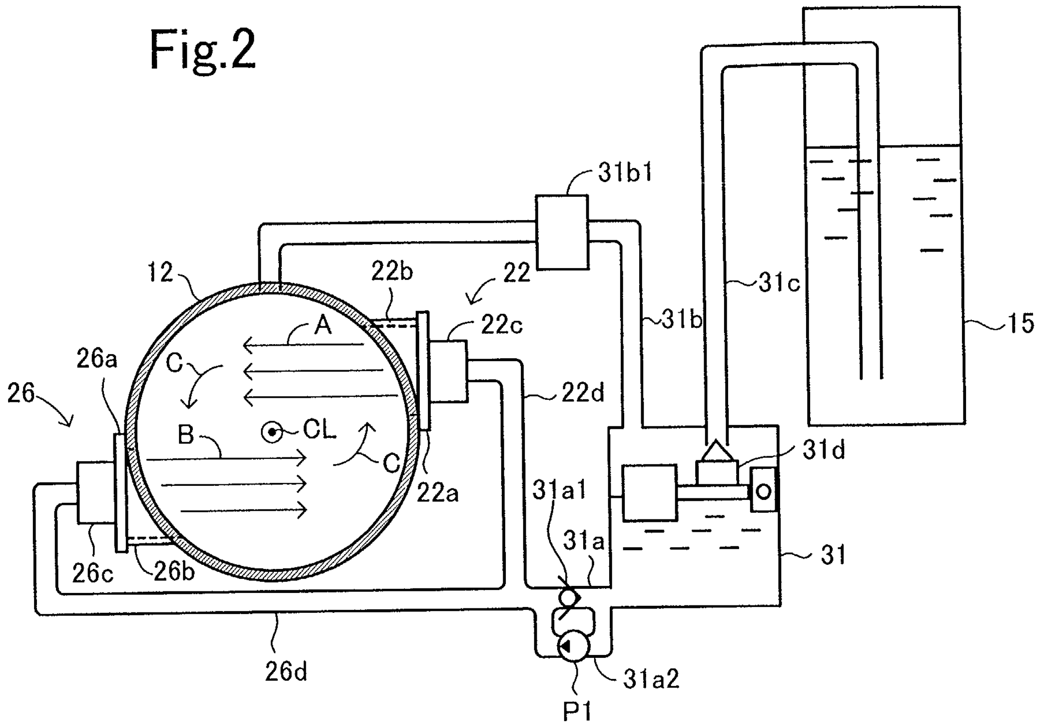
23c
24
24a
24c
24d
25
25a
25c
26
26a
26c
26d
27
27a
27c
28
28a
28c
28d
31
31b
31b1
32
32b
32b1
CL
II

Fig.1

Fig.2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12
22b
22
22c
31c
31b
15
26a
A
C
22d
26
B
CL
C
22a
31d
31a1
31a
26c
26b
31
26d
31a2
P1

