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Asai et al.

(54) **PERISTALTIC PUMP DEVICE**

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CPC ***F04B 49/065*** (2013.01); ***F04B 49/20*** (2013.01); ***F04B 43/0072*** (2013.01); ***F04B 43/1253*** (2013.01)

(57) **ABSTRACT**

A micro peristaltic pump of a peristaltic pump device presses a rotor against a circular arc shaped flow path inside a microfluidic chip formed to be sheet-like, rotary-drives the rotor by a motor, and causes the circular arc shaped flow path to make a peristaltic motion by the rotation of the rotor, to send a fluid. The peristaltic pump device is provided with a rotation sensor that detects a rotational position of the rotor, a memory that stores in advance a rotational position of the rotor and rotation speed data of the motor corresponding to the rotational position, and a control circuit that calculates a command rotation speed of the motor from data stored in the memory based on a detection signal of the rotation sensor, and controls rotation of the motor based on the command rotation speed.

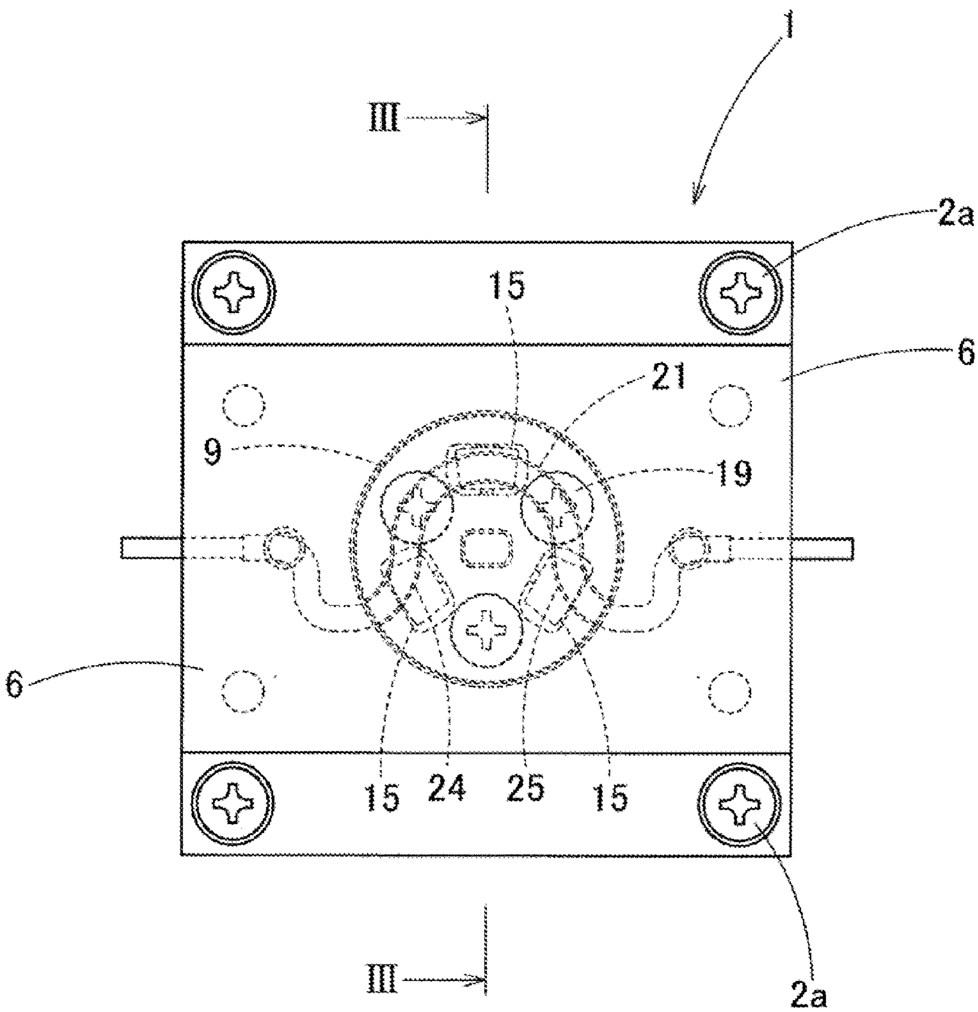


FIG.1A

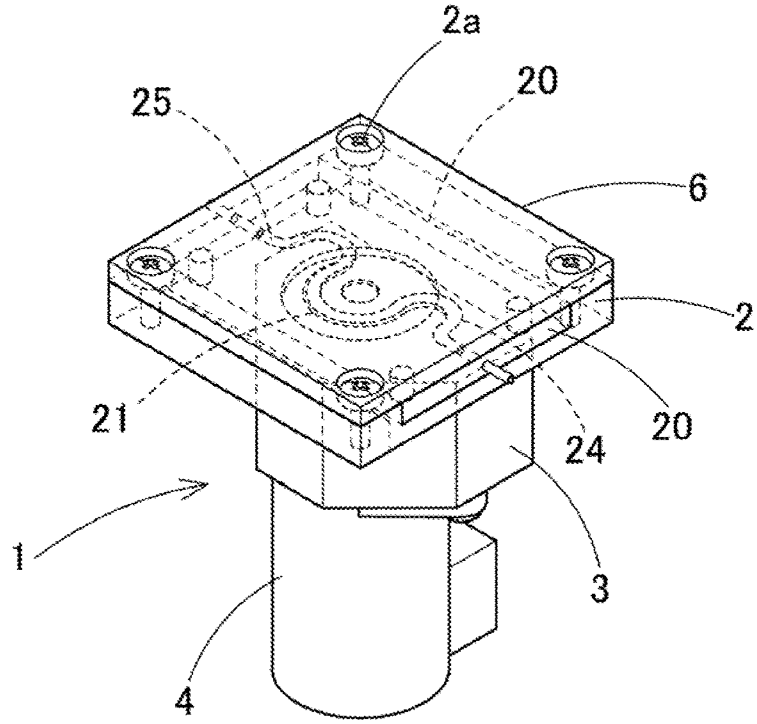
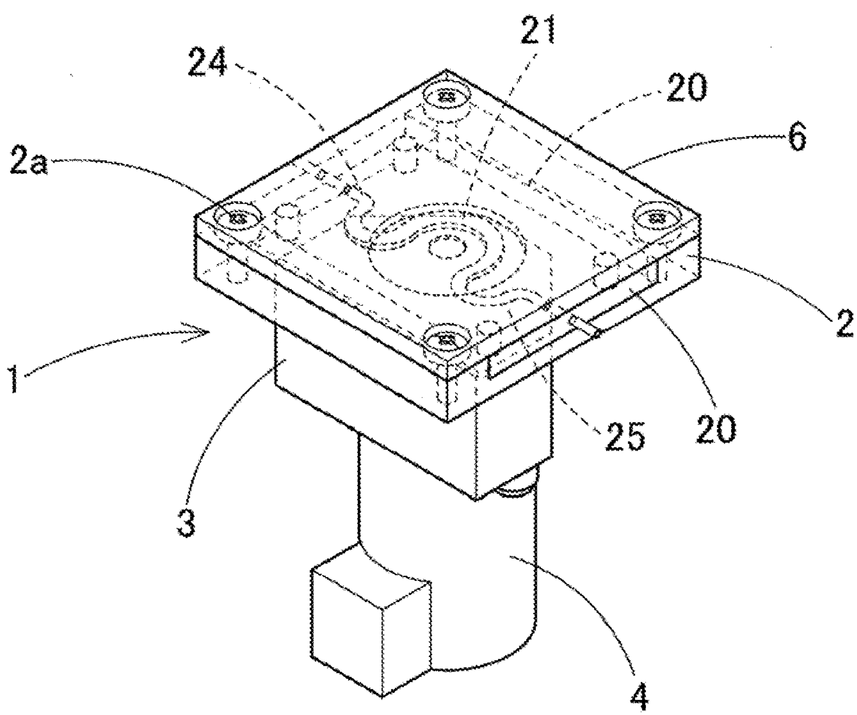


FIG.1B



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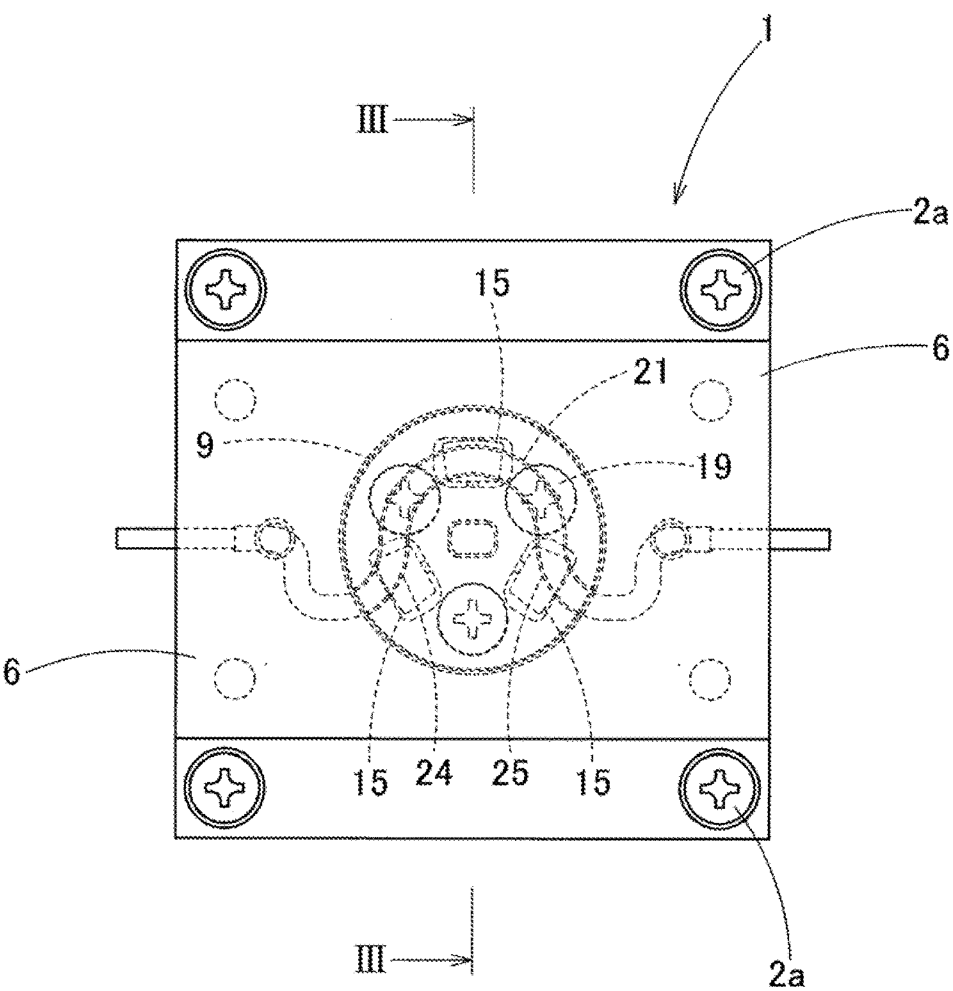

