(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 February 2004 (26.02.2004)

PCT

(10) International Publication Number
WO 2004/017150 A1

(51) International Patent Classification[7]: G05D 16/00

(21) International Application Number: PCT/KR2003/001644

(22) International Filing Date: 14 August 2003 (14.08.2003)

(25) Filing Language: Korean

(26) Publication Language: English

(30) Priority Data:
10-2002-0048144 14 August 2002 (14.08.2002) KR

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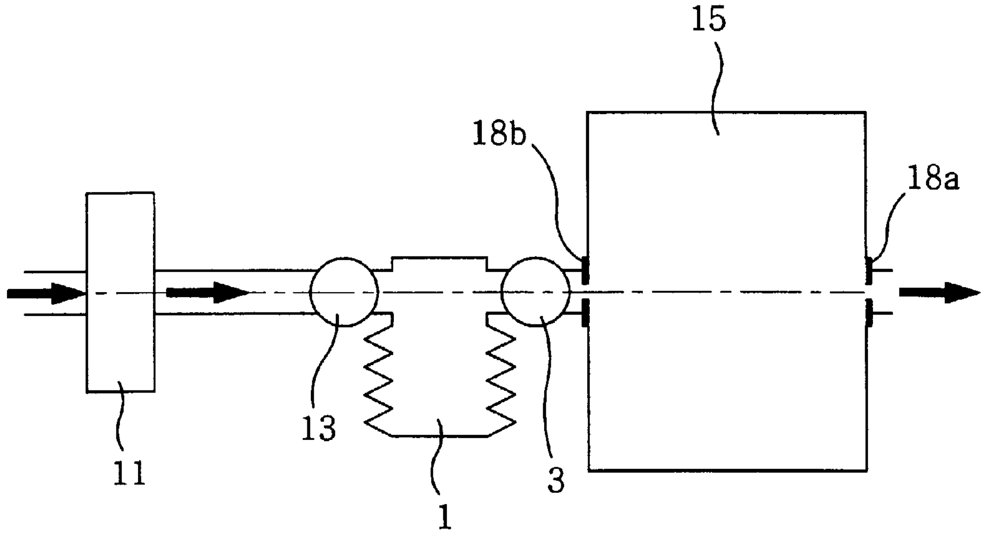
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) **Title:** TIME BASED FLOW CONTROLLER FOR INCOMPRESSIBLE FLUID AND METHOD FOR CONTROLLING FLOW RATE OF INCOMPRESSIBLE FLUID USING IT



(57) **Abstract:** A time based flow controller for incompressible fluid includes at least one reservoir 1, the volume of each reservoir 1 changing in a cycle, at least one inlet valve 13, each inlet valve 13 opening/closing an inlet of a corresponding reservoir 1, at least one outlet valve 3, each outlet valve 3 opening/closing an outlet of a corresponding reservoir 1, and a controller for controlling the number of opening/closing loops of the inlet valve 13 and the outlet valve 3 per unit time and/or mass/volume of the incompressible fluid stored and discharged at the reservoir 1 per unit opening/closing loop of the inlet valve 13 and the outlet valve3 , the controller opening the inlet valve 13 to allow the incompressible fluid to flow into the reservoir 1 when the outlet valve 3 is in a closed state, and thereafter opening the outlet valve 3 to allow the incompressible fluid to flow out from the reservoir 1 when the inlet valve 13 is in a closed state, so that the controller may control the mass/volume flow rate of the outflow incompressible fluid from the reservoir 1.

WO 2004/017150 A1

TIME BASED FLOW CONTROLLER FOR INCOMPRESSIBLE FLUID AND METHOD FOR CONTROLLING FLOW RATE OF INCOMPRESSIBLE FLUID USING IT

TECHNICAL FIELD

The present invention relates to a time based flow controller for incompressible fluid which can accurately measure and control a volume/mass flow rate of the incompressible fluid based on time.

BACKGROUND ART

Various types of flow meters and controllers for fluid have been introduced, such as differential pressure type flow meters, displacement type flow meters, rotary inferential type flow meters, fluid oscillatory type flow meters, electromagnetic type flow meters and ultrasonic type flow meters.

However, most of them are complex and expensive in installation and maintenance. In addition, the conventional meters and controllers infer flow rates from parameters such as pressure loss or rotation. These parameters are subject to change with the properties of the fluid involved, with different viscosity, density and compressibility properties, and thus not easily measurable and controllable.

Accordingly, there have been increasing demands for a new flow controller based on very accurate but easily measurable and controllable variables.

In order to satisfy such demands, the present applicant has suggested a flow controller for compressible fluid, namely gas phase fluid through the PCT Patent Publication WO 02/054020 as shown in Fig. 1 (Title of the Invention: Time based mass flow controller and method for controlling flow rate using it).

Briefly, the flow controller of Fig. 1 includes a reservoir 101, an inlet valve 113, an outlet valve 103, a pressure sensor 105 for sensing the pressure in the reservoir 101, and a controller. The inlet valve 113 is opened when the outlet valve 103 is in a closed state, and the outlet valve 103 is opened when the inlet valve 113 is in a closed state. The controller controls the number of opening/closing loops of the inlet valve 113 and the outlet valve 103 per unit time and/or mass/volume of gas stored and discharged at the reservoir 101 per unit opening/closing loop of the inlet valve 113 and the outlet valve 103, and thus controls the mass/volume of the outflow gas from the reservoir 101.

The flow controller accurately measures and controls the flow rate of the outflow fluid from the reservoir 101 based on time. It has advantages that the flow rate can easily and accurately be measured and controlled.

Reference numerals 111 and 115 denote a pressure regulator and a buffer, respectively.

However, the flow controller of Fig. 1 relies on gas phase fluid flowing into the reservoir 101, and thus is not suitable to measure and control a flow rate of incompressible fluid.

In detail, the pressure in the reservoir 101 in Fig. 1 rises from a low to a high pressure and a fixed size reservoir 101 is used. The flow controller measures the elapsed time to charge and discharge the reservoir 101 as a parameter for defining the flow rate. Therefore, the important factor is determining the amount of the fluid when the reservoir 101 is fully charged and ensuring that this amount is accurately repeatable. The pressure in the reservoir 101 rises with the volume flow rate of the compressible fluid into it in a monotonic, relatively slow and almost linear rate.

However, in the case that this flow controller having the fixed volume reservoir 101 is also used to control the flow rate of incompressible fluid, the pressure in the reservoir 101 would increase infinitely fast with even small flow into the reservoir 101. This would invalidate the time based mass flow controller.

The fixed volume reservoir 101 cannot control the flow rate of the incompressible fluid.

That is, the fixed volume reservoir 101 has a volume of '$V = const = C_1$'.

Based on the definition, the incompressible fluid has a specific volume of '$\upsilon = const = C_2$'.

As a result, a mass stored and discharged at the reservoir 101 per unit cycle is represented by '$m = V/\upsilon = C_1/C_2 = const$'.

Accordingly, in the incompressible fluid, the flow controller of Fig. 1 cannot perform the function of controlling the flow rate.

It is thus necessary to develop a new flow controller which has advantages of the time based mass flow controller of Fig. 1 and, at the same time, can measure and control the flow rate of the incompressible fluid.

DISCLOSURE OF THE INVENTION

The present invention is made to solve the above problems. An object of the present invention is to provide a flow controller for incompressible fluid also having advantages of the time based flow controller in the inventor's previous patent application.

That is, the object of the present invention is to provide a flow controller for incompressible fluid which can easily measure and control a flow rate of the fluid.

Time can be measured more accurately than any other physical values by using a quartz crystal timing device. Accordingly, the present invention can provide a flow controller for incompressible fluid which easily but accurately controls a flow rate, even a very low flow rate of the fluid, without a precise implemental structure.

The present invention also provides a flow controller for incompressible fluid which has excellent reliability and durability.

In addition, the present invention provides a flow controller for incompressible fluid which has high performance but cuts down the installation and maintenance cost at the same time. For example, time can be measured very accurately (better than

1/10^8 second) at a low cost. Therefore, this invention is characterized in that the flow rate of the incompressible fluid can accurately be controlled based on time.

In order to achieve the above-described object of the invention, there is provided a time based flow controller for incompressible fluid including: at least one reservoir, the volume of each reservoir changing in a cycle; at least one inlet valve, each inlet valve opening/closing an inlet of a corresponding reservoir; at least one outlet valve, each outlet valve opening/closing an outlet of a corresponding reservoir; and a controller for controlling the number of opening/closing loops of the inlet valve and the outlet valve per unit time and/or mass/volume of the incompressible fluid stored and discharged at the reservoir per unit opening/closing loop of the inlet valve and the outlet valve, the controller opening the inlet valve to allow the incompressible fluid to flow into the reservoir when the outlet valve is in a closed state, and thereafter opening the outlet valve to allow the incompressible fluid to flow out from the reservoir when the inlet valve is in a closed state, so that the controller may control the mass/volume flow rate of the outflow incompressible fluid from the reservoir.

According to another aspect of the invention, there is provided a method for controlling a flow rate of incompressible fluid using a time based flow controller for incompressible fluid including at least one reservoir, the volume of each reservoir changing in a cycle, at least one inlet valve, each inlet valve opening/closing an inlet of a corresponding reservoir, and at least one outlet valve, each outlet valve opening/closing an outlet of a corresponding reservoir, the method including: opening the inlet valve to allow the incompressible fluid to flow into the reservoir when the outlet valve is in a closed state, opening the outlet valve to allow the incompressible fluid to flow out from the reservoir when the inlet valve is in a closed state, and controlling the number of opening/closing loops of the inlet valve and the outlet valve per unit time and/or mass/volume of the incompressible fluid stored and discharged at the reservoir per unit opening/closing loop of the inlet valve and the outlet valve, so as to control the mass/volume flow rate of the outflow incompressible fluid from the reservoir.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 schematically illustrates a structure of a conventional flow controller for compressible gas;

Figs. 2A to 2C schematically illustrate the concept of the present invention;

Figs. 3A to 3D schematically illustrate reservoirs in accordance with various embodiments of the present invention;

Figs. 4A to 4C illustrate volume change of a bellows type reservoir versus time to explain the concept of the present invention;

Fig. 5 schematically illustrates the whole structure of a flow controller in accordance with one embodiment of the present invention;

Fig. 6 is a diagram for explaining influence of volume-pressure characteristics on the design of the reservoir;

Fig. 7 schematically illustrates the whole structure of a flow controller in accordance with another embodiment of the present invention;

Fig. 8 schematically illustrates the whole structure of a flow controller in accordance with yet another embodiment of the present invention;

Fig. 9 schematically illustrates the whole structure of a flow controller in accordance with yet another embodiment of the present invention;

Figs. 10A and 10B schematically illustrate the whole structures of flow controllers in accordance with yet another embodiment of the present invention;

Fig. 11 schematically illustrates the whole structure of a flow controller in accordance with yet another embodiment of the present invention;

Fig. 12 schematically illustrates the whole structure of a flow controller in accordance with yet another embodiment of the present invention;

Fig. 13 schematically illustrates the whole structure of a test flow controller used in tests on the present invention;

Fig. 14 schematically illustrates a reservoir of the test flow controller of Fig. 13;

Fig. 15 schematically illustrates a sensor amplifier circuit of the test flow controller of Fig. 13;

Fig. 16 shows how constitutional units of the test flow controller of Fig. 13 are controlled;

Fig. 17 illustrates a control program sequence executed in the test flow controller of Fig. 13;

Fig. 18 illustrates the relationship between the extension of the bellows and the pressure variation obtained from testing of the test flow controller of Fig. 13;

Fig. 19A illustrates the relationship between the time and the extension of the bellows during the charging process of the test flow controller of Fig. 13;

Fig. 19B illustrates the relationship between the time and the pressure variation during the charging process of the test flow controller of Fig. 13;

Fig. 19C illustrates the relationship between the time and the instantaneous flow rate during the charging process of the test flow controller of Fig. 13;

Fig. 20A illustrates the relationship between the time and the extension of the bellows during the discharging process of the test flow controller of Fig. 13;

Fig. 20B illustrates the relationship between the time and the pressure variation during the discharging process of the test flow controller of Fig. 13;

Fig. 20C illustrates the relationship between the time and the instantaneous flow rate during the discharging process of the test flow controller of Fig. 13;

Fig. 21 illustrates the relationship between the cycle rate and the flow rate obtained from testing of the test flow controller of Fig. 13;

Fig. 22 illustrates flow rate errors between the target flow rate and the measured flow rate obtained from testing of the test flow controller of Fig. 13;

Fig. 23 illustrates the relationship between the inflow pressure into the reservoir and the elapsed time for performing each charging process obtained from testing of the test flow controller of Fig. 13;

Fig. 24A illustrates the relationship between the extension of the reservoir and the instantaneous flow rate during the charging process of the test flow controller of Fig. 13; and

Fig. 24B illustrates the relationship between the extension of the reservoir and the instantaneous flow rate during the discharging process of the test flow controller of Fig. 13.

BEST MODE FOR CARRYING OUT THE INVENTION

A time based flow controller for incompressible fluid and a method for controlling a flow rate of incompressible fluid using it in accordance with the present invention will now be described in detail with reference to the accompanying drawings.

Figs. 2A to 2C schematically illustrate the concept of the present invention.

An inlet valve 13 and an outlet valve 3 are in a closed state (Fig. 2A). At this time, fluid is already entrained in the control volume. The inlet valve 13 is opened, high pressure fluid flows into the control volume, namely a reservoir 1, and the control volume is expanded until the inlet valve 13 is closed (Fig. 2B). The outlet valve 3 is opened, and the fluid in the reservoir 1 is discharged (Fig. 2C).

The present invention can control a flow rate of incompressible fluid such as water, by using the reservoir 1 expanded and contracted to charge and discharge the fluid in each cycle. Accordingly, the inflow fluid can be charged and discharged smoothly without cavitation or separation.

Figs. 3A to 3D schematically illustrate reservoirs in accordance with various embodiments of the present invention.

The solutions suggested to control the flow rate of the incompressible fluid include two types of reservoirs.

The first type reservoir is a flexible reservoir which can be expanded or contracted, such as a bellows type reservoir 1a of Fig. 3A and a flexible membrane type reservoir 1b of Fig. 3B. The second type reservoir is a cylinder type reservoir 1c having a piston 2 returned by a spring 4a of Fig. 3C or gravity as shown in Fig. 3D.

The bellows type is most preferable in real applications because it is one of the simpler designs, is easily adapted to integration of sensory measurement and control equipment, and forms a hermetically sealed reservoir.

The bellows type reservoir 1a may include a spring means operated against the pressure increase in the reservoir 1a, to readily discharge the fluid from the reservoir 1a.

Consistent elastic responses of the flexible membrane show too short lifetime and pose difficulties in integrating the necessary sensory devices for accurately controlling the size of the reservoir 1b.

On the other hand, the cylinder type reservoir 1c hardly obtains tolerances for preventing fluid leakage. The fluid must not be leaked because the leaked fluid makes it difficult to efficiently control a low flow rate. As illustrated in Figs. 3C and 3D, in order to discharge the incompressible fluid, the cylinder type reservoir 1c includes a spring means 4a or a mass weight 4b operated onto the piston 2 against the volume expansion of the reservoir 1c. Moreover, a motor actuator may be coupled with the piston 2 to mechanically operate it.

Figs. 4A to 4C illustrate volume variation of the bellows type reservoir versus time to explain the concept of the present invention.

Here, ΔV indicates the volume variation, Δt_f indicates the charging time, Δt_e indicates the discharging time, and T indicates the total elapsed time for one cycle.

The most important parameter for measuring and controlling the flow rate is the total elapsed time for completing one charging and discharging cycle in the provided volume.

As the bellows type reservoir 1 is expanded, the reaction force increases according to the Hooke's law. Accordingly, the rate at which the bellows expands decreases. The charging or discharging time is proportional to the difference in pressure and the upstream ΔP (namely, difference between the pressure of supply fluid and the pressure in the bellows when it has been contracted to the minimum volume) is much lower than the difference between the pressure in the bellows when it is full and the atmospheric pressure.