Fig.3

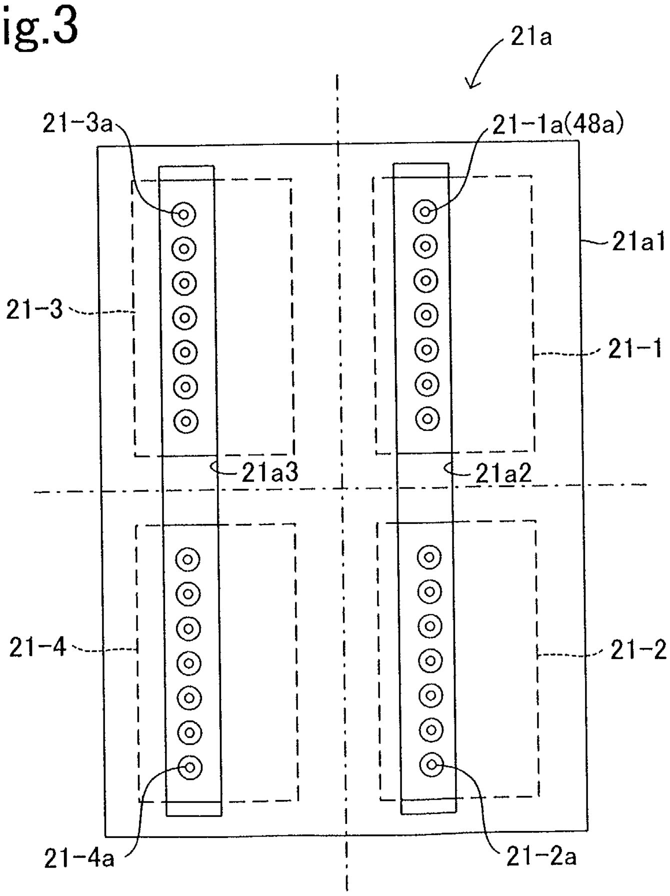

21a
21-3a
21-1a(48a)
21a1
21-3
21-1
21a3
21a2
21-4
21-2
21-4a
21-2a

Fig.4

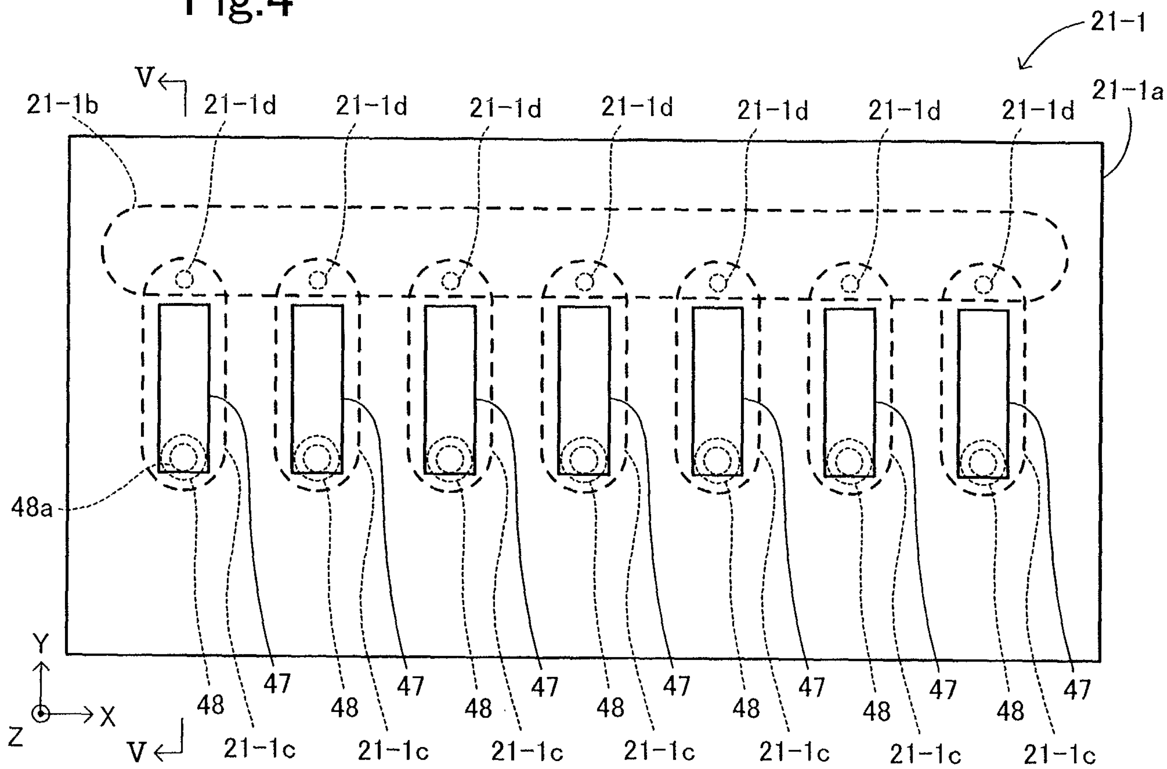
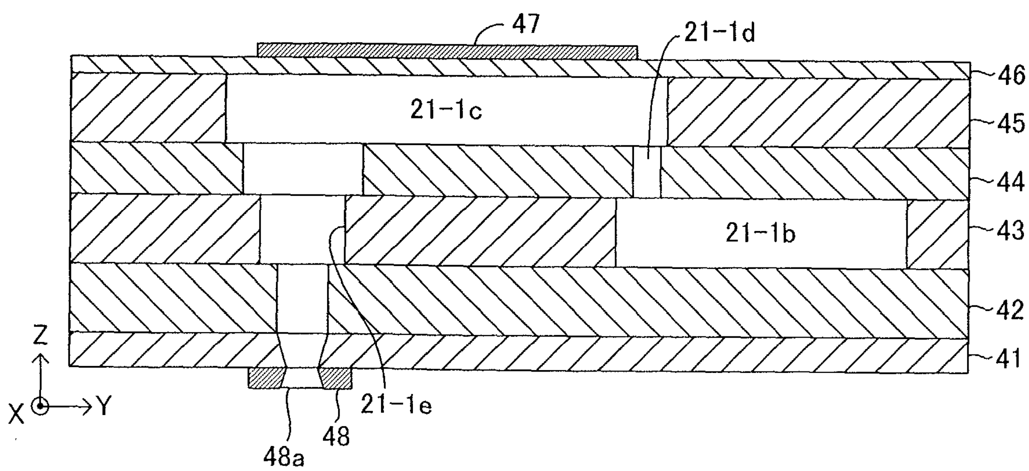