FIG. 3

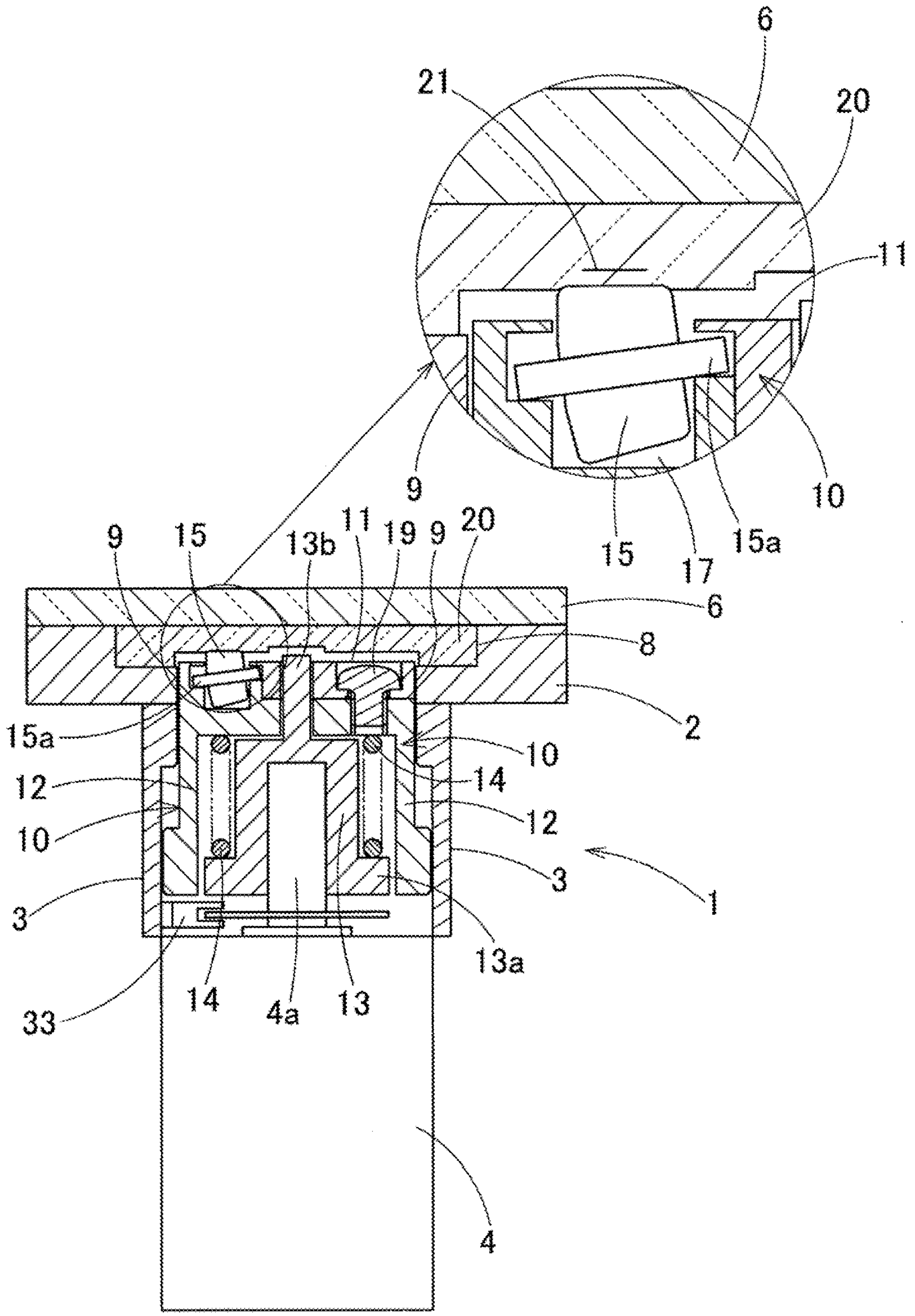
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FIG. 4