Fig. 4B illustrates the volume variation versus time when the upstream pressure is higher than in Fig. 4A.

As shown in Fig. 4B, when the upstream pressure is higher than in Fig. 4A, the charging time significantly decreases. The transition from the charging to discharging (and vice versa) is not instantaneous, but needs a finite time during which the respective valves open and close. This means that the control software must have a built-in delay for valve state switching.

Fig. 4C is a more realistic representation of the cycle sequence. The dotted line represents the extension of the bellows between its minimum and maximum extensions. Here, the lower limit to extension is selected as a measure to ensure that the extension of the bellows always reaches this point. The slight inconsistency in the position reading from the sensor means that the value corresponding to the zero is not always attained. To prevent this, a slightly offset base (V_{empty}) is stipulated. The upper limit to the extension is also stipulated relative to the base and may be varied to suit the required flow rate.

The cycle rate can be controlled by an additional delay at the bottom of the system's cycle.

Fig. 5 schematically illustrates the whole structure of a flow controller in accordance with one embodiment of the present invention.

As illustrated in Fig. 5, the flow controller includes a reservoir 1, an inlet valve

13, an outlet valve 3 and a controller.

The volume of the reservoir 1 changes in a cycle. Not only the bellows type reservoir 1a of Fig. 5 but also the flexible membrane type reservoir 1b and the cylinder-piston type reservoir 1c may be used.

The inlet valve 13 and the outlet valve 3 open and close an inlet and an outlet of the reservoir 1 under the control of the controller, respectively. The inlet valve 13 and the outlet valve 3 must be rapidly opened and closed at the opening/closing time points. For this, a fast acting valve may be used. In addition, an exclusive logic digital machine for controlling the operation of the fast acting valve based on the volume of the reservoir 1 may be used to control the inlet valve 13 and the outlet valve 3.

Under the control of the controller, the inlet valve 13 is opened to allow incompressible fluid to flow into the reservoir 1 when the outlet valve 3 is in a closed state, and the outlet valve 3 is opened to allow the incompressible fluid to flow out from the reservoir 1 when the inlet valve 13 is in a closed state.

In order to control mass/volume flow rate of outflow incompressible fluid from the reservoir 1, the controller controls the number of opening/closing loops of the inlet valve 13 and the outlet valve 3 per unit time and/or mass/volume of the incompressible fluid stored and discharged at the reservoir 1 per unit opening/closing loop of the inlet valve 13 and the outlet valve 3.

This process is very similar to a process of placing a bucket under a water tap and filling the bucket with water. For example, if the bucket having a volume of Vm^3 is filled with water five times and the water is supplied into a tank for 10 minutes, the volume flow rate of water supplied into the tank is represented by the following equation:

$$\text{Volume flow rate} = V \times 5/10 \ (m^3/min)$$

The mass flow rate can be easily calculated by multiplying the volume flow rate by density. (Here, it should be noted that the density or specific volume of incompressible fluid such as water is constant.)

Therefore, the flow rate of the fluid supplied into the tank can be changed by changing either the number of filling the bucket with water and supplying the water into the tank per unit time, namely the cycle rate, or the volume (mass) of the bucket.

Controlling the flow rate can be embodied in various methods, which will be explained with Fig. 5.

First, the volume of the reservoir 1 is measured by a volume sensor 6. When the volume of the reservoir 1 is a reference minimum volume, the inlet valve 13 is opened, when the volume of the reservoir 1 is a reference maximum volume, the inlet valve 13 is closed, when the volume of the reservoir 1 is the reference minimum volume, the outlet valve 3 is closed, and when the volume of the reservoir 1 is the reference maximum volume, the outlet valve 3 is opened. The reference minimum volume and/or the reference maximum volume of the reservoir 1 are/is controlled as control variables, by which the flow rate can be controlled.

Various types of sensors including a position sensor and a limit switch sensor turned on/off with contact for sensing the reference maximum volume and the reference minimum volume may be used as the volume sensor 6.

Second, the volume of the reservoir 1 is measured by the volume sensor 6, and time periods between an opening and a closing of the inlet valve 13 and the outlet valve 3 are measured by a time sensor. When the volume of the reservoir 1 is the reference minimum volume, the outlet valve 3 is closed and the inlet valve 13 is opened. A time period from an opening to a closing of the inlet valve 13 and a time period from a closing to an opening of the outlet valve 3 are controlled as control variables, by which the flow rate can be controlled.

Third, the volume of the reservoir 1 is measured by the volume sensor 6, and time periods between an opening and a closing of the inlet valve 13 and the outlet valve 3 are measured by the time sensor. When the volume of the reservoir 1 is the reference maximum volume, the inlet valve 13 is closed and the outlet valve 3 is opened. A time period from a closing to an opening of the inlet valve 13 and a time period from an opening to a closing of the outlet valve 3 are controlled as control variables, by which the flow rate can be controlled.

Here, in accordance with one embodiment of the present invention, the flow controller includes a pressure sensor 5 for sensing pressure in the reservoir 1, and determines control variables based on the pressure of the incompressible fluid in the reservoir 1 sensed by the pressure sensor 5.

This relates to an upstream side pressure, namely the pressure of supply fluid. That is, when the pressure of the supply fluid is high, the fluid in the reservoir 1 is operated in the high pressure range. In this case, even if the inlet valve 13 and the outlet valve 3 are opened and closed according to the same reference minimum volume and reference maximum volume, the elapsed time for one cycle decreases, and thus the flow rate increases. Accordingly, if the pressure in the reservoir 1 is high, the reference minimum volume must be set higher or the reference maximum volume must be set lower in order to obtain the same flow rate.

In another aspect, it means that the flow rate can increase even with the same cycle rate. Therefore, in order to obtain the same flow rate, if the pressure in the reservoir 1 is high, time periods between an opening and a closing of the inlet valve 13 and the outlet valve 3 must be set smaller.

Preferably, a temperature sensor for sensing temperature in the reservoir 1 is installed, and control variables are determined based on the temperature of the incompressible fluid in the reservoir 1 sensed by the temperature sensor.

The fourth to sixth control methods are quite different from the first to third control methods. Here, the pressure sensor 5 substitutes for the volume sensor 6.

Fourth, the pressure sensor 5 is installed to sense the pressure in the reservoir 1. When the pressure in the reservoir 1 is a reference minimum pressure, the inlet valve 13 is opened, when the pressure in the reservoir 1 is a reference maximum pressure, the inlet valve 13 is closed, when the pressure in the reservoir 1 is the reference minimum pressure, the outlet valve 3 is closed, and when the pressure in the reservoir 1 is the reference maximum pressure, the outlet valve 3 is opened. The reference minimum pressure and/or the reference maximum pressure in the reservoir 1 are/is controlled as control variables, by which the flow rate can be controlled.

Fifth, the pressure in the reservoir 1 is sensed by the pressure sensor 5, and time periods between an opening and a closing of the inlet valve 13 and the outlet valve 3 are measured by a time sensor. When the pressure in the reservoir 1 is the reference minimum pressure, the outlet valve 3 is closed and the inlet valve 13 is opened. A time period from an opening to a closing of the inlet valve 13 and a time period from a closing to an opening of the outlet valve 3 are controlled as control variables, by which the flow rate can be controlled.

Sixth, the pressure in the reservoir 1 is sensed by the pressure sensor 5, and time periods between an opening and a closing of the inlet valve 13 and the outlet valve 3 are measured by a time sensor. When the pressure in the reservoir 1 is the reference maximum pressure, the inlet valve 13 is closed and the outlet valve 3 is opened. A time period from a closing to an opening of the inlet valve 13 and a time period from an opening to closing of the outlet valve 3 are controlled as control variables, by which the flow rate can be controlled.

The fourth to sixth control methods would be less preferable than the first to third control methods with respect to control performance. However, the fourth to sixth control methods are advantageous in that the time based mass flow controller for compressible gas of the inventor and software used therewith can be used with compatibility. That is, the time based mass flow controller for compressible gas can be used to control incompressible gas, simply by using the flexible variable volume reservoir 1 instead of the non-flexible fixed volume reservoir 101, which will attract equipment users.

In the fourth to sixth control methods, the pressure is measured to infer volume changes, and the active volume of the reservoir 1 becomes a function of the pressure as shown in Fig. 6. It would be preferable that the designer carefully selects the material and structure of the bellows so that the reservoir 1 can be operated in the range of linear volume-pressure relation. However, it must be recognized that linearity is preferable but not essential. Only one essential condition of the invention is that the volume must increase with the pressure.

Seventh, a time delay is provided between a closing of the inlet valve 13 and an opening of the outlet valve 3 and/or between a closing of the outlet valve 3 and an opening of the inlet valve 13, and the length of the time delay is controlled as a control variable, by which the flow rate can be controlled. The seventh control method can be individually used, or used in combination with the above-described methods.

In case that the flow controller of Fig. 5 is used to control the flow rate, it is practical to obtain the relationship between the volume and the flow rate, the pressure and the flow rate or the time and the flow rate in the form of an equation or a table through experiments or works with appropriate relational expressions, and use it for controlling.

However, it should be noted that such pre-works are not always essential. For example, the flow rate can be controlled by repeating a procedure of setting an extension range of the reservoir 1, charging and discharging the reservoir 1 within the extension range, obtaining an accurate flow rate by measuring the elapsed time, and correcting the extension range if the flow rate is different from a desired flow rate. However, this would not be practical.

Fig. 7 schematically illustrates the whole structure of a flow controller in accordance with another embodiment of the present invention.

As depicted in Fig. 7, the flow controller includes a reservoir 1, an inlet valve 13, an outlet valve 3, a controller and a pressure regulator 11.

Preferably, the flow controller has an inflow fluid state regulator such as the pressure regulator 11 at the upstream side of an inlet of the reservoir 1.

As described above, when pressure at the upstream side of the reservoir 1 is changed, the time for charging the fluid in the reservoir 1 is also changed. Therefore, the pressure of the incompressible fluid flowing into the reservoir 1 needs to have a fixed value, which is attained by the pressure regulator 11.

Figs. 8 to 11 illustrate a means for minimizing perturbation of outflow fluid from the reservoir 1.

Fig. 8 schematically illustrates the whole structure of a flow controller in accordance with yet another embodiment of the present invention.

Referring to Fig. 8, the flow controllers of Fig. 5 may be connected in parallel. The flow controller of Fig. 5 can control a flow rate very accurately based on time. However, fluid is intermittently supplied from the reservoirs 1, and thus not steadily supplied to a fluid user equipment at the downstream side of the reservoirs 1. In order to solve such problem, at least two reservoirs 1 are preferably connected in parallel, and the opening/closing time points of the inlet valves 13 and the outlet valves 3 of each reservoir 1 are set differently. As a result, perturbation of the fluid which is supplied to the fluid user equipment at the downstream side of the reservoirs 1 can be minimized.

According to yet another embodiment of the invention, at least two reservoirs 1 are connected in parallel, and the length of flow lines between each reservoir 1 and the fluid user equipment are set differently, to obtain the same effect.

Fig. 9 schematically illustrates the whole structure of a flow controller in accordance with yet another embodiment of the present invention.

As illustrated in Fig. 9, the flow controller further includes a buffer 15 at the downstream side of the reservoir 1 of the flow controller of Fig. 5.

The buffer 15 also serves to avoid perturbation of the fluid at the downstream side of the reservoir 1 as explained in connection with Fig. 8. The buffer 15 needs to have a larger volume than the reservoir 1 to obtain sufficient buffering capability. The volume of the buffer 15 is influenced by the pressure of supply fluid and pressure in a fluid user equipment. In order to more efficiently minimize perturbation of the fluid supplied to the fluid user equipment, the buffer 15 can be used in combination with the plurality of parallel reservoirs of Fig. 8.

So at to smoothly discharge the fluid from the reservoir 1, the buffer 15 is preferably installed lower than the reservoir 1.

Figs. 10A and 10B schematically illustrate the whole structures of flow controllers in accordance with yet another embodiment of the present invention.

Figs. 10A and 10B show that the buffer 15 of the flow controller of Fig. 9 may have a variable volume. The flow controllers of Figs. 10A and 10B more efficiently prevent perturbation of the fluid supplied to the fluid user equipment than the flow controller of Fig. 9.

Fig. 10A illustrates the buffer 15 having a piston type spring means 16a on its one side. Here, the piston type spring means 16a is operated against the pressure increase of the fluid in the buffer 15, to avoid perturbation of the pressure of the fluid in the buffer 15. When the pressure of the fluid in the buffer 15 increases, the spring means 16a is contracted to store the elastic force. Conversely, when the pressure of the fluid in the buffer 15 decreases, the spring means 16a is expanded to release the elastic force. Accordingly, perturbation of the pressure of the fluid in the buffer 15 is avoided.

The buffer 15 may include a mass weight operated against the pressure increase in the buffer 15 similarly to Fig. 3D. In addition, the buffer 15 may have a pressure sensor for sensing the pressure in the buffer 15 together with the piston, and a displacement of the piston may be controlled, to prevent perturbation of the fluid in the buffer 15.

Fig. 10B illustrates the buffer 15 including a bellows type spring means 16b. The bellows type spring means 16b is operated against the pressure increase of the fluid in the buffer 15, to avoid perturbation of the pressure of the fluid in the buffer 15.

Fig. 11 schematically illustrates the whole structure of a flow controller in accordance with yet another embodiment of the present invention.

As depicted in Fig. 11, the flow controller includes a first flow resistance valve 18a and a second flow resistance valve at the downstream side and the upstream side of the buffer 15, and thus more efficiently prevents perturbation of the fluid supplied to the fluid user equipment than the flow controller of Fig. 9. It is preferable that the second flow resistance valve 18b has a lower flow resistance than the first flow resistance valve 18a. The second flow resistance valve 18b can be omitted.

A flow resistance value is influenced by the pressure of the supply fluid and the pressure in the fluid user equipment. The flow resistance value must be set so that the fluid in the reservoir 1 can relatively quickly flow into the buffer 15 and the fluid in the buffer 15 can slowly flow out. Especially, the resistance value of the first flow resistance valve 18a must not be so high as to cause the pressure in the reservoir 1 to rise to such levels as to significantly slow down the discharge of the fluid from the reservoir 1 to the buffer 15. In addition, the flow resistance should not act as a flow block filter.

Preferably, needle valves are used as the flow resistance valves 18a and 18b, and electronically controlled to provide desired pressure loss characteristics and flow rates.

The methods for minimizing perturbation of the fluid supplied to the fluid user equipment have been described with reference to Figs. 8 to 11. However, it is also useful to lower the pressure of the supply fluid. In this case, it should be noted that the flow controller must be operated at a sufficiently high frequency to obtain the same flow rate as in the high supply pressure conditions.

As another preferable method, pipe lines of an inlet and an outlet of the buffer 15 with small diameter can be used, or an orifice plates can be used. This method simplifies manufacture and does not require any special controlling.

As another complex method, a cyclone type device which will ensure that flow resistance will increase very rapidly with the mass flow rate can be used.

Fig. 12 schematically illustrates the whole structure of a flow controller in accordance with yet another embodiment of the present invention.

As illustrated in Fig. 12, the pressure regulator 11 of Fig. 7, the buffer 15 of Fig. 9 and the flow resistance valves 18a and 18b of Fig. 11 can be incorporated into the flow controller.

In order to prove effectiveness of the invention, a test flow controller was fabricated and tested, as follows.

Fig. 13 schematically illustrates the whole structure of a test flow controller used in tests on the present invention.

A bellows type reservoir 1 is mounted upside down in order to ensure that any air in the system is expelled in the first few cycles of operation. A tank 21 is raised to give a natural head. A small air pump 22 is further used to overcome the losses in the system and obtain a suitable cycle rate. In order to maintain pressure in the tank 21, a pressure gage is regularly monitored and the tank tops up with air when necessary. The upstream pressure fed into the reservoir 1 is maintained at a constant pressure using a pressure regulator 11. A simple measuring container 19 is also used to measure outlet flowrate from the reservoir 1.