21-1
21-1a
21-1b
V
21-1d
48a
47
48
21-1c
Y
X
Z

Fig.5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21-1c
45
44
43
21-1b
42
41
Z
X
Y
21-1e
48
48a

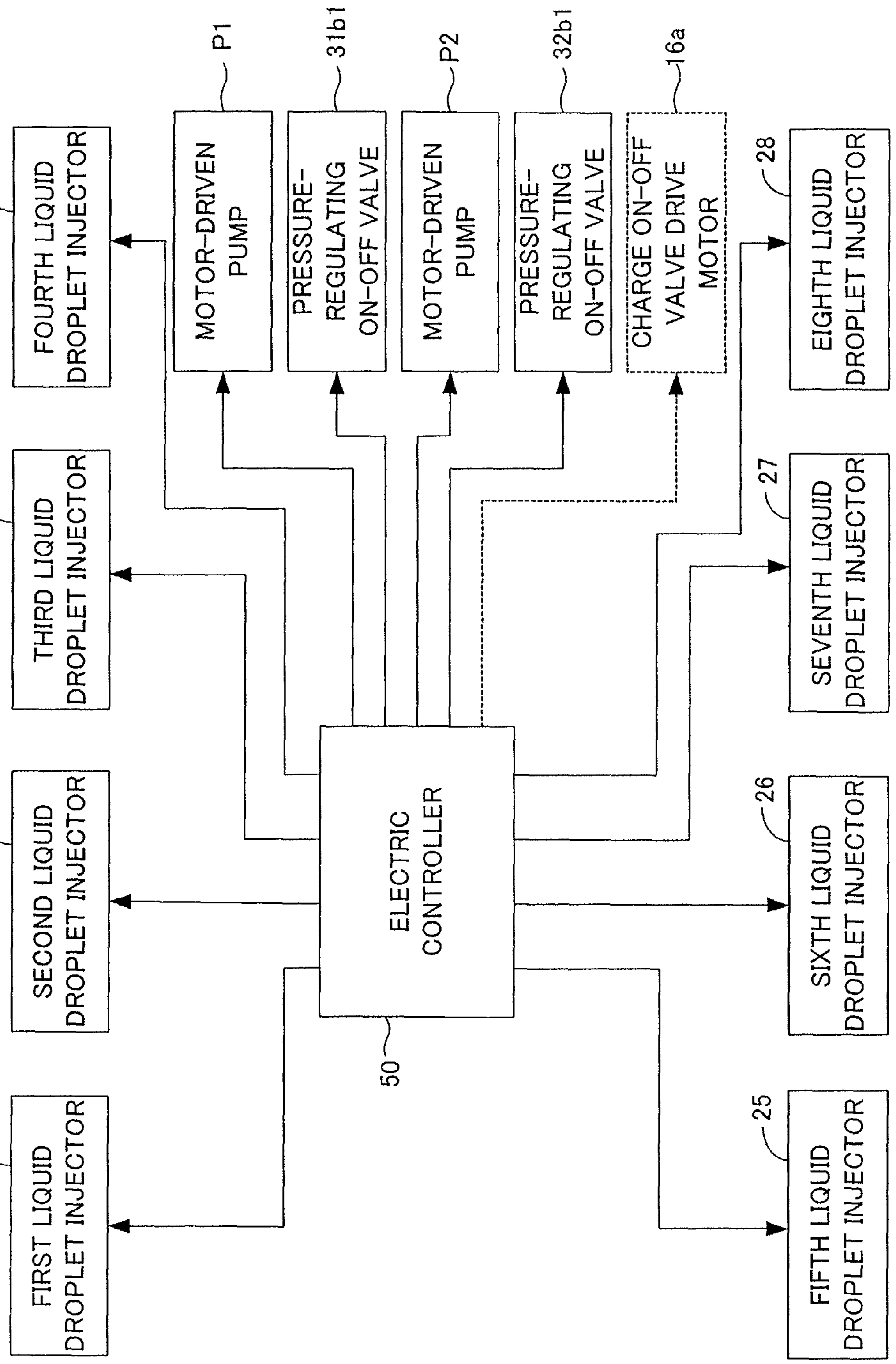

FOURTH LIQUID DROPLET INJECTOR
24
THIRD LIQUID DROPLET INJECTOR
23
SECOND LIQUID DROPLET INJECTOR
22
FIRST LIQUID DROPLET INJECTOR
21
MOTOR-DRIVEN PUMP
P1
PRESSURE-REGULATING ON-OFF VALVE
31b1