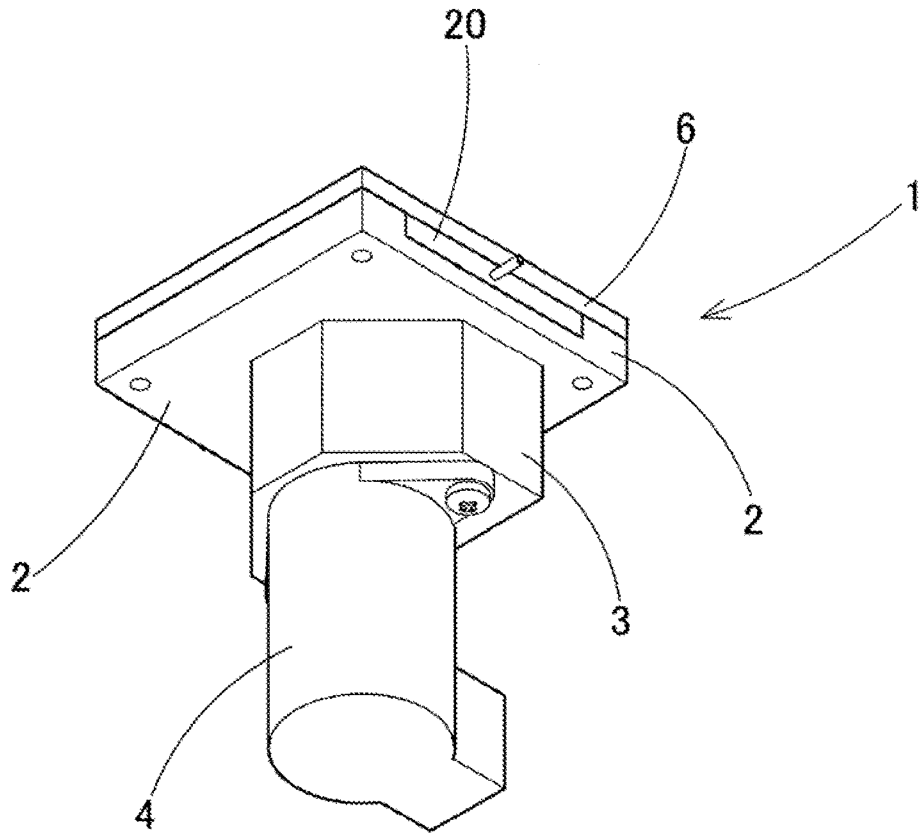


FIG. 5

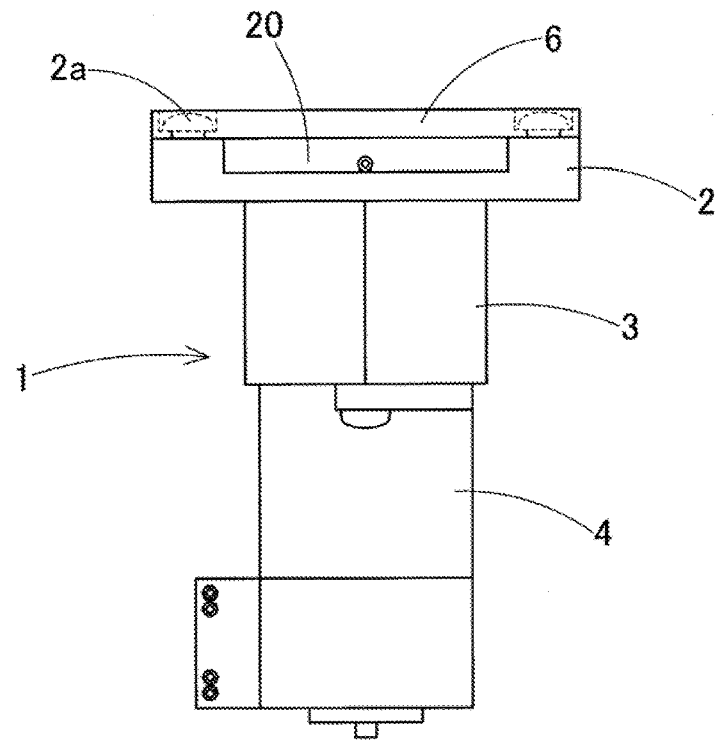


FIG. 6

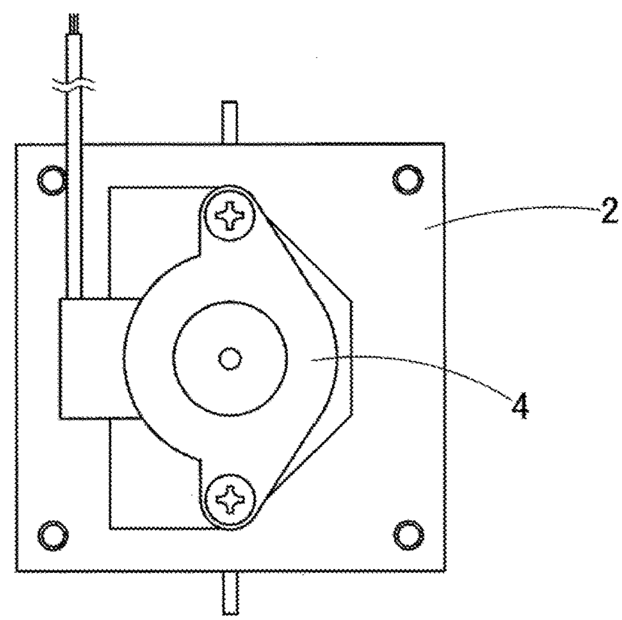


FIG. 7