While the system is running, the pressure in the reservoir 1 and its overall extension under the pressure are monitored. In an ideally elastic system with little or no hysteresis, the two parameters would be directly proportional to each other.

To measure these two parameters, an uncompensated gauge pressure sensor and a conductive polymer potentiometer type linear position sensor as the volume sensor 6 are used.

Fig. 14 schematically illustrates the reservoir 1 of the test flow controller of Fig. 13.

The mechanical design of the reservoir 1 is determined by system requirements and the availability of materials and components. Detailed calculations are carried out to determine the response of the reservoir 1 to different pressure conditions, how quickly the reservoir can be charged and discharged, and what the upstream pressure requirements are. The results of these calculations are used to select the mechanical components used, the geometry and design of the arrangement and the functions of the control software and electronics.

The bellows which is hermetically sealed and can retain its elastic properties for much longer than other systems is used as the reservoir 1. The flexible membrane, while relatively easy to make watertight, would be subject to some plastic deformation over time, which is not allowable under any circumstances. The piston system would have difficulty in obtaining required tolerance for preventing water leakage.

The bellows is made of phosphor-bronze, soldered to a metal sheet 9, and installed in a cylindrical bellows housing 8. In addition, an O-ring is used for sealing. The phosphor-bronze bellows shows excellent resistance to corrosion and relatively low creep and hysteresis. It means that its response characteristics are approximate to perfect elasticity. The bellows with a low spring constant is selected to minimize pressure requirements of the system and maximize a cycle rate.

A linear position sensor includes a spring loaded metal plunger 7 connected to a potentiometer. The potentiometer measures resistance changes with displacements. The linear position sensor is mounted underneath the bellows type reservoir 1. The reservoir 1 is expanded during the charging process to press the plunger 7. This increases the required upstream pressure head or the charging time, but also helps to discharge the fluid from the reservoir 1 during the discharging process and to maintain an elastic response of the bellows.

Fig. 15 schematically illustrates a sensor amplifier circuit of the test flow controller of Fig. 13.

As shown in Fig. 15, the amplifier circuit is used to utilize small outputs from the pressure sensor 5. The amplifier circuit includes two operational amplifiers. The first operational amplifier is a differential amplifier and the second operational amplifier is a single supply voltage feedback amplifier.

Fig. 16 shows how constitutional units of the test flow controller of Fig. 13 are controlled.

As depicted in Fig. 16, analog inputs from the sensor are inputted to an A/D interface 39 via the amplifying circuit. The A/D interface 39 is connected directly to a computer with an A/D card. Reference numeral 27 denotes a power driver.

Fig. 17 illustrates a control program sequence executed in the test flow controller of Fig. 13.

As shown in Fig. 17, the first step is a step of initializing an A/D converter. Then, the user selects a predetermined flow rate or a specific combination of an extension and a cycle rate of the bellows. Necessary calculations are performed to convert binary readings from the A/D card into values representing the current extension and the internal pressure in the bellows, and the values are displayed on the screen. Then, states of each valve are displayed, and data collected during the running of the equipment are displayed. The final procedure is used at the beginning and end of the program to remove any remaining liquid from the bellows before/after the run.

In this sequence, instantaneous flow rates of the fluid flowing into and flowing out from the bellows are calculated by using the difference in extension over the measured time period. The volume flow rate is calculated from the following equation:

Volume flow rate = $A \cdot \frac{\delta x}{\delta t} \cdot f$

Here, A is the cross-sectional area of the bellows, δx is the change in bellows extension, δt is the time between two samples, and f represents the variation of volume due to the influence of the convolutions.

The instantaneous flow rate data calculated for each sample in both the charging and discharging sequences are stored for each charging and discharging sample along with the values of pressure, position (namely, extension of the bellows) and cycle number for later review.

The results from testing of the system have been collected by a series of experiments during which control program was run with a range of input parameters. A simple assessment of the collected data yields to following conclusions:

a. The rate at which the control volume is charged (namely, the bellows expands) is entirely dependent upon the upstream pressure.

b. The discharging time does not increase linearly with extension due to the corresponding parabolic increase in restoring force.

Fig. 18 illustrates the relationship between the extension of the bellows and the pressure variation obtained from testing of the test flow controller of Fig. 13.

As could be expected, the extension of the bellows was directly proportional to the internal pressure in the bellows.

Fig. 19A illustrates the relationship between the time and the extension of the bellows during the charging process of the test flow controller of Fig. 13.

That is, Fig. 19A shows a process of reaching a target extension of 4mm at a constant inlet pressure.

Fig. 19B illustrates the relationship between the time and the pressure variation during the charging process of the test flow controller of Fig. 13.

Fig. 19C illustrates the relationship between the time and the instantaneous flow rate during the charging process of the test flow controller of Fig. 13.

The intermittent and sudden changes in flowrate as shown in Fig. 19C are due to an erroneous increase in δt, i.e. the sampling rate. Overall, however, the instantaneous flow rate decreases with time.

Fig. 20A illustrates the relationship between the time and the extension of the bellows during the discharging process of the test flow controller of Fig. 13.

The extension can be seen to drop just below the predetermined 'zero', which results from control inaccuracy.

Fig. 20B illustrates the relationship between the time and the pressure variation during the discharging process of the test flow controller of Fig. 13.

The residual pressure at the final sampling point indicates that the bellows has not been allowed to fully contract, using a larger offset in the control program in order to ensure consistency of the operation.

Fig. 20C illustrates the relationship between the time and the instantaneous flow rate during the discharging process of the test flow controller of Fig. 13.

The plot of data on instantaneous flowrate is once again rather unstable due to the rude nature of the calculation used in its generation. Overall, however, it shows a trend following that of the bellows extension.

Fig. 21 illustrates the relationship between the cycle rate and the flow rate obtained from testing of the test flow controller of Fig. 13.

As shown in Fig. 21, the maximum extensions of the reservoir 1 were set to be 0.5mm, 1mm, 2mm, 3mm and 4mm in the test, respectively. The set of data points for each sample are discrete, but the fitted curve aids to show the system performance. At the small extensions, the cycle rate has a steady effect on the overall flow rate and the outputs of the system vary as expected with increasing extension. For larger extension, however, the effects of increasing the cycle rate are limited to the finite time taken to perform each cycle.

Fig. 22 illustrates flow rate errors between the target flow rate and the measured flow rate obtained from testing of the test flow controller of Fig. 13.

Flow rate samples for stipulated extensions and cycle rate were used in conjunction with the target flow rate calculated from the parameters. As illustrated in Fig. 22, as the extension increases, inaccuracy in the metered flow rate decreases steadily between 40 and 10%. At the extension of 4mm, the increased error of 20% is likely to be due to the inability of the system to achieve the required cycle rate.

Fig. 23 illustrates the relationship between the inflow pressure into the reservoir and the elapsed time for performing each charging process obtained from testing of the test flow controller of Fig. 13.

Fig. 24A illustrates the relationship between the extension of the reservoir 1 and the instantaneous flow rate (namely, the rate of flow into the bellows in charging) during the charging process of the test flow controller of Fig. 13. The three sets of data were collected from the cycles in which the bellows extensions were limited to 1mm, 2.5mm and 4mm, respectively. As the bellows expanded, the flow rate of the fluid flowing into the bellows decreased. This results from increase of the internal pressure opposing the flow of the fluid.

Fig. 24B illustrates the relationship between the extension of the reservoir 1 and the instantaneous flow rate (namely, the rate of flow out of the bellows in discharging) during the discharging process of the test flow controller of Fig. 13. The extension and pressure decrease during the discharging process of the bellows, and thus the outflow flow rate decreases. The interesting point is that the flow rate is greater at the start of the discharging process than at the beginning of the charging process.

Till now, we have constructed the test flow controller and have evaluated the results from testing it. Here, we should note errors in the constitutional units used in the test and errors resulted from outputs of the position sensors. Such errors cannot be overcome through simple calibration but can be overcome through more precise construction and more accurate calibration.

The aim of the test was to design, fabricate and test the time based flow controller which can accurately measure and control the flow rate of the incompressible fluid. In the test, the incompressible fluid was used as working fluid, and the flow rate was successfully measured and controlled in the range of 0 to 70ml/min with an accuracy of ±10% for certain level.

The main drawback to the system lies on the rate at which the data samples are taken from the sensor. This means that the extension of the bellows is allowed to overshoot the maximum and minimum points. Such a problem can be easily resolved by using a personal computer with a faster processor and possibly a control program that monitors not just the position, but can also predict the point at which the required extension is reached by looking at the rate of change in position or an instantaneous flow rate. Further, purely mechanical faults with the valves and pressure regulator can be solved by selecting those suitable for pressurized hydraulic use. A reduction in the complexity of equipment would also help to minimize upstream pressure requirements and losses in the system, enabling operation at atmospheric pressure.

The time based flow controller for incompressible fluid in accordance with the present invention can be used and developed in high compatibility with the time based mass flow controller for compressible fluid in the inventor's previous patent application.

Although the preferred embodiments of the present invention have been described, it is understood that the present invention should not be limited to these preferred embodiments but various changes and modifications can be made by one skilled in the art within the spirit and scope of the present invention as hereinafter claimed.

What is claimed is:

1. A time based flow controller for incompressible fluid, comprising:

at least one reservoir, the volume of each reservoir changing in a cycle;

at least one inlet valve, each inlet valve opening/closing an inlet of a corresponding reservoir;

at least one outlet valve, each outlet valve opening/closing an outlet of a corresponding reservoir; and

a controller opening the inlet valve to allow the incompressible fluid to flow into the reservoir when the outlet valve is in a closed state, opening the outlet valve to allow the incompressible fluid to flow out from the reservoir when the inlet valve is in a closed state, and controlling the number of opening/closing loops of the inlet valve and the outlet valve per unit time and/or mass/volume of the incompressible fluid stored and discharged at the reservoir per unit opening/closing loop of the inlet valve and the outlet valve, so that the controller may control the mass/volume flow rate of the outflow incompressible fluid from the reservoir.

2. The time based flow controller as claimed in claim 1, comprising a volume sensor for sensing a volume of the reservoir,

wherein the controller opens the inlet valve when the volume of the reservoir is a reference minimum volume, closes the inlet valve when the volume of the reservoir is a reference maximum volume, closes the outlet valve when the volume of the reservoir is the reference minimum volume, and opens the outlet valve when the volume of the reservoir is the reference maximum volume, the controller controlling the reference minimum volume and/or the reference maximum volume of the reservoir as control variables, so that the controller may control the mass/volume flow rate of the outflow incompressible fluid from the reservoir.

3. The time based flow controller as claimed in claim 1, comprising a volume sensor for sensing a volume of the reservoir, and a time sensor for measuring time periods between an opening and a closing of the inlet valve and the outlet valve,

wherein the controller closes the outlet valve and opens the inlet valve when the volume of the reservoir is a reference minimum volume, the controller controlling a time period from an opening to a closing of the inlet valve and a time period from a closing to an opening of the outlet valve as control variables, so that the controller may control the mass/volume flow rate of the outflow incompressible fluid from the reservoir.

4. The time based flow controller as claimed in claim 1, comprising a volume sensor for sensing a volume of the reservoir, and a time sensor for measuring time periods between an opening and a closing of the inlet valve and the outlet valve,

wherein the controller closes the inlet valve and opens the outlet valve when the volume of the reservoir is a reference maximum volume, the controller controlling a time period from a closing to an opening of the inlet valve and a time period from an opening to a closing of the outlet valve as control variables, so that the controller may control the mass/volume flow rate of the outflow incompressible fluid from the reservoir.

5. The time based flow controller as claimed in any one of claims 2 to 4, comprising a pressure sensor for sensing pressure in the reservoir,

wherein the controller determines values of the control variables based on the pressure of the incompressible fluid in the reservoir sensed by the pressure sensor.

6. The time based flow controller as claimed in claim 1, comprising a pressure

sensor for sensing pressure in the reservoir,

wherein the controller opens the inlet valve when the pressure in the reservoir is a reference minimum pressure, closes the inlet valve when the pressure in the reservoir is a reference maximum pressure, closes the outlet valve when the pressure in the reservoir is the reference minimum pressure, and opens the outlet valve when the pressure in the reservoir is the reference maximum pressure, the controller controlling the reference minimum pressure and/or the reference maximum pressure in the reservoir as control variables, so that the controller may control the mass/volume flow rate of the outflow incompressible fluid from the reservoir.

7. The time based flow controller as claimed in claim 1, comprising a pressure sensor for sensing pressure in the reservoir, and a time sensor for measuring time periods between an opening and a closing of the inlet valve and the outlet valve,

wherein the controller closes the outlet valve and opens the inlet valve when the pressure in the reservoir is a reference minimum pressure, the controller controlling a time period from an opening to a closing of the inlet valve and a time period from a closing to an opening of the outlet valve as control variables, so that the controller may control the mass/volume flow rate of the outflow incompressible fluid from the reservoir.

8. The time based flow controller as claimed in claim 1, comprising a pressure sensor for sensing pressure in the reservoir, and a time sensor for measuring time periods between an opening and a closing of the inlet valve and the outlet valve,

wherein the controller closes the inlet valve and opens the outlet valve when the pressure in the reservoir is a reference maximum pressure, the controller controlling a time period from a closing to an opening of the inlet valve and a time period from an opening to a closing of the outlet valve as control variables, so that the controller may control the mass/volume flow rate of the outflow incompressible fluid from the reservoir.

9. The time based flow controller as claimed in any one of claims 2 to 4 and 6 to 8, comprising a temperature sensor for sensing temperature in the reservoir,

wherein the controller determines values of the control variables based on the temperature of the incompressible fluid in the reservoir sensed by the temperature sensor.

10. The time based flow controller as claimed in any one of claims 2 to 4 and 6 to 8, wherein the controller provides a time delay between a closing of the inlet valve and an opening of the outlet valve and/or between a closing of the outlet valve and an opening of the inlet valve, the controller controlling the length of the time delay as a control variable, so that the controller may control the mass/volume flow rate of the outflow incompressible fluid from the reservoir.

11. The time based flow controller as claimed in claim 1, wherein the controller provides a time delay between a closing of the inlet valve and an opening of the outlet valve and/or between a closing of the outlet valve and an opening of the inlet valve, the controller controlling the length of the time delay as a control variable, so that the controller may control the mass/volume flow rate of the outflow incompressible fluid from the reservoir.

12. The time based flow controller as claimed in any one of claims 1 to 4 and 6 to 8 and 11, wherein the reservoir is a bellows type reservoir.

13. The time based flow controller as claimed in claim 12, wherein the bellows

type reservoir has one end to be fixed and the other end to be expandable /contractible, and the volume sensor is installed at the other end of the reservoir to sense the position of the other end of the reservoir.

14. The time based flow controller as claimed in claim 12, wherein the reservoir comprises a spring means operated against the volume expansion of the reservoir.

15. The time based flow controller as claimed in any one of claims 1 to 4, 6 to 8 and 11, wherein the reservoir is a flexible membrane type reservoir.

16. The time based flow controller as claimed in any one of claims 1 to 4, 6 to 8 and 11, wherein the reservoir is a piston-cylinder type reservoir.

17. The time based flow controller as claimed in claim 16, wherein the reservoir comprises a spring means operated onto the piston against the volume expansion of the reservoir.

18. The time based flow controller as claimed in claim 16, wherein the reservoir comprises a mass weight operated toward the piston against the volume expansion of the reservoir.

19. The time based flow controller as claimed in any one of claims 1 to 4, 6 to 8 and 11, comprising a pressure regulator at the upstream side of an inlet of the reservoir, the pressure regulator keeping the pressure of the incompressible fluid flowing into the reservoir constant.

20. The time based flow controller as claimed in any one of claims 1 to 4, 6 to 8

and 11, comprising a buffer at the downstream side of an outlet of the reservoir, the buffer having a larger volume than the reservoir.