MOTOR-DRIVEN PUMP
P2
PRESSURE-REGULATING ON-OFF VALVE
32b1
CHARGE ON-OFF VALVE DRIVE MOTOR
16a
ELECTRIC CONTROLLER
50
EIGHTH LIQUID DROPLET INJECTOR
28
SEVENTH LIQUID DROPLET INJECTOR
27
SIXTH LIQUID DROPLET INJECTOR
26
FIFTH LIQUID DROPLET INJECTOR
25

Fig.6

Fig.7

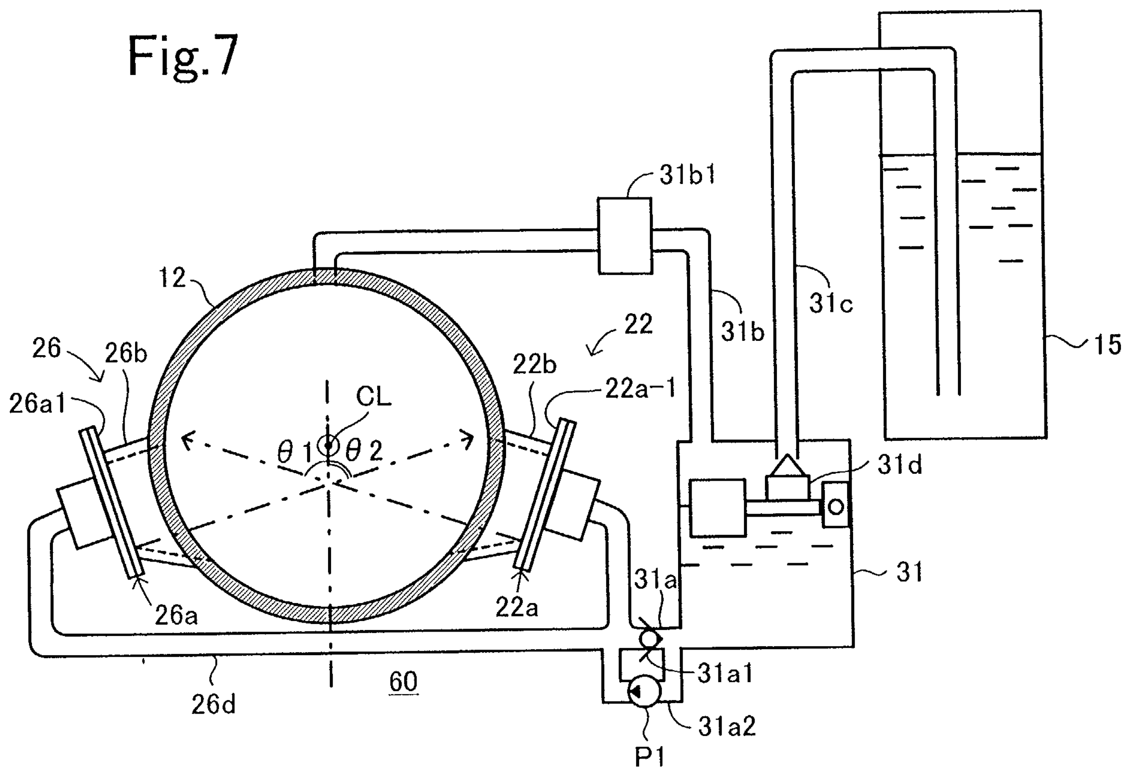

31b1
12
26
26b
22
22b
22a-1
26a1
CL
θ1
θ2
31b
31c
15
31d
31
31a
26a
22a
31a1
26d
60
31a2
P1