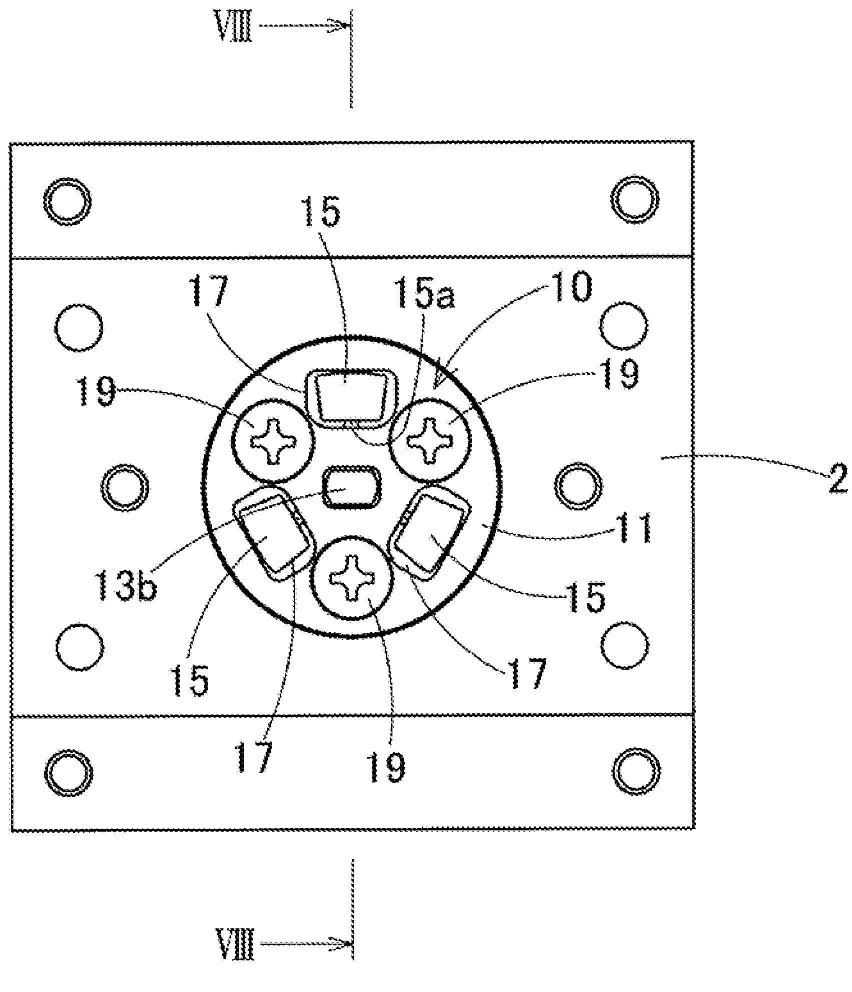


FIG. 8

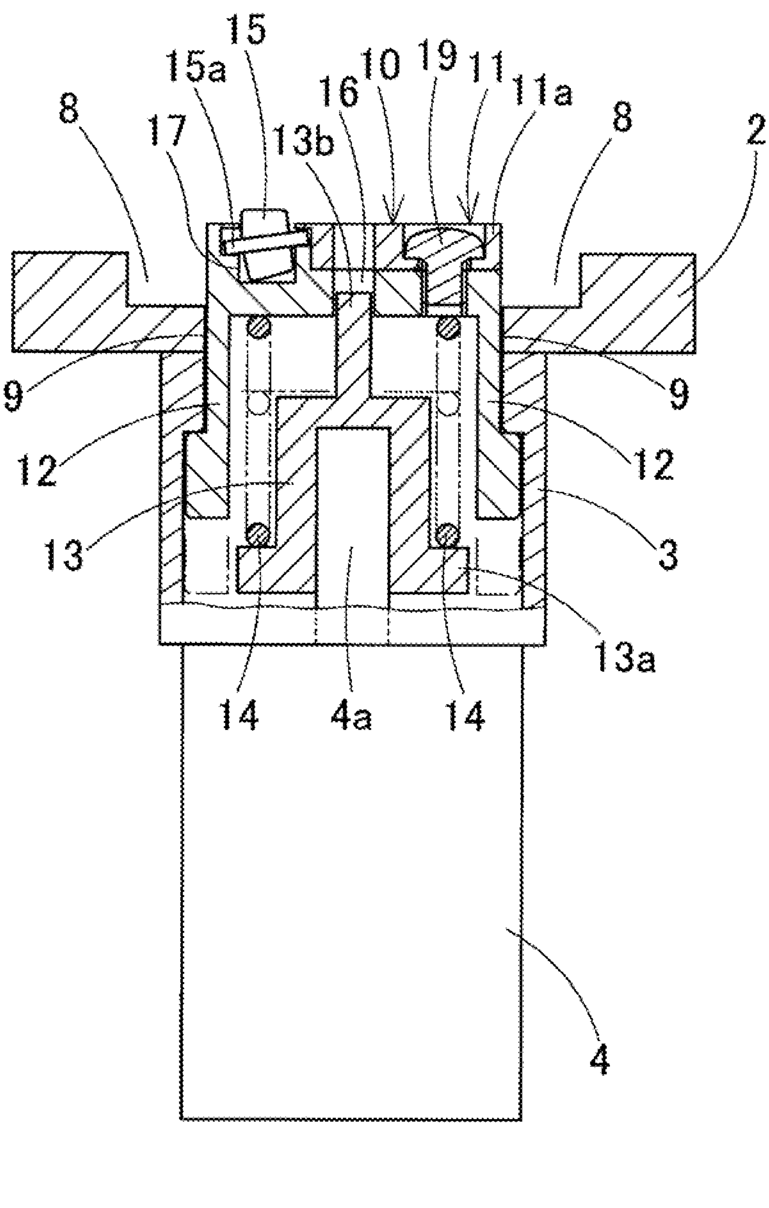


FIG. 9A

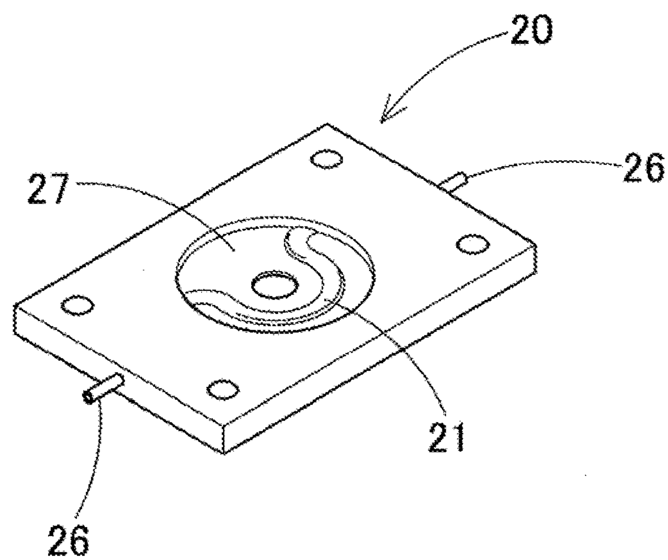


FIG. 9B

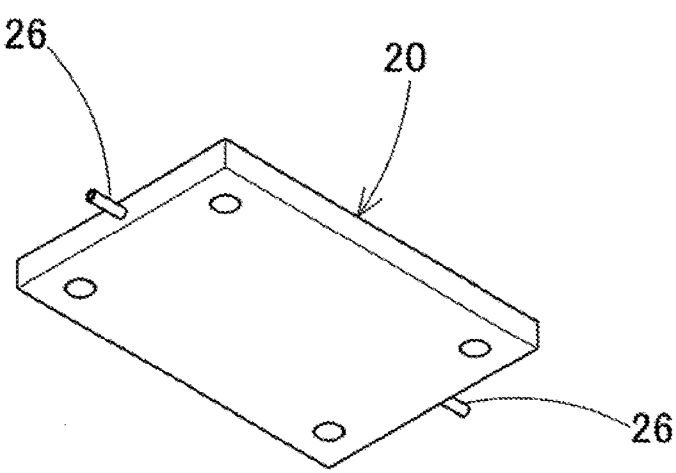