21. The time based flow controller as claimed in claim 20, wherein the buffer is installed lower than the reservoir.

22. The time based flow controller as claimed in claim 20, comprising a first flow resistance valve at the downstream side of an outlet of the buffer to minimize perturbation of the outflow fluid from the buffer.

23. The time based flow controller as claimed in claim 22, comprising a second flow resistance valve at the upstream side of an inlet of the buffer having a lower flow resistance than the first flow resistance valve, the second flow resistance valve minimizing perturbation of the outflow fluid from the buffer along with the first flow resistance valve.

24. The time based flow controller as claimed in claim 22 or 23, wherein the flow resistance valve is a needle valve.

25. The time based flow controller as claimed in claim 20, wherein the buffer has a variable volume.

26. The time based flow controller as claimed in claim 25, wherein the buffer comprises a spring means operated against the pressure increase in the buffer.

27. The time based flow controller as claimed in any one of claims 1 to 4, 6 to 8 and 11, wherein at least two reservoirs are installed in parallel, each of the inlet valves

and the outlet valves of the respective reservoirs having different opening/closing points in time.

28. The time based flow controller as claimed in claim 27, comprising a buffer at the downstream side of an outlet of the reservoir, the buffer having a larger volume than the reservoir.

29. A method for controlling a flow rate of incompressible fluid using a time based flow controller for incompressible fluid including at least one reservoir, the volume of each reservoir changing in a cycle, at least one inlet valve, each inlet valve opening/closing an inlet of a corresponding reservoir, and at least one outlet valve, each outlet valve opening/closing an outlet of a corresponding reservoir, the method comprising:

opening the inlet valve to allow the incompressible fluid to flow into the reservoir when the outlet valve is in a closed state, opening the outlet valve to allow the incompressible fluid to flow out from the reservoir when the inlet valve is in a closed state, and controlling the number of opening/closing loops of the inlet valve and the outlet valve per unit time and/or mass/volume of the incompressible fluid stored and discharged at the reservoir per unit opening/closing loop of the inlet valve and the outlet valve, so as to control the mass/volume flow rate of the outflow incompressible fluid from the reservoir.