Fig.8

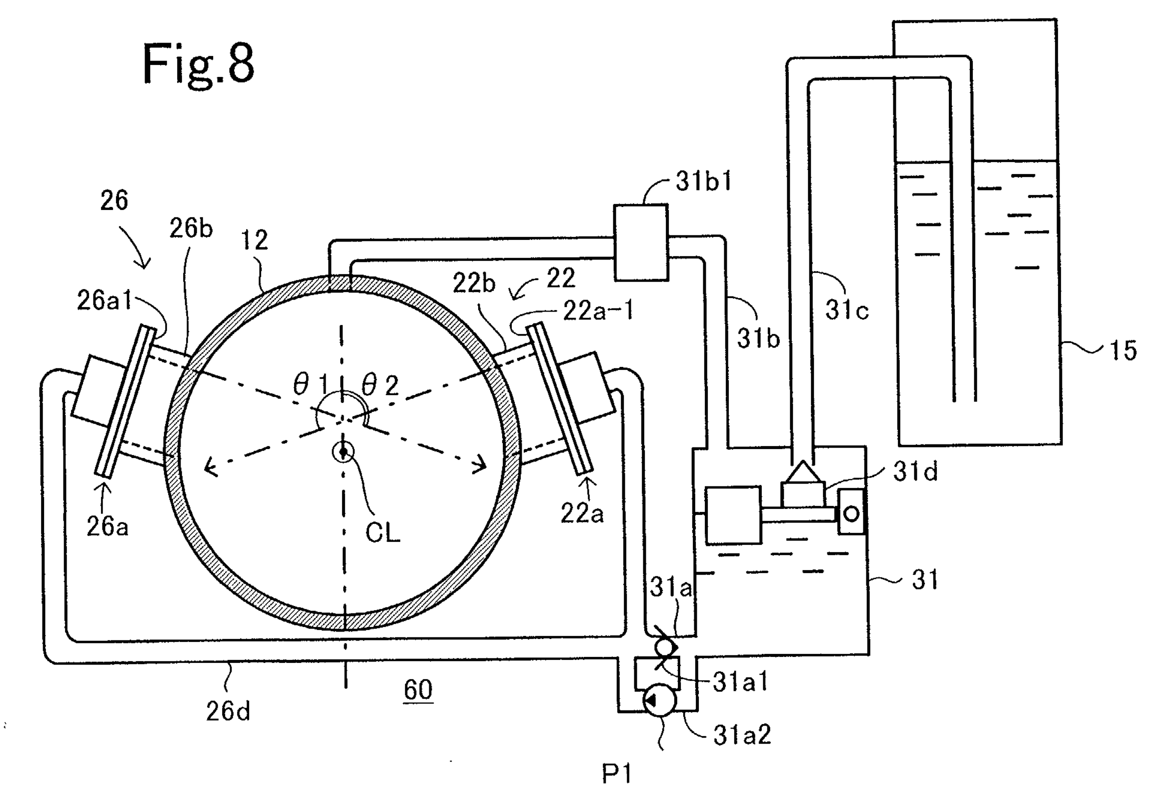

31b1
26
26b
12
22b
22
22a-1
26a1
θ1
θ2
31b
31c
15
31d
26a
CL
22a
31
31a
31a1
26d
60
31a2
P1