FIG. 10A

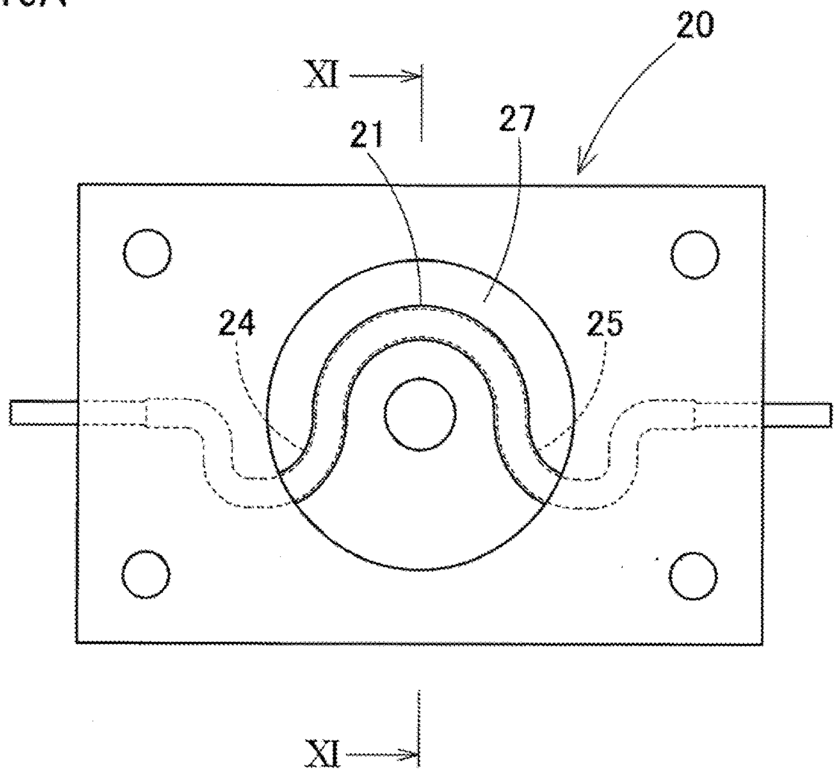


FIG. 10B

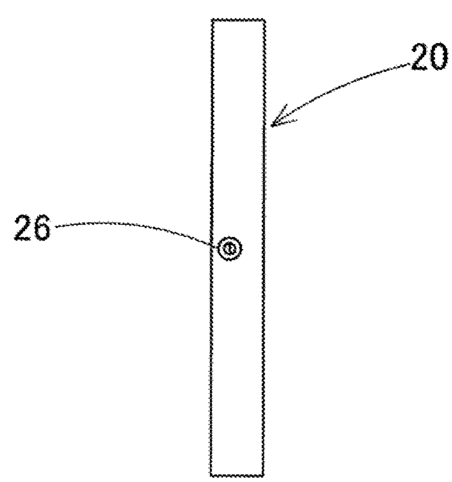


FIG. 11

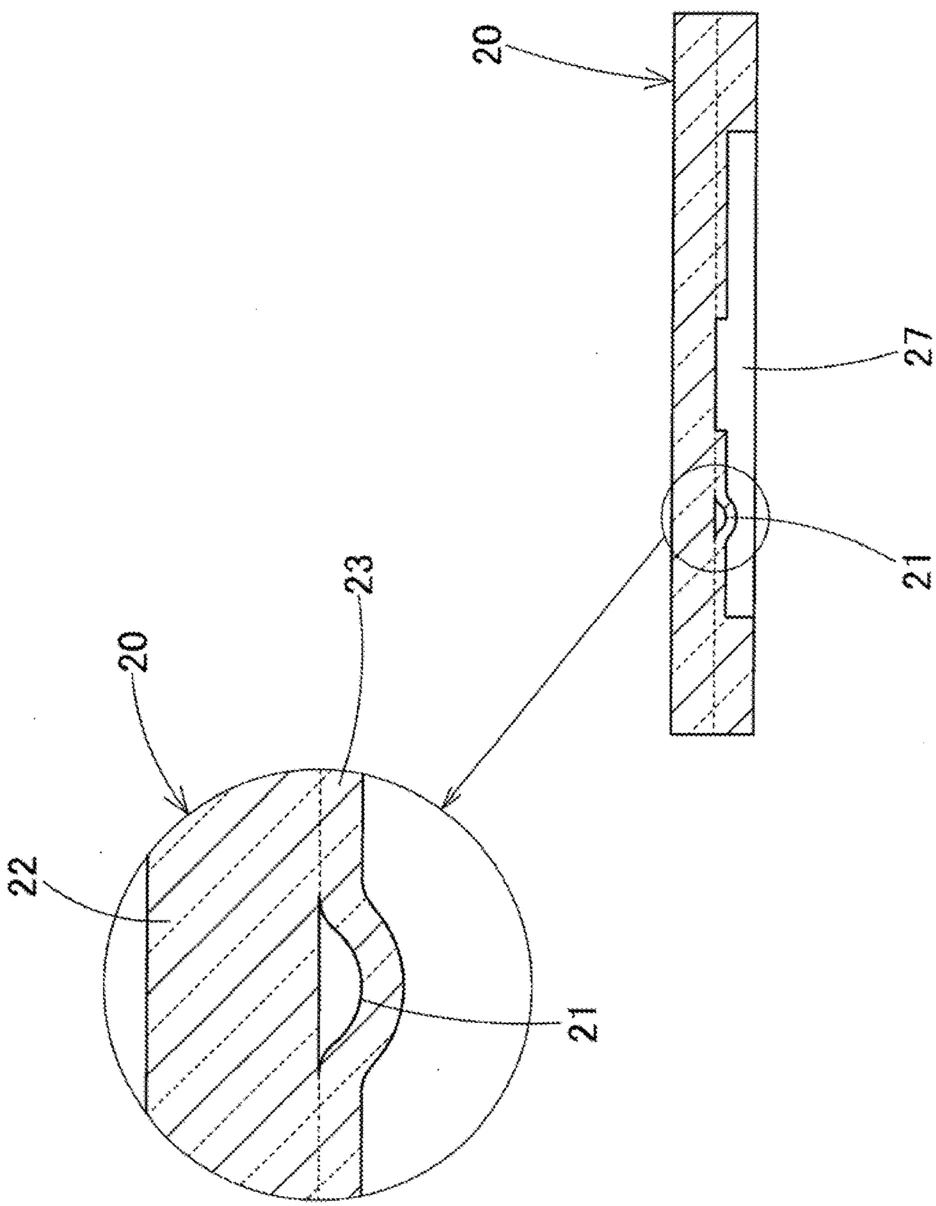