Fig. 1

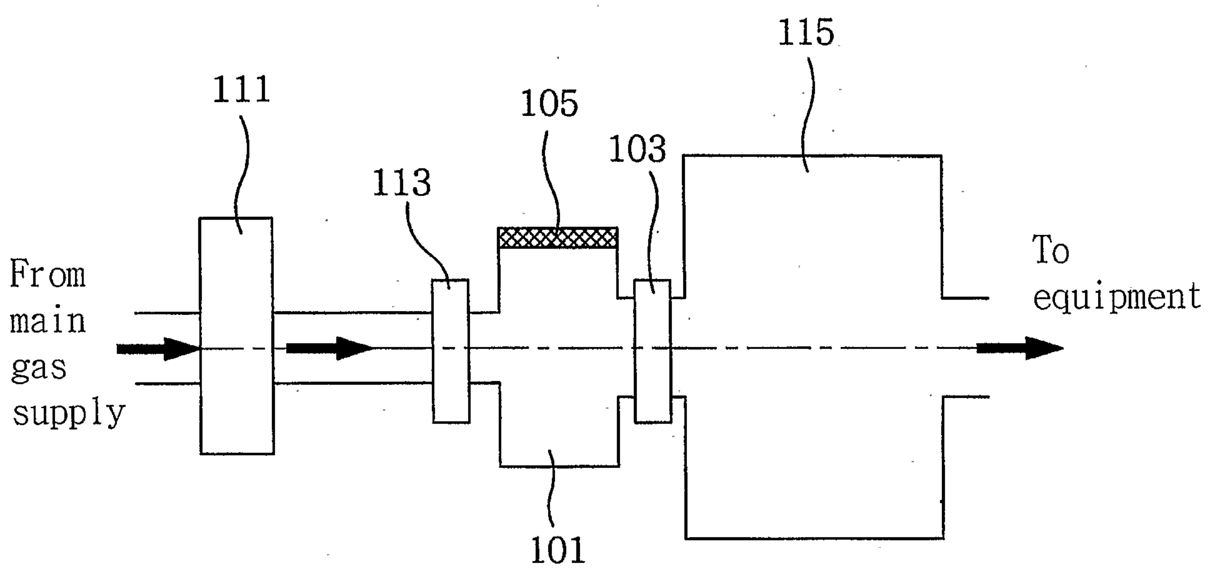


Fig. 2A

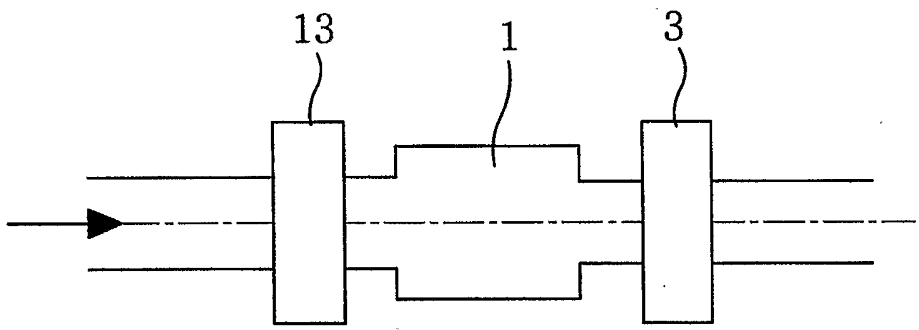


Fig. 2B

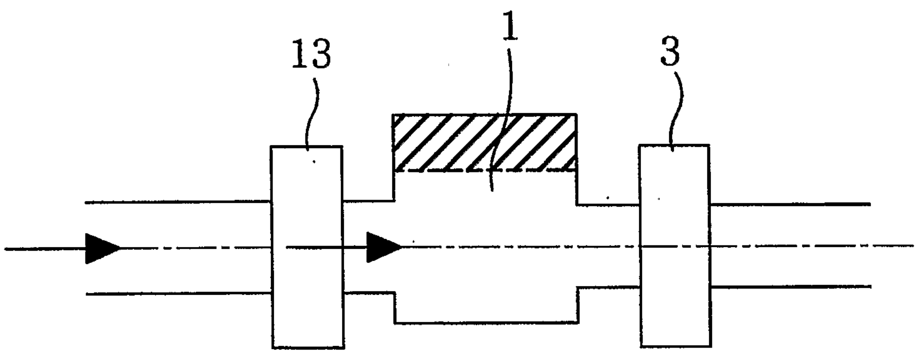


Fig. 2C

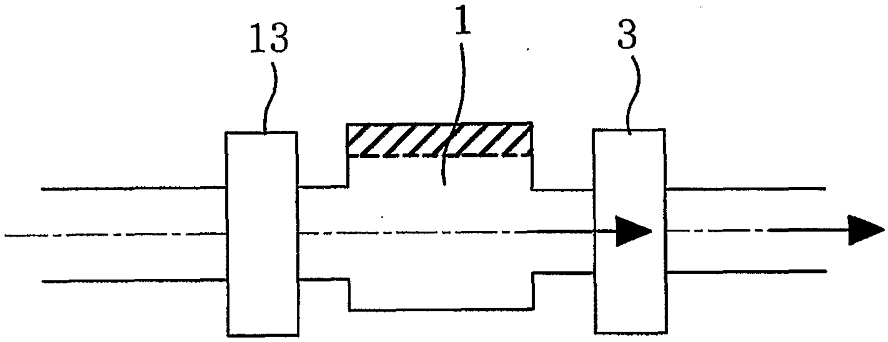


Fig. 3A

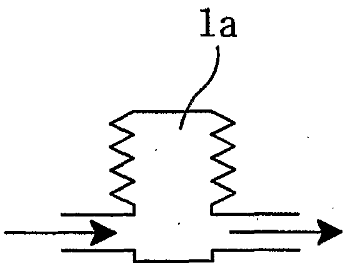


Fig. 3B

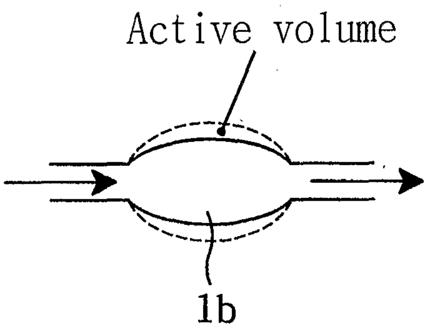


Fig. 3C

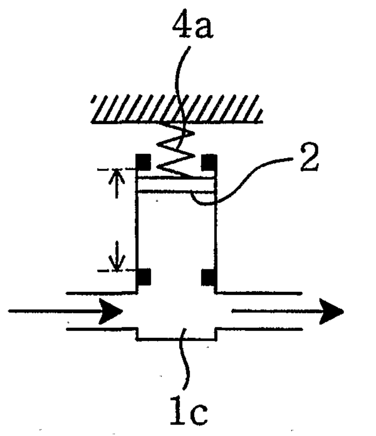


Fig. 3D

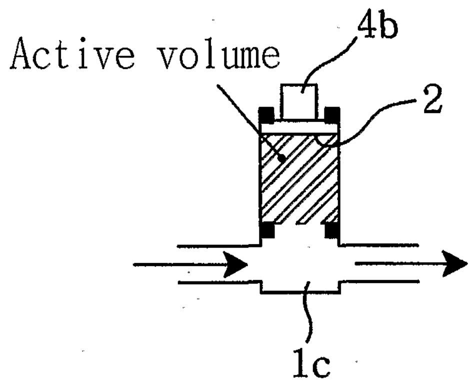


Fig. 4A

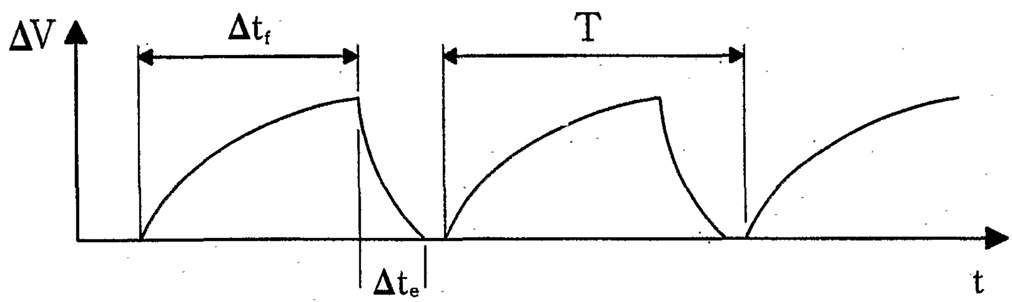


Fig. 4B

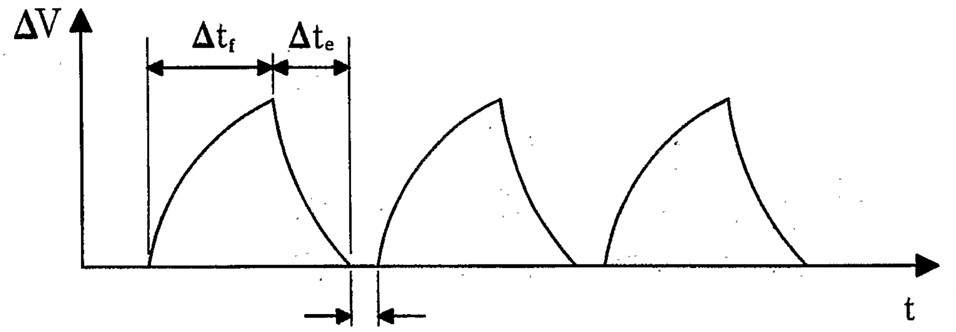


Fig. 4C

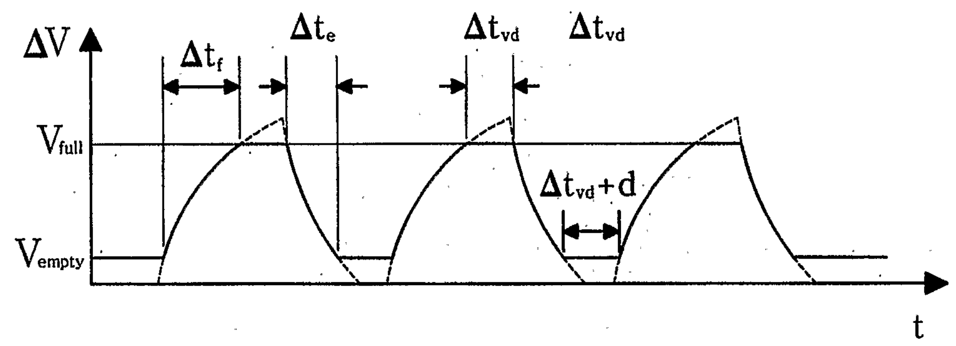


Fig. 5

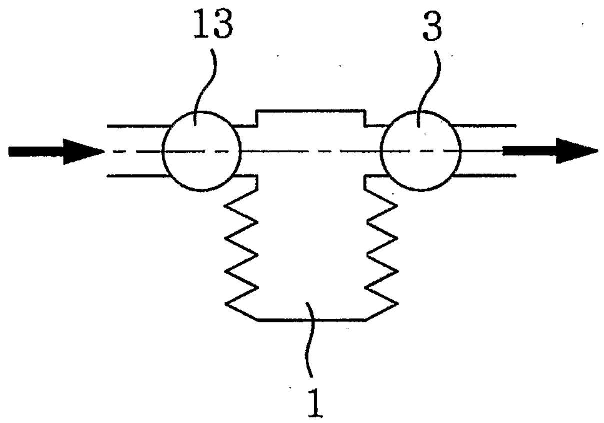


Fig. 6

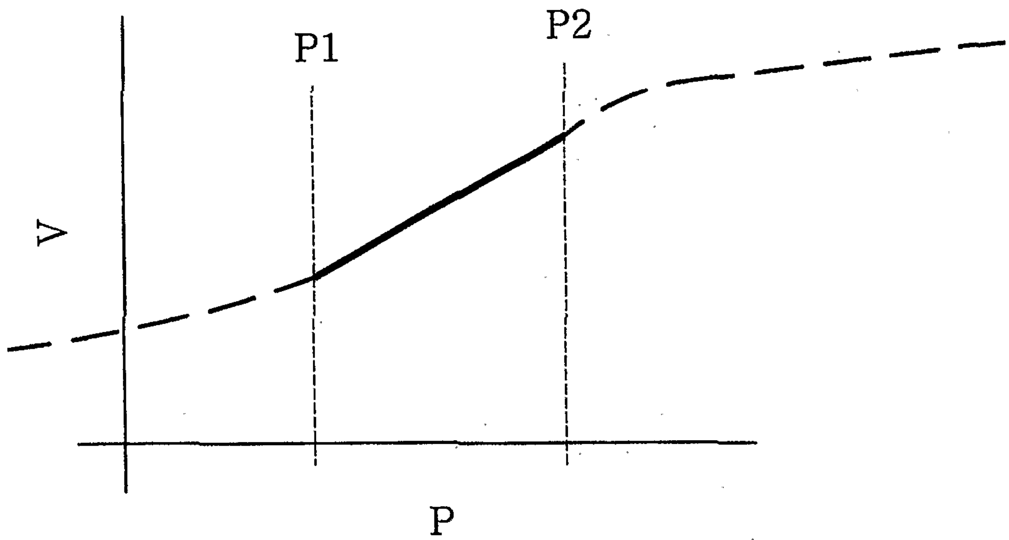


Fig. 7

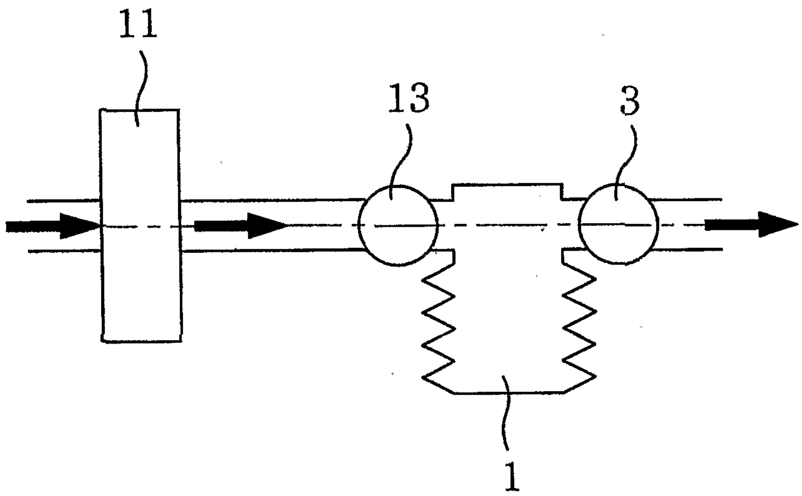


Fig. 8

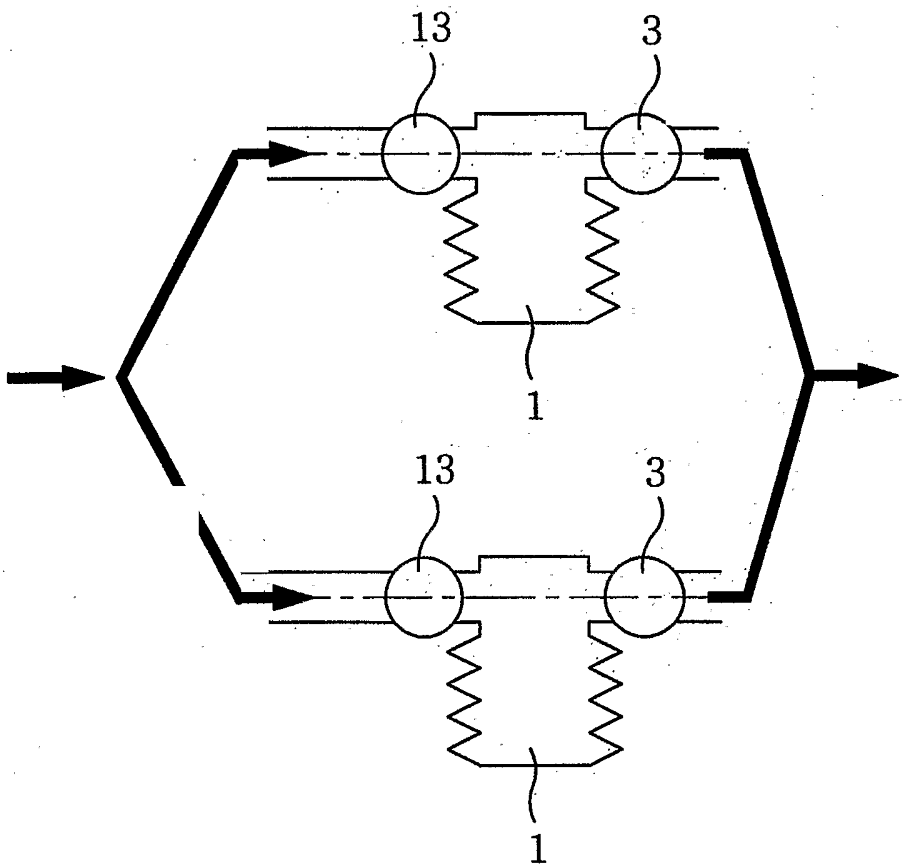


Fig. 9

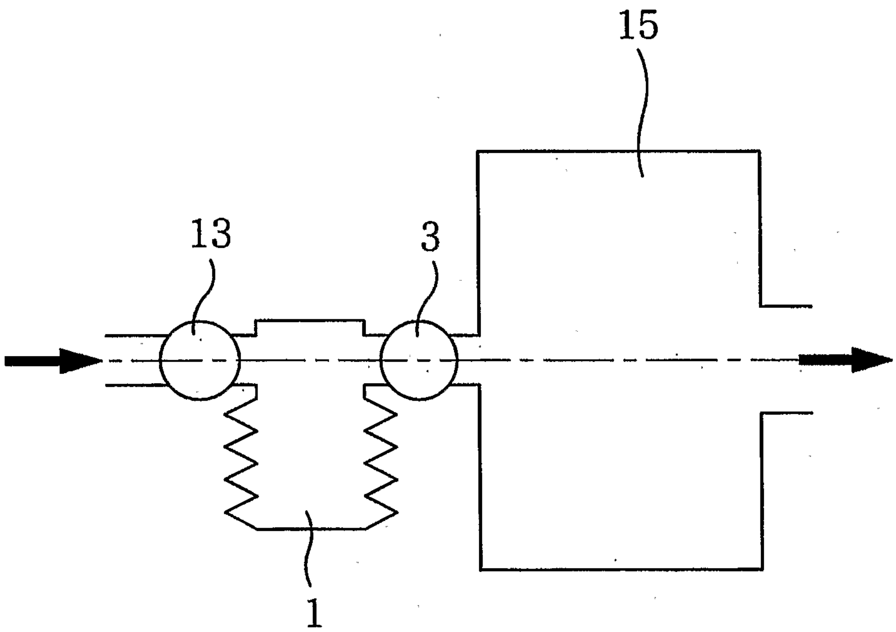


Fig. 10A

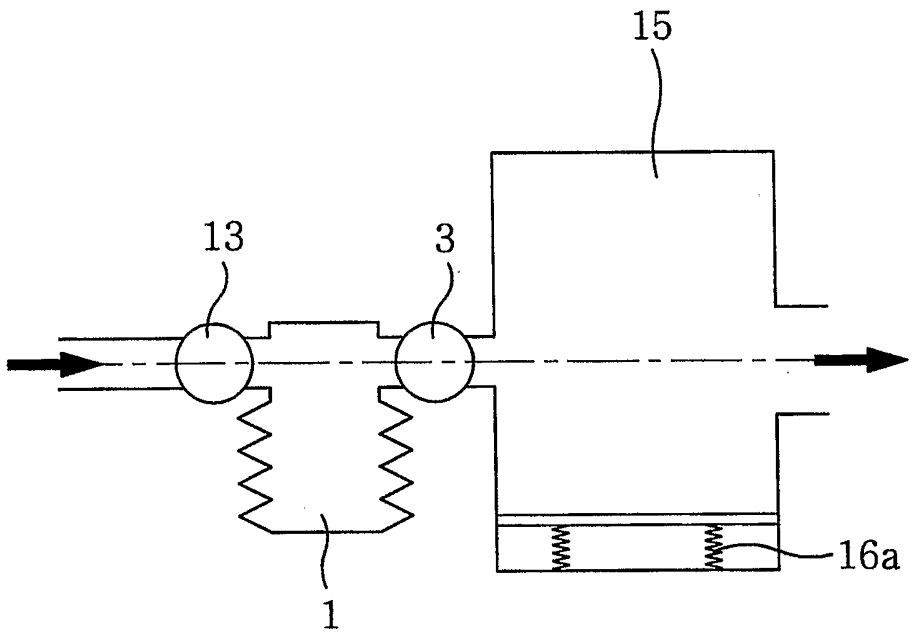


Fig. 10B

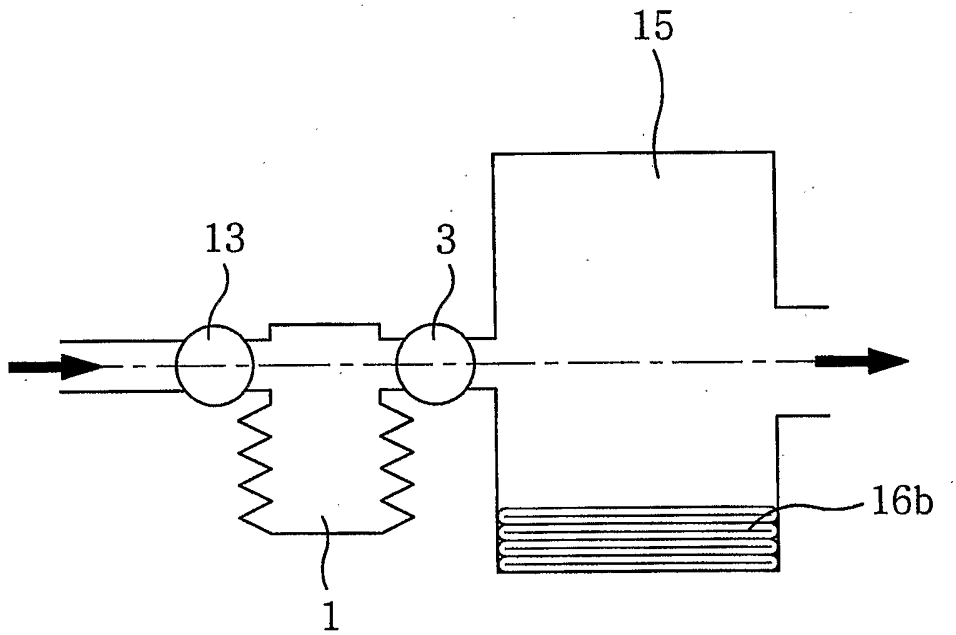


Fig. 11