Fig.9

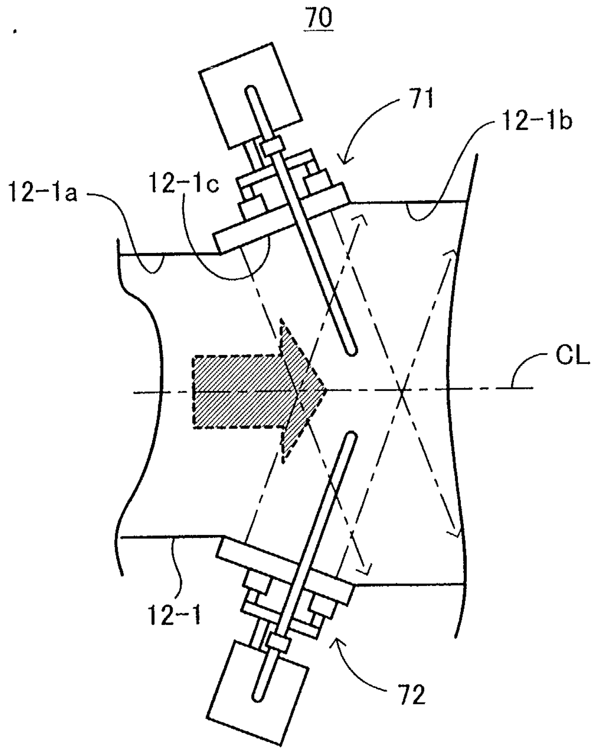

70
71
12-1b
12-1a
12-1c
CL
12-1
72

Fig.10

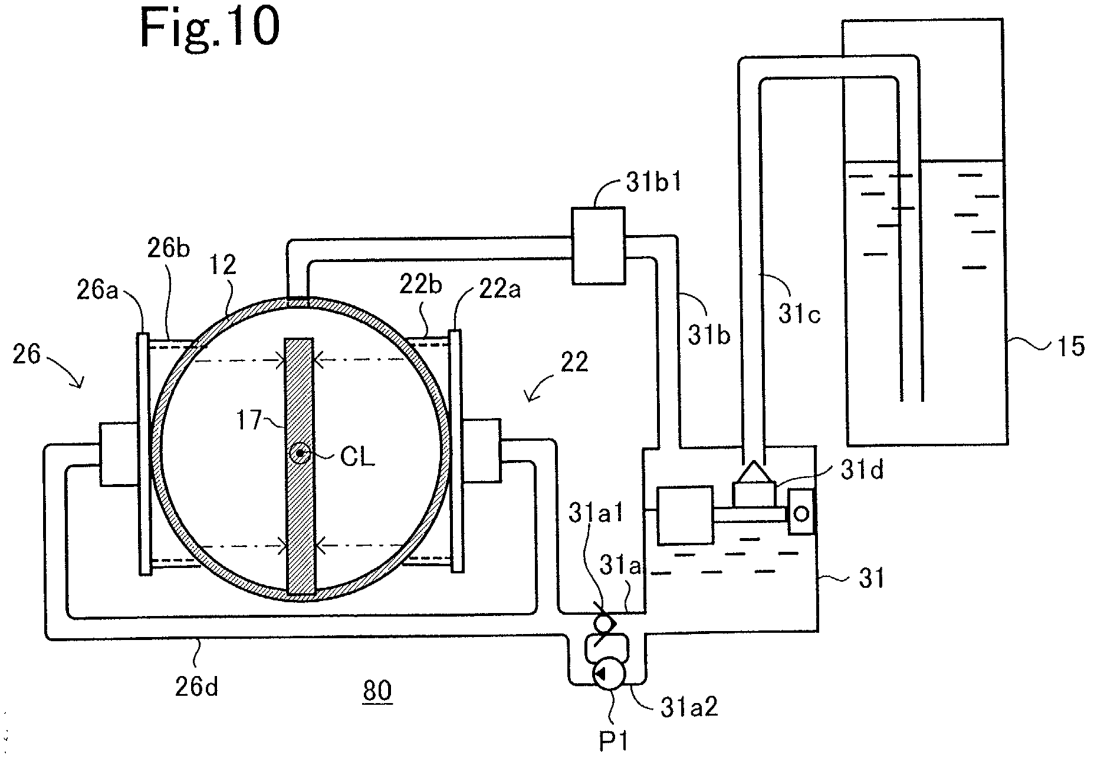
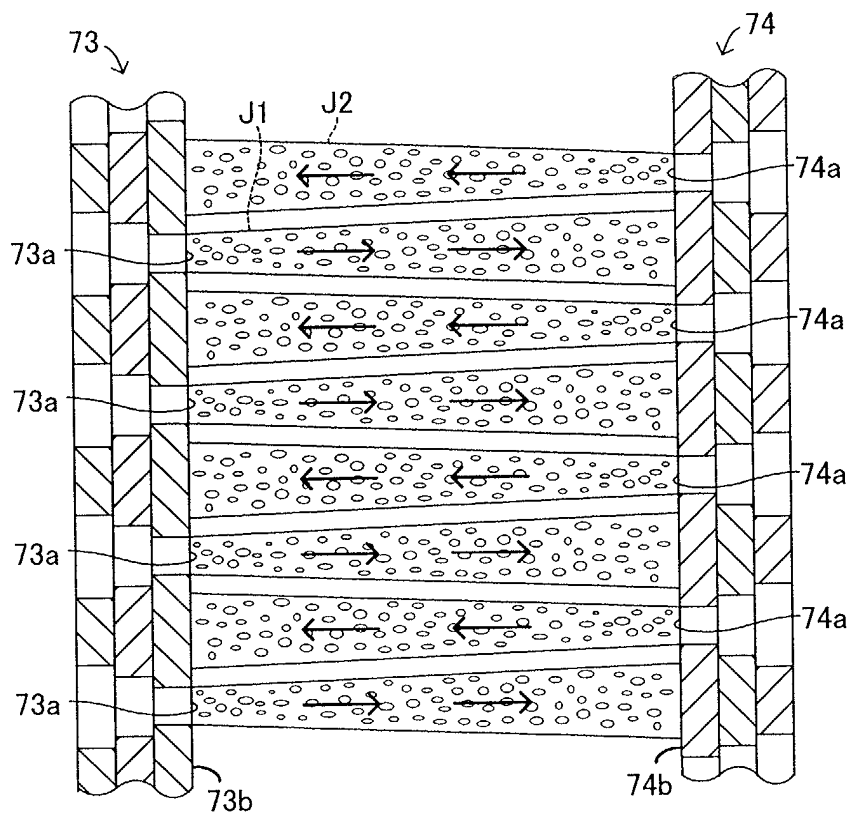