FIG. 12A

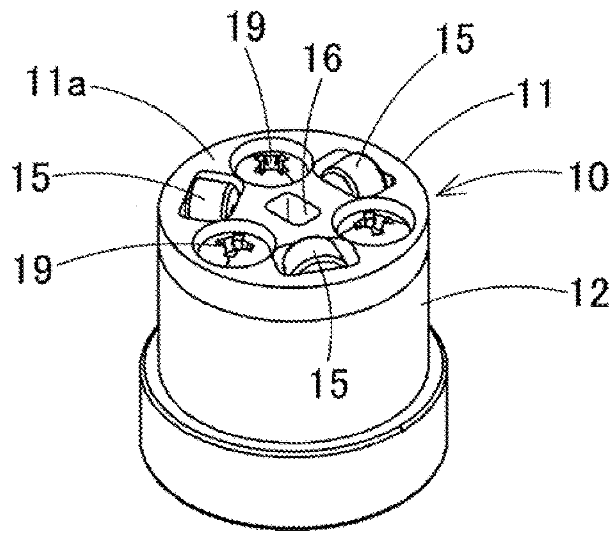


FIG. 12B

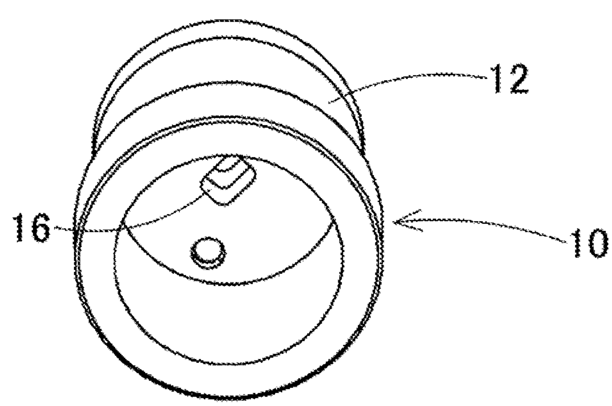


FIG. 13A

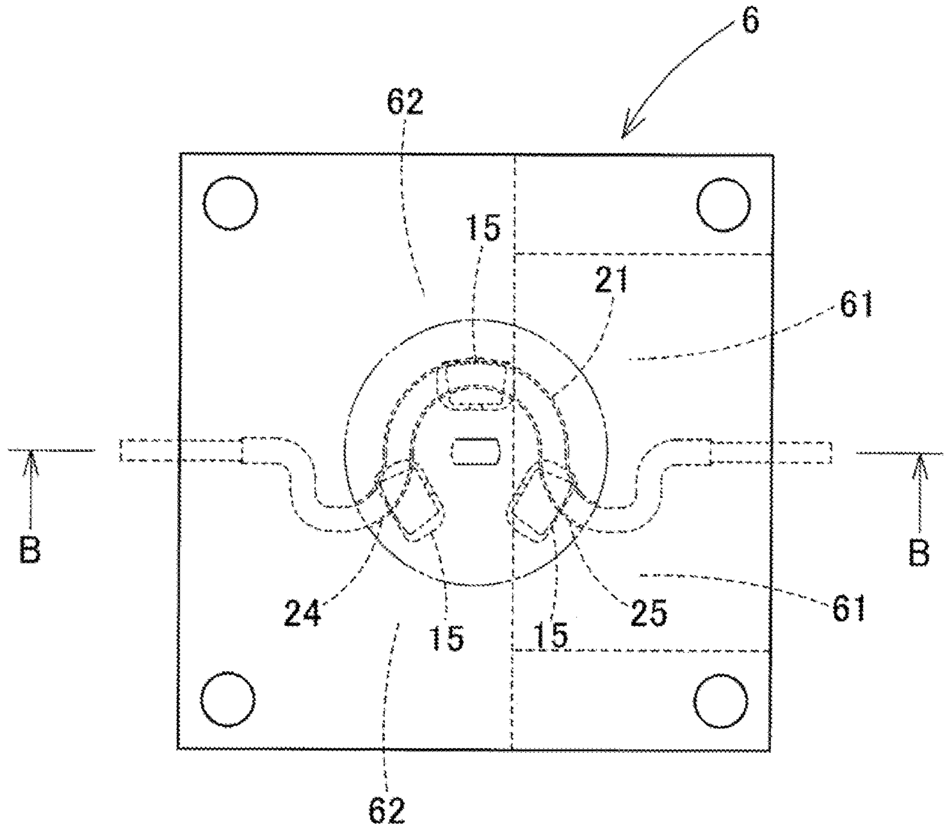