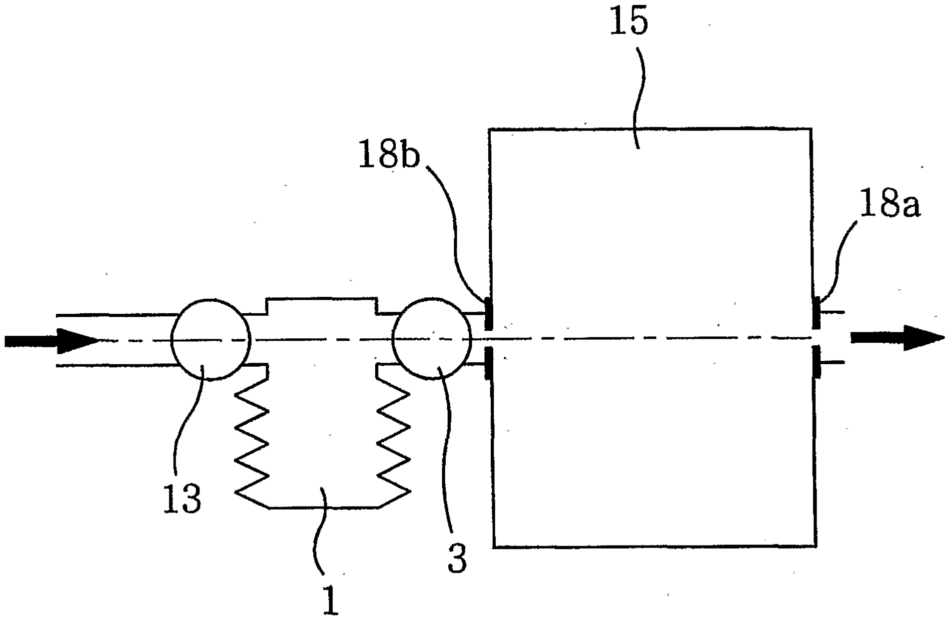


Fig. 12

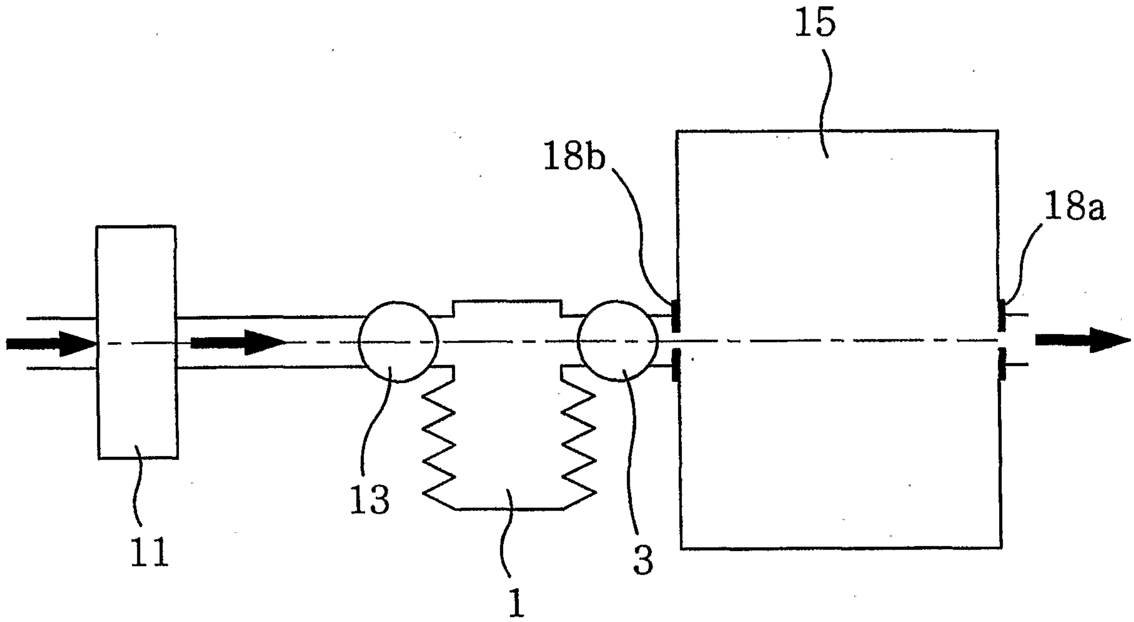


Fig. 13

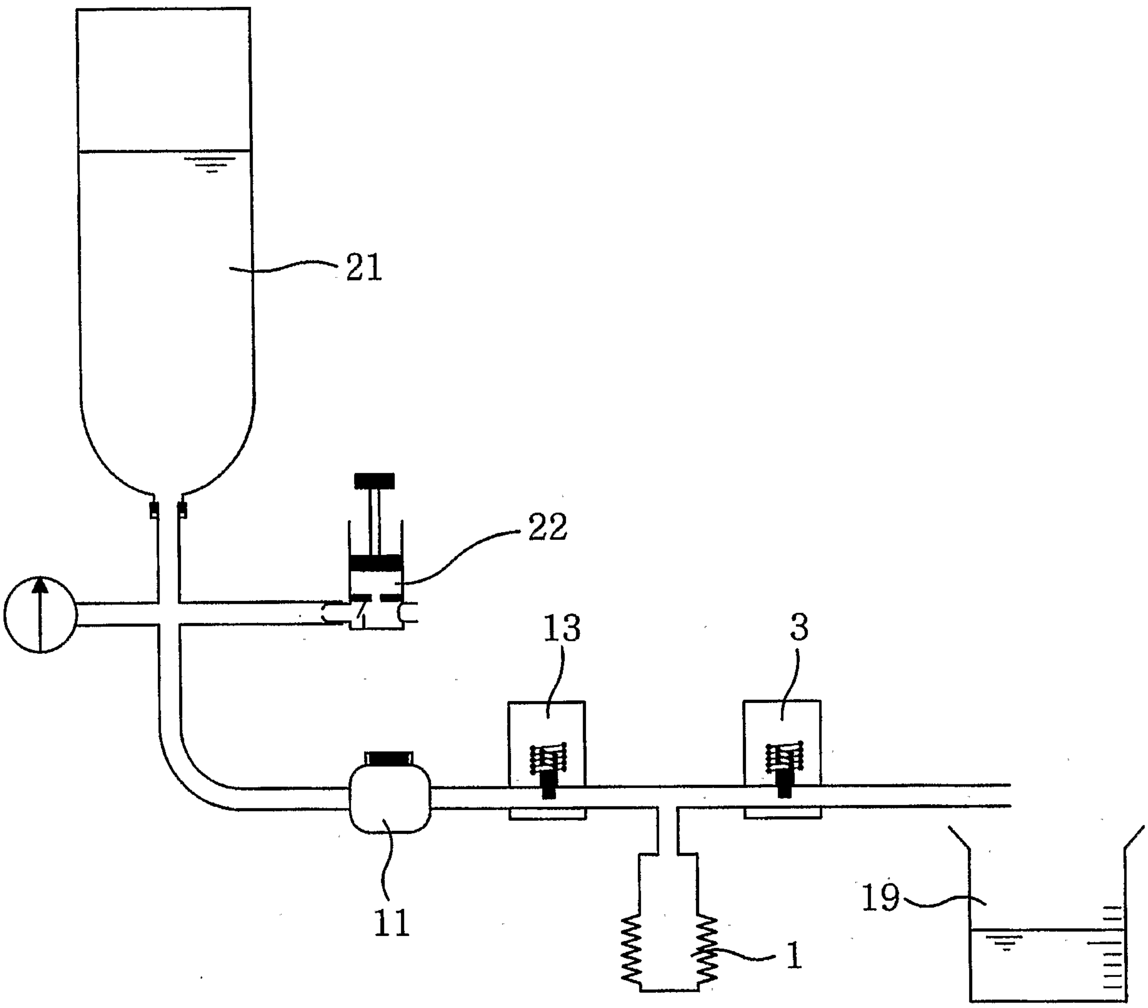


Fig. 14

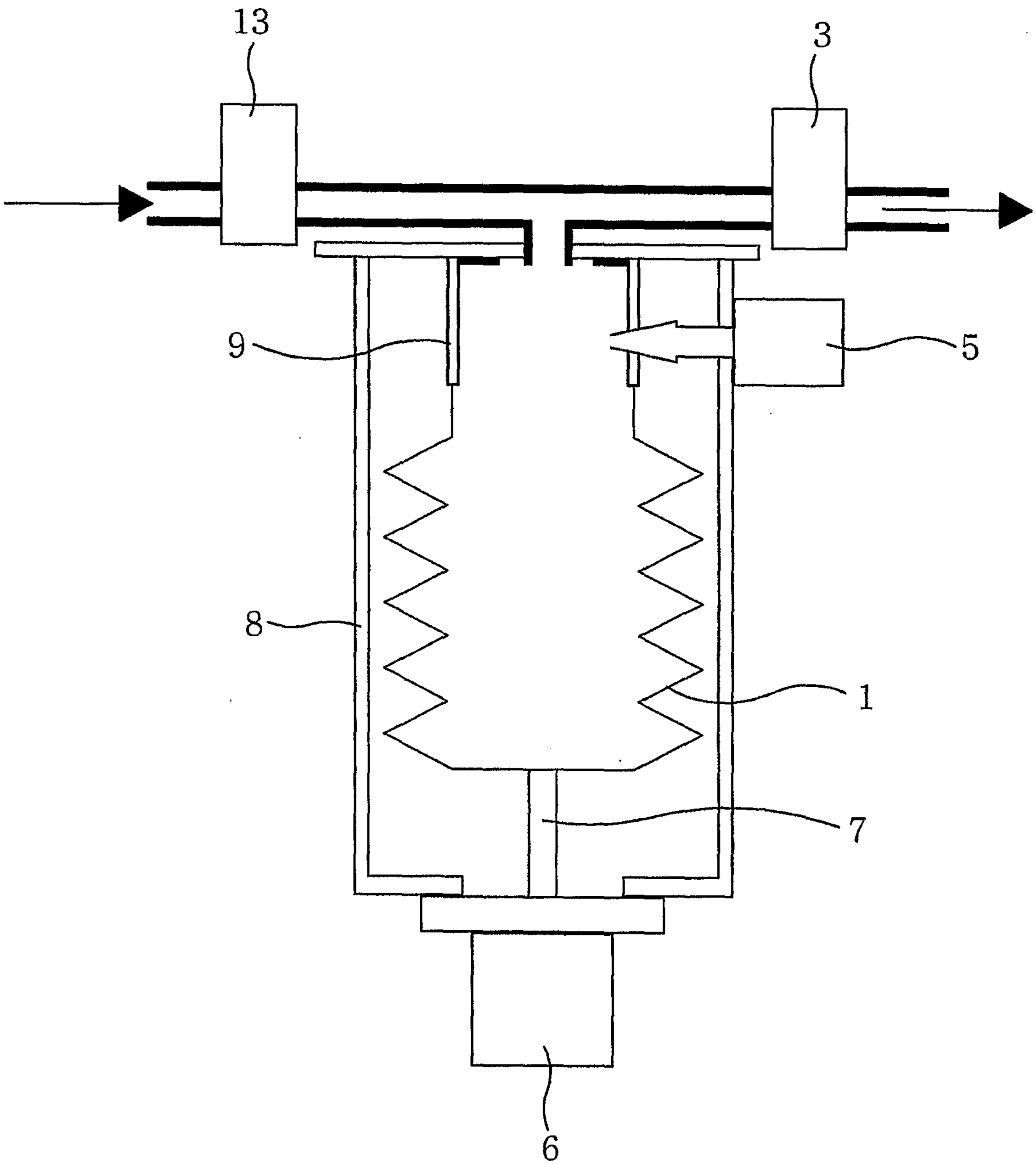


Fig. 15

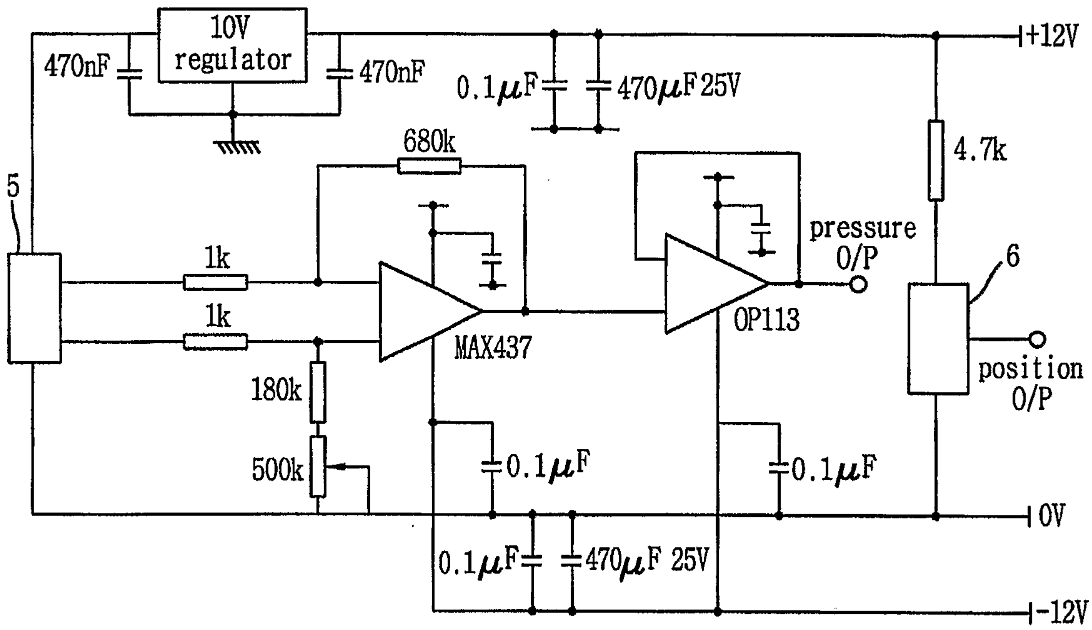

10V
regulator
470nF
470nF
0.1μF
470μF 25V
+12V
680k
4.7k
5
1k
1k
MAX437
OP113
pressure
O/P
6
position
O/P
180k
500k
0.1μF
0.1μF
0V
0.1μF
470μF 25V
-12V

Fig. 16

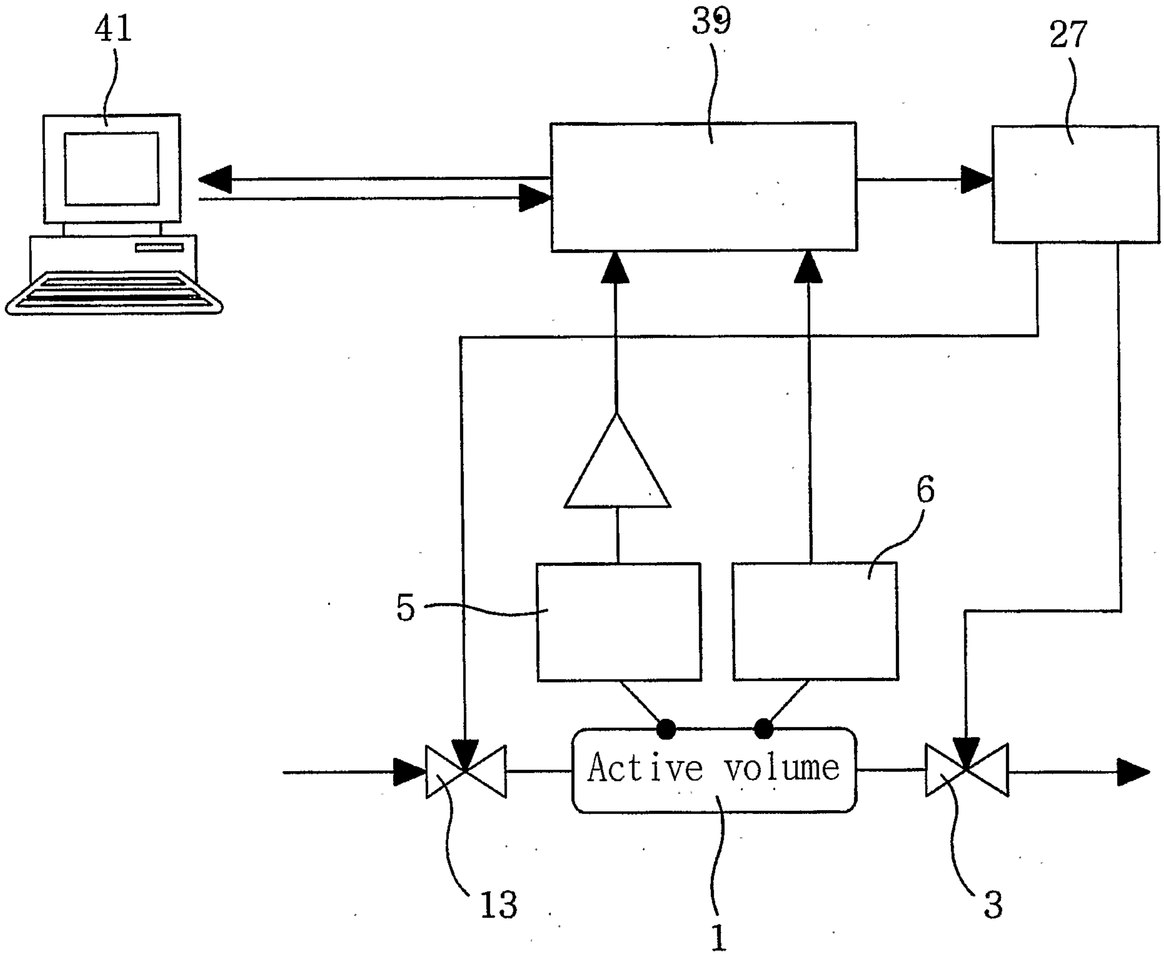
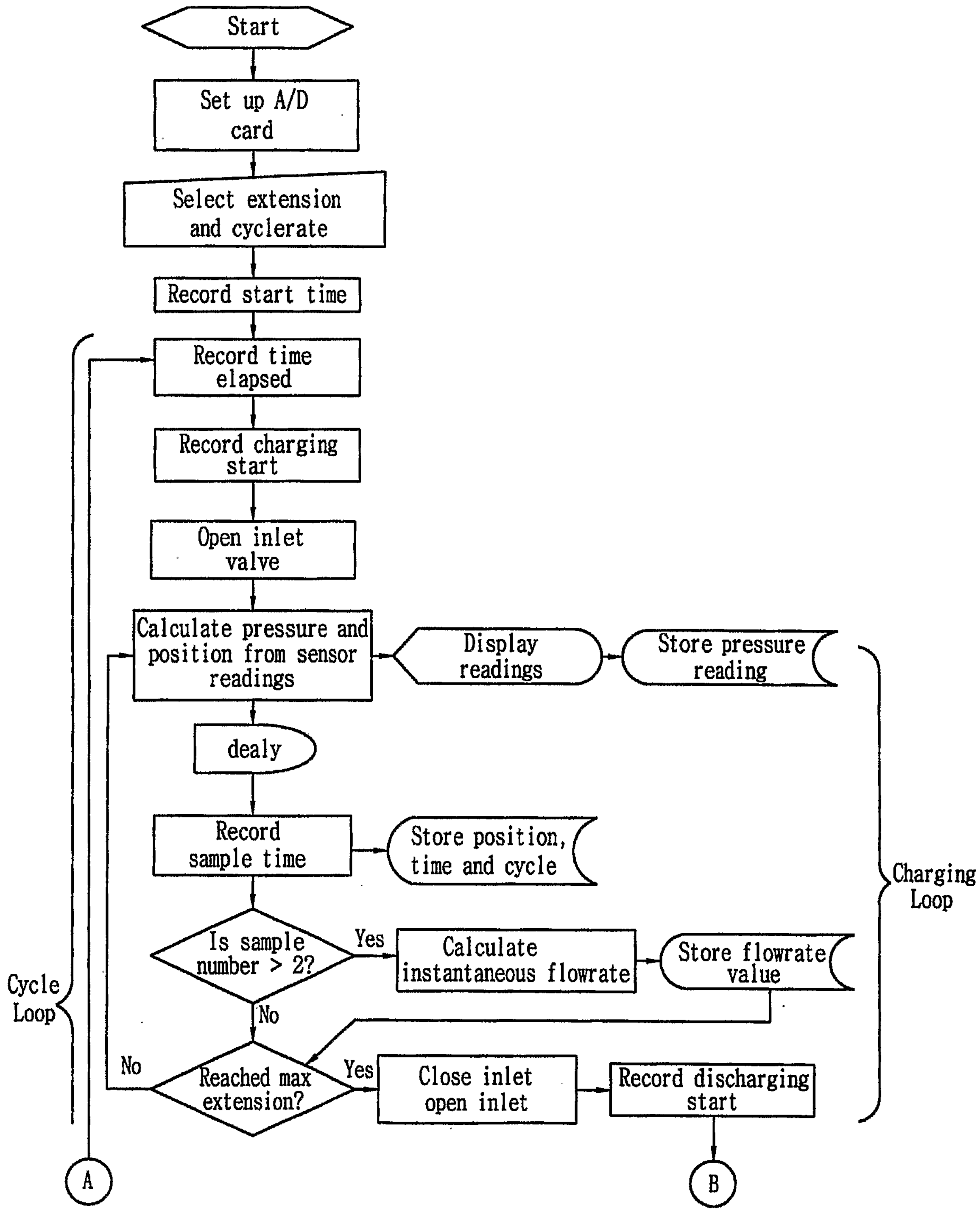


Fig. 17


Start
Set up A/D card
Select extension and cyclerate
Record start time
Record time elapsed
Record charging start
Open inlet valve
Calculate pressure and position from sensor readings
Display readings
Store pressure reading
dealy
Record sample time
Store position, time and cycle
Is sample number > 2?
Yes
Calculate instantaneous flowrate
Store flowrate value
No
Reached max extension?
No
Yes
Close inlet open inlet
Record discharging start
Cycle Loop
Charging Loop
A
B