31b1
26b
12
22b
22a
26a
31c
31b
15
26
22
17
CL
31d
31a1
31a
31
26d
80
31a2
P1

Fig.11



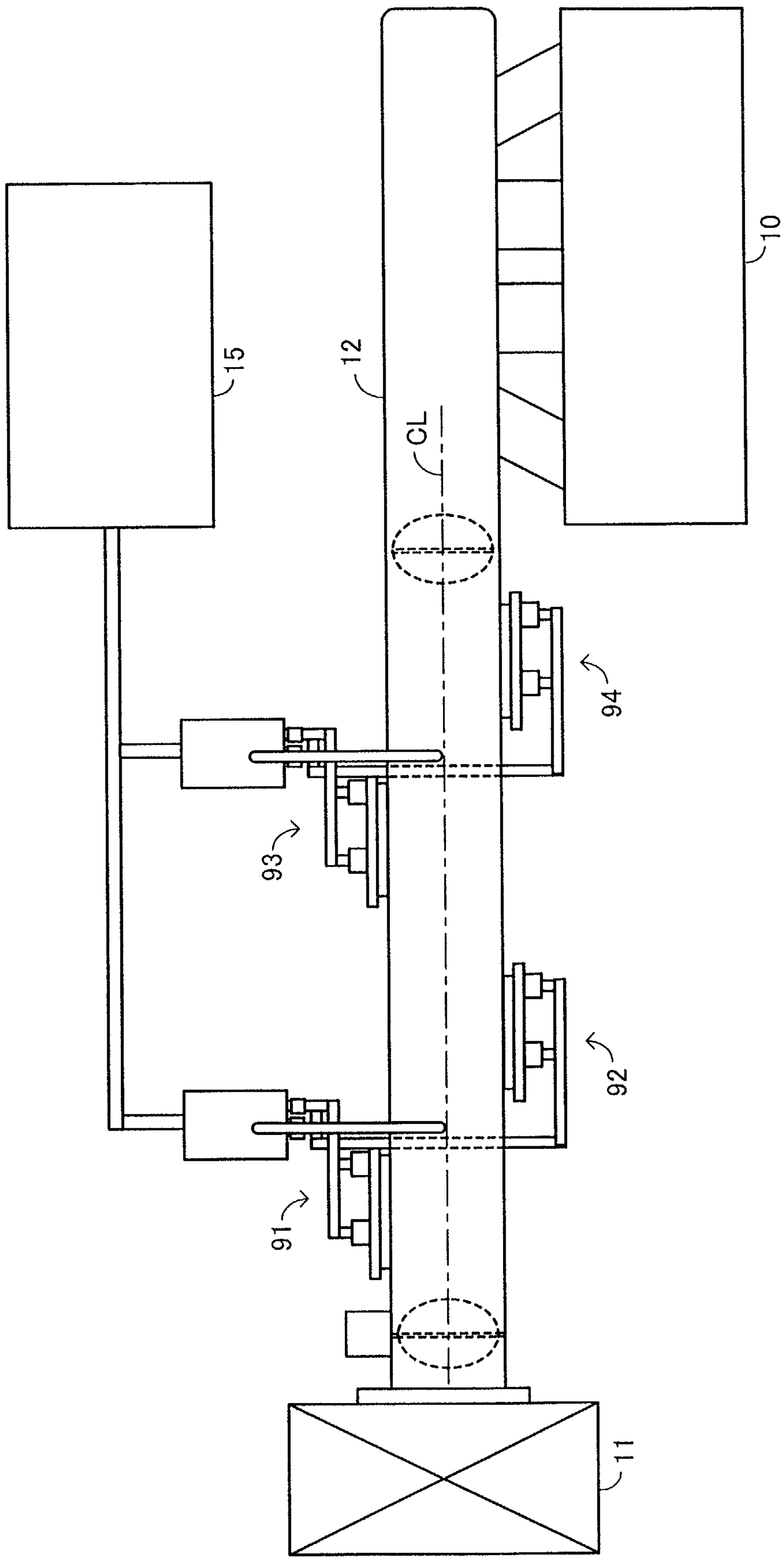
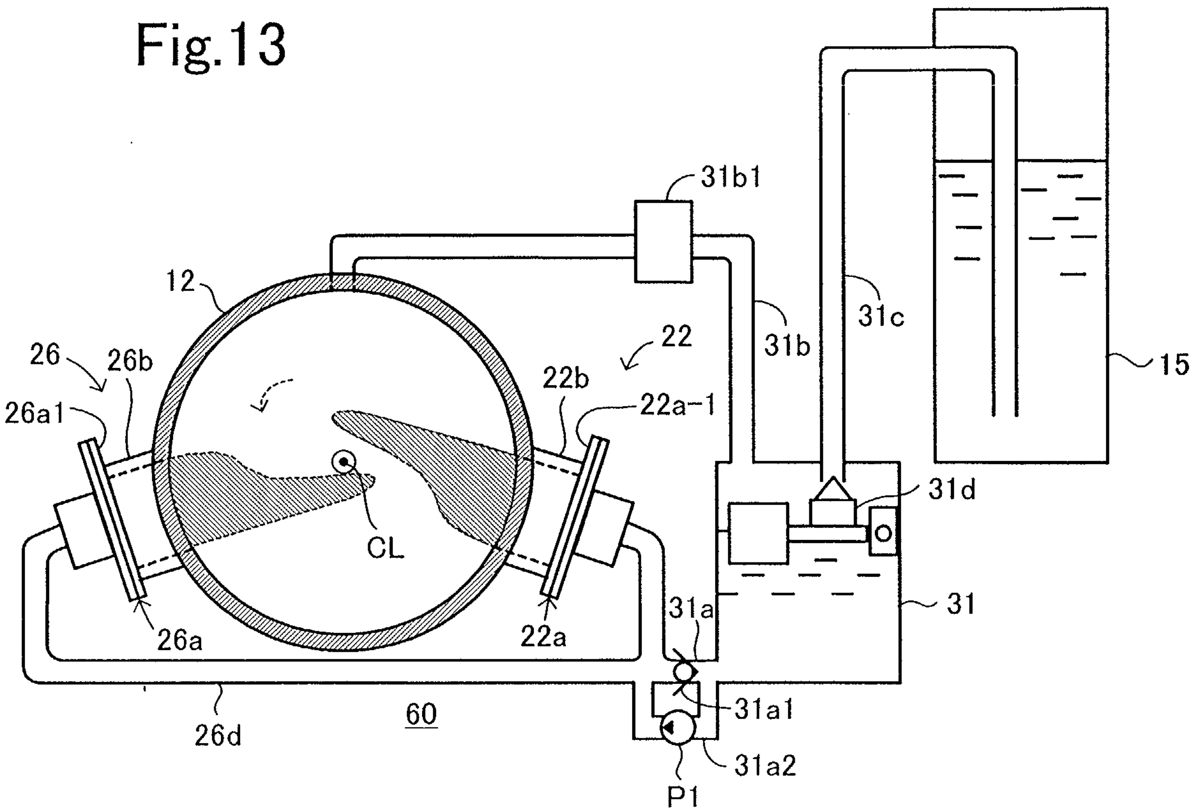


Fig.12

Fig.13


31b1
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31b
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15
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22a-1
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31d
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22a
31a1
60
26d
31a2
P1