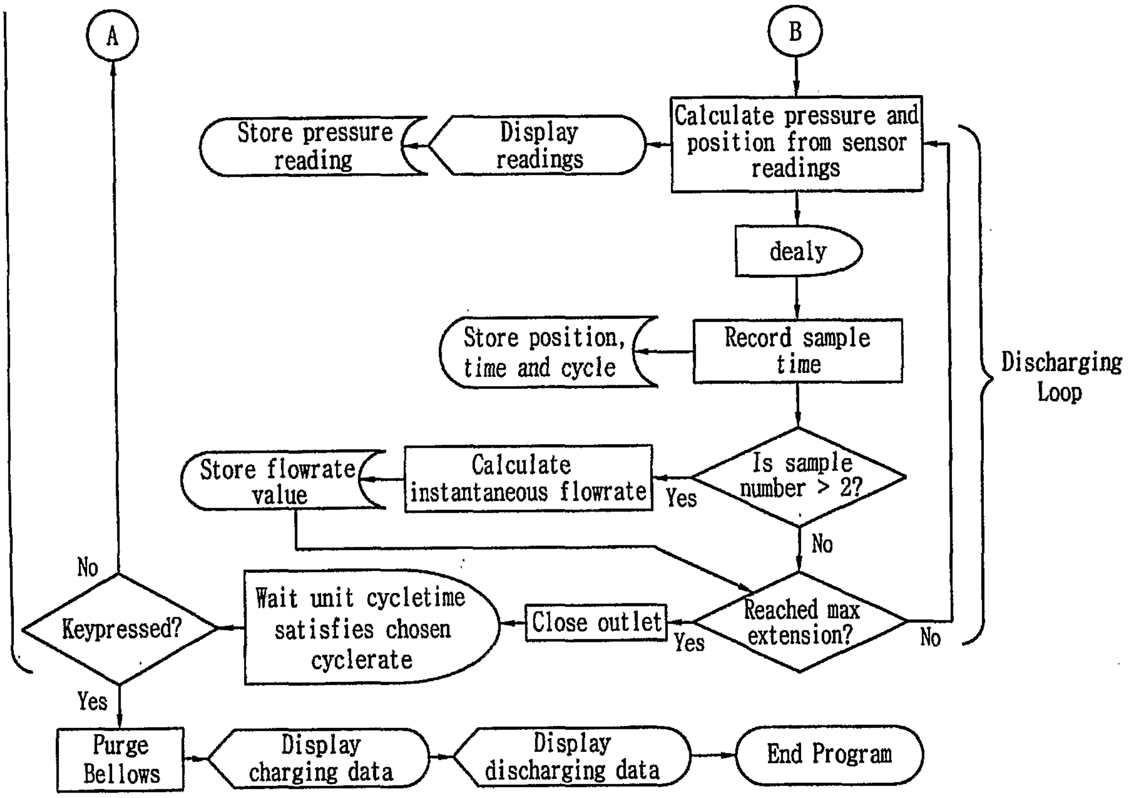

A
B
Calculate pressure and position from sensor readings
Display readings
Store pressure reading
dealy
Record sample time
Store position, time and cycle
Discharging Loop
Is sample number > 2?
Yes
Calculate instantaneous flowrate
Store flowrate value
No
Reached max extension?
No
Yes
Close outlet
Wait unit cycletime satisfies chosen cyclerate
Keypressed?
No
Yes
Purge Bellows
Display charging data
Display discharging data
End Program

Fig. 18

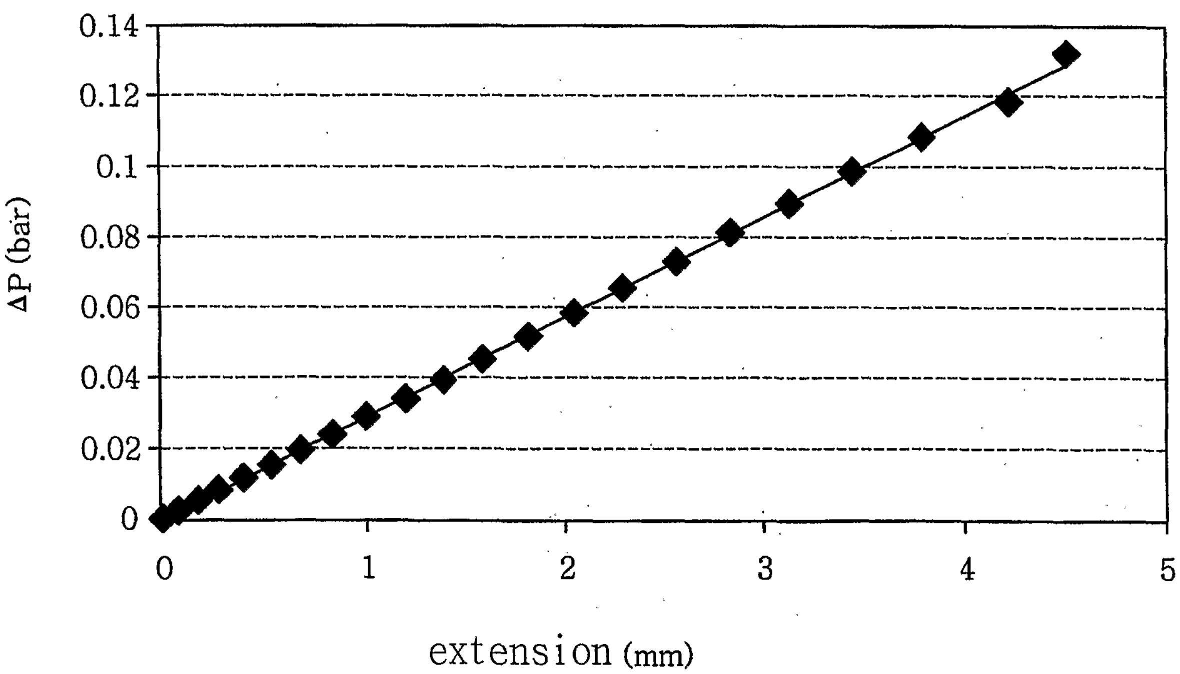

ΔP (bar)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
1
2
3
4
5
extension (mm)

Fig. 19A

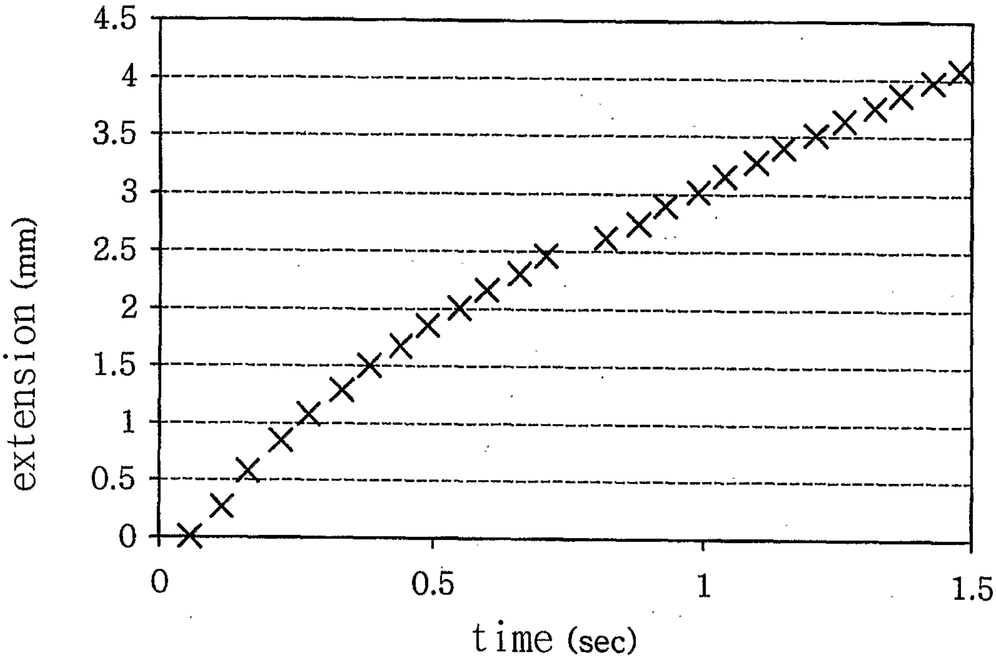


Fig. 19B

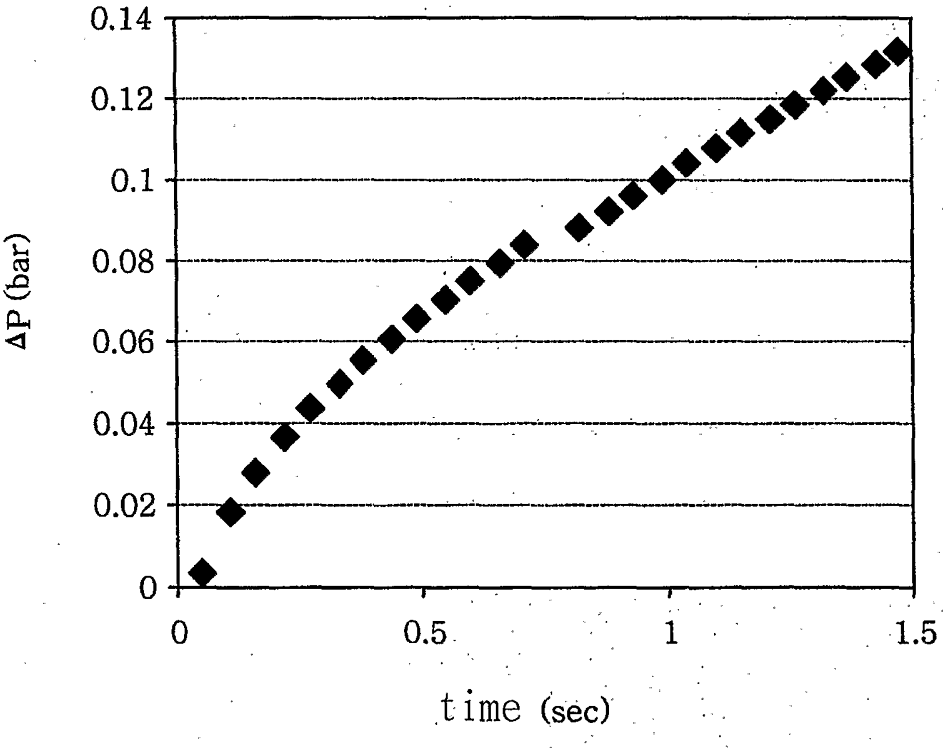


Fig. 19C

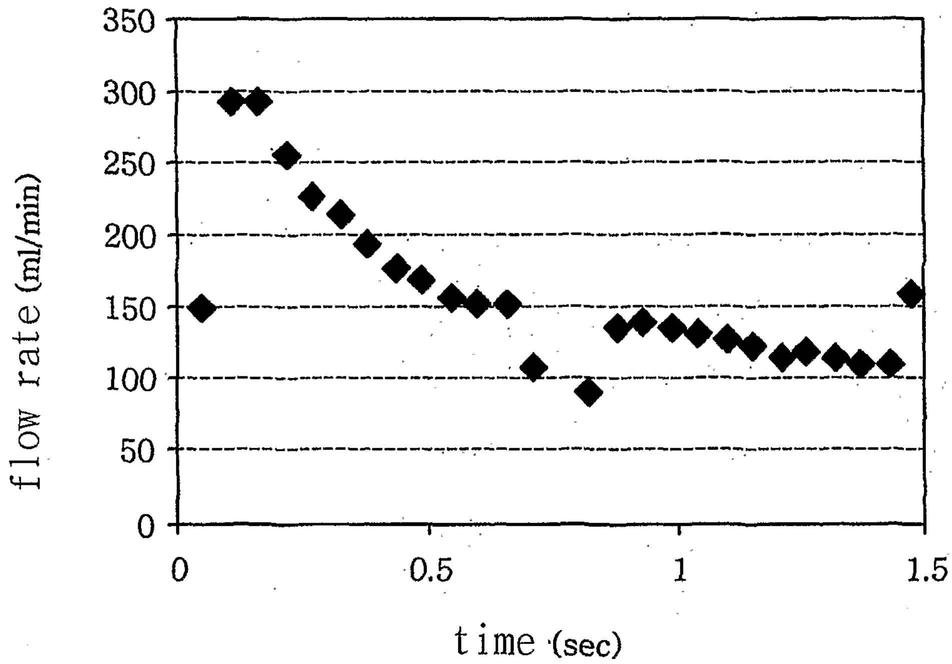


Fig. 20A

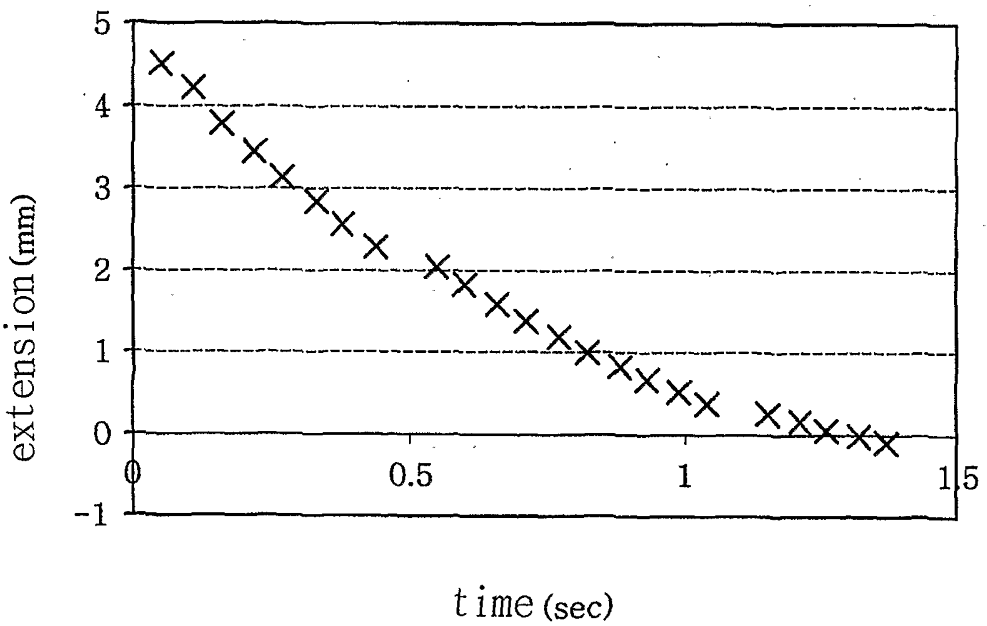


Fig. 20B

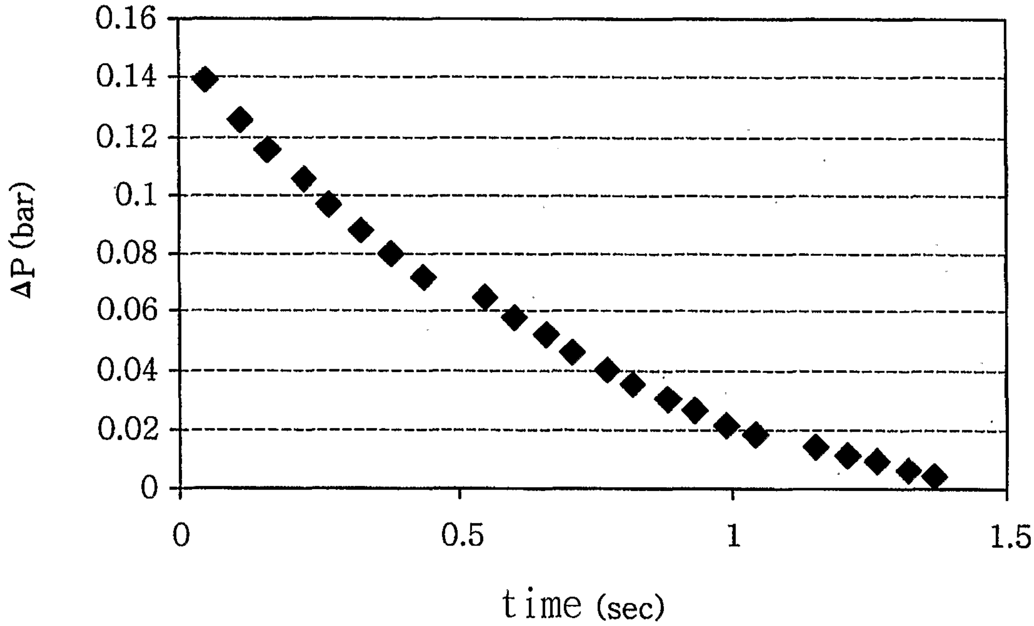


Fig. 20C

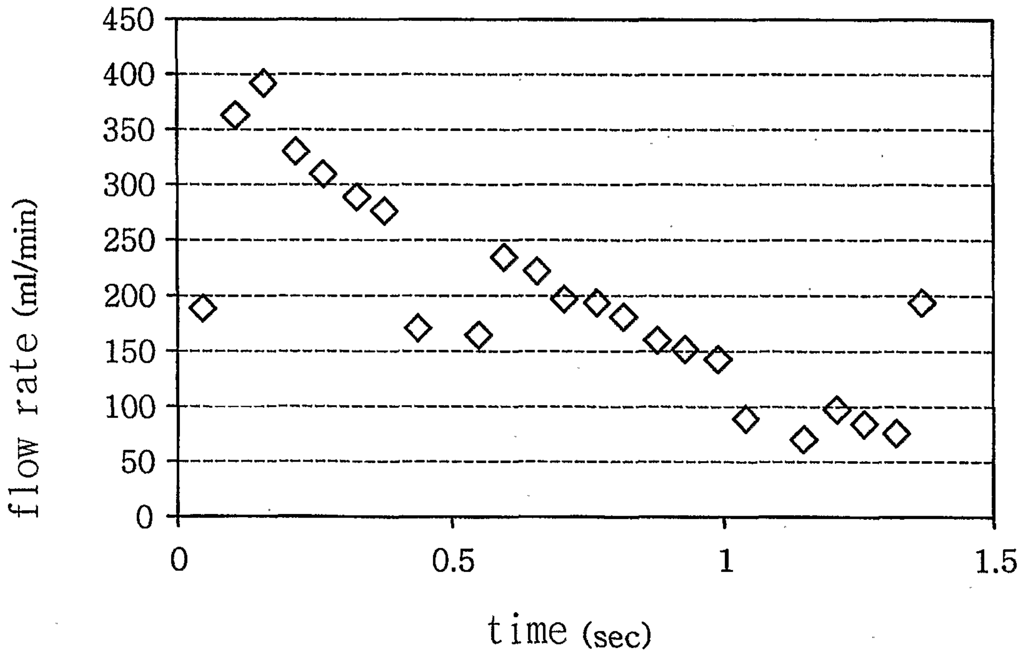


Fig. 21

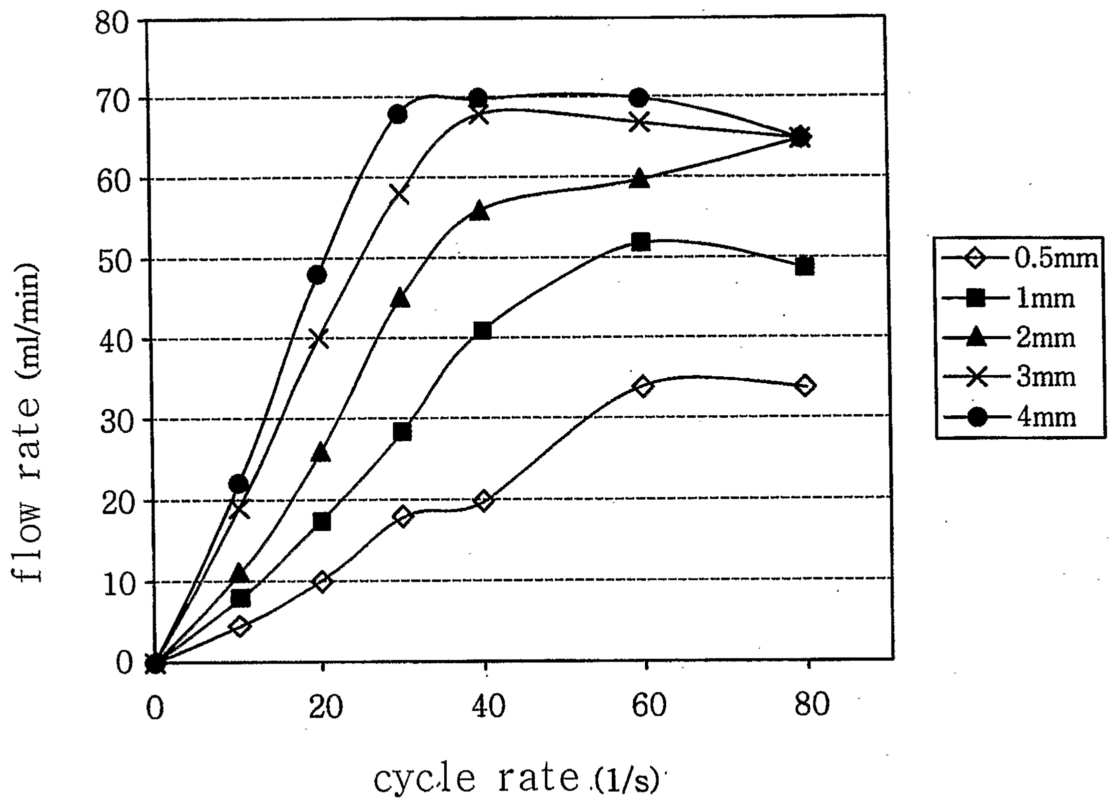

flow rate (ml/min)
80
70
60
50
40
30
20
10
0
0
20
40
60
80
cycle rate (1/s)
0.5mm
1mm
2mm
3mm
4mm

Fig. 22

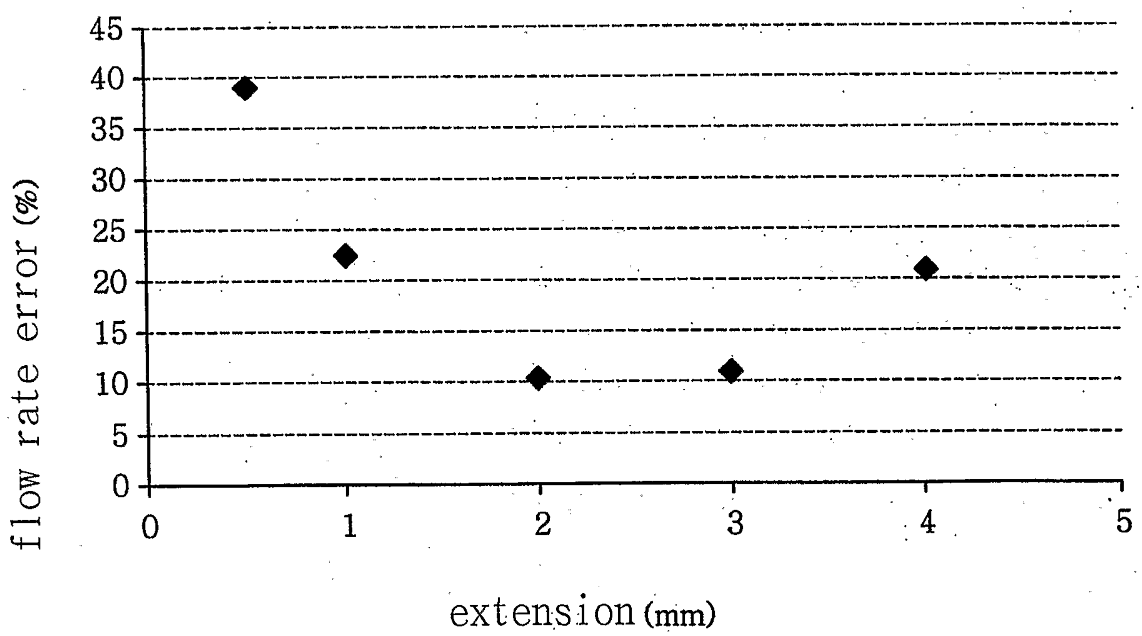

flow rate error (%)
45
40
35
30
25
20
15
10
5
0
0
1
2
3
4
5
extension (mm)

Fig. 23

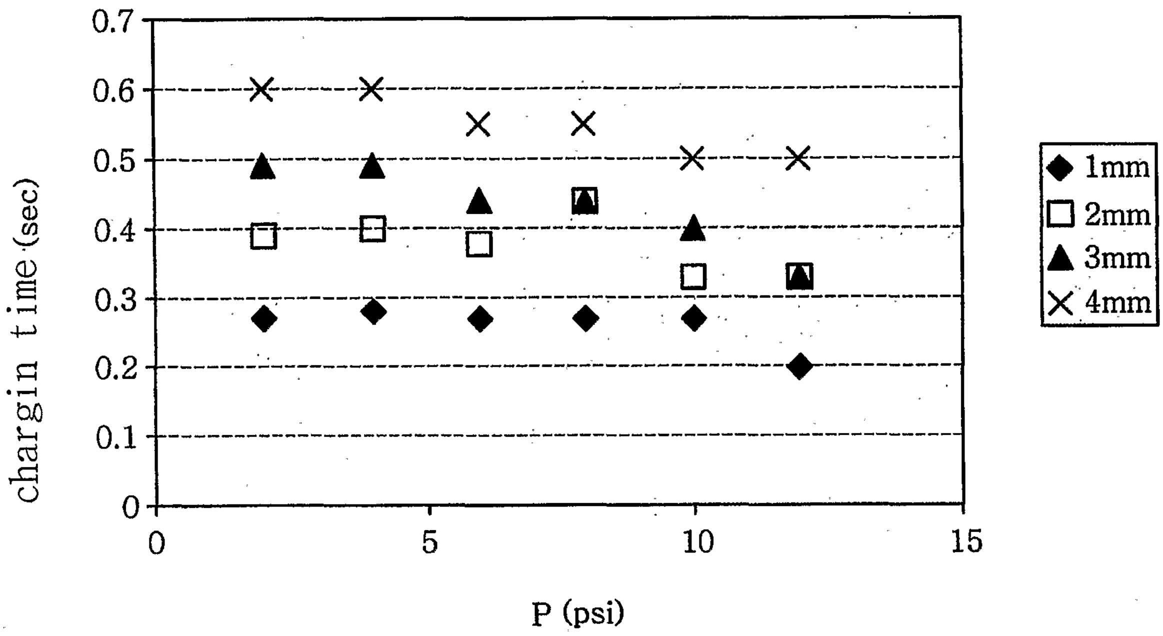


Fig. 24A

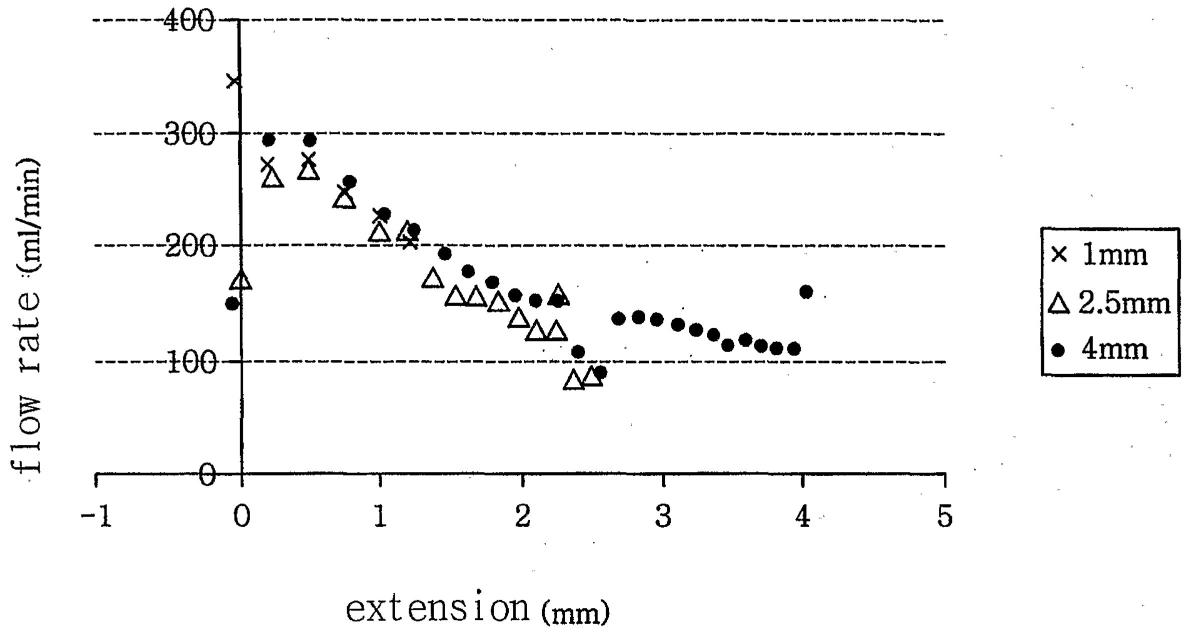
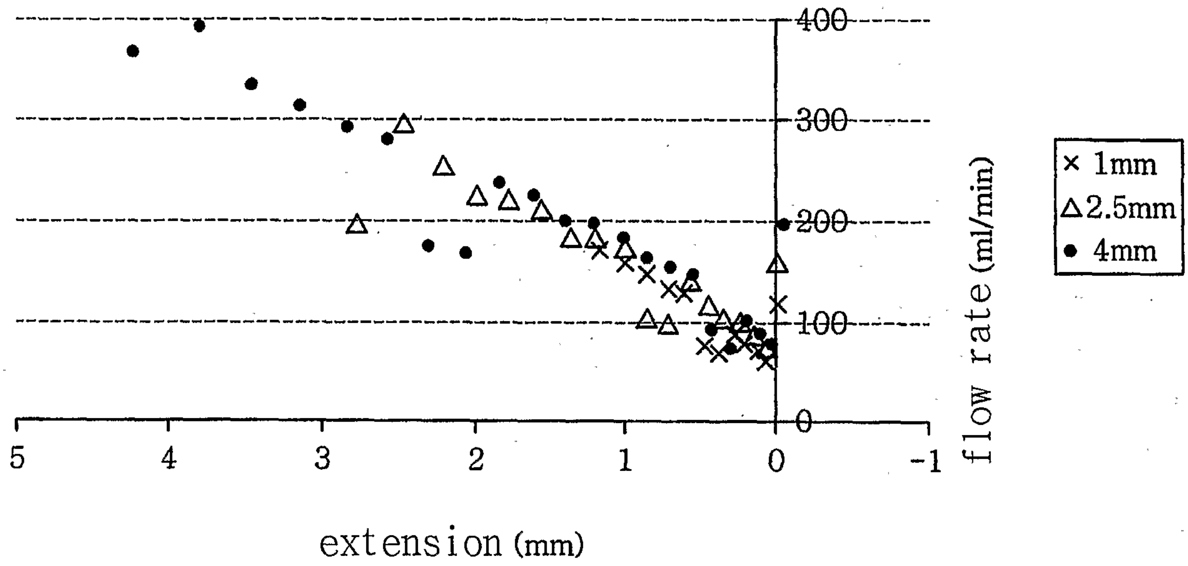


Fig. 24B


400
300
200
100
0
5
4
3
2
1
0
-1
extension (mm)
flow rate (ml/min)
× 1mm
△2.5mm
● 4mm

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR03/01644

A. CLASSIFICATION OF SUBJECT MATTER

IPC7 G05D 16/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G05D, G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the intertnational search (name of data base and, where practicable, search terms used)
WPI, KIPASS(Searching system of Korean Intellectual Property Office), INSPECT "fluid, flow controller,rate,mass"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US5,865,205 A (APPLIED MATERIALS INC (US)), Feb.2,1999 See abstract, Fig.3A, Fig.3B, Fig.5, and the claims	1-29
A	US4,717,596 A (IBM (US)), Jan.5,1988 See abstract, Figure and the detailed description	1-29
A	JP63-40739 A (SUMITOMO ELECTRIC IND LTD (JP)), Feb.22,1988 See fig.2,fig.3, and the the detailed description	1-29
A	JP04-214117 A (NEC KYUSHU LTD(JP)), Aug.5,1992 See figure.2 and the detailed description	1-29

☐ Further documents are listed in the continuation of Box C.　　☒ See patent family annex.

* Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 SEPTEMBER 2003 (29.09.2003)	29 SEPTEMBER 2003 (29.09.2003)

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Telephone No. 82-42-481-5724

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/KR03/01644

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US5,865,205 A	Feb.2,1999	JP11-45122	Feb.16,1999
US4,717,596 A	Jan.5,1988	NONE	
JP63-040739 A	Feb.22,1988	NONE	
JP04-214117 A	Aug.5,1992	NONE	