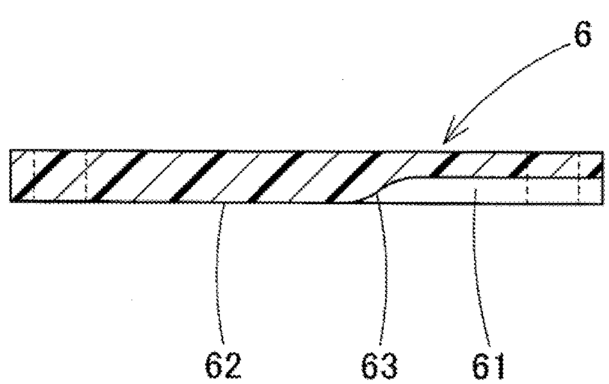


FIG. 13B



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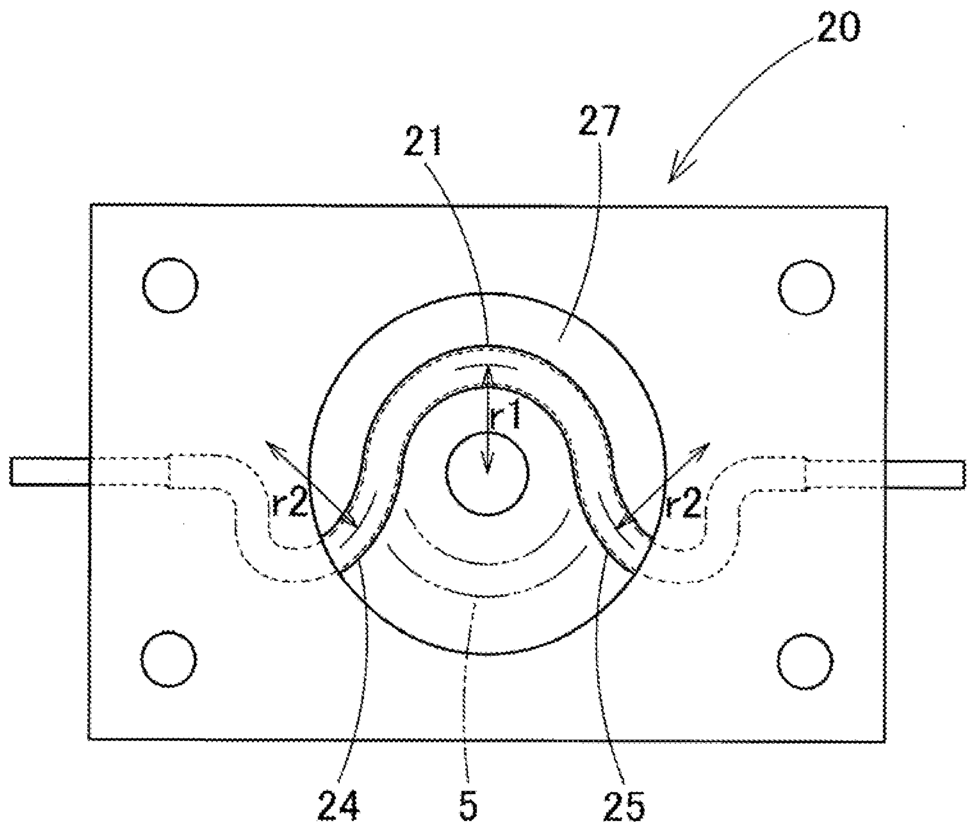


FIG. 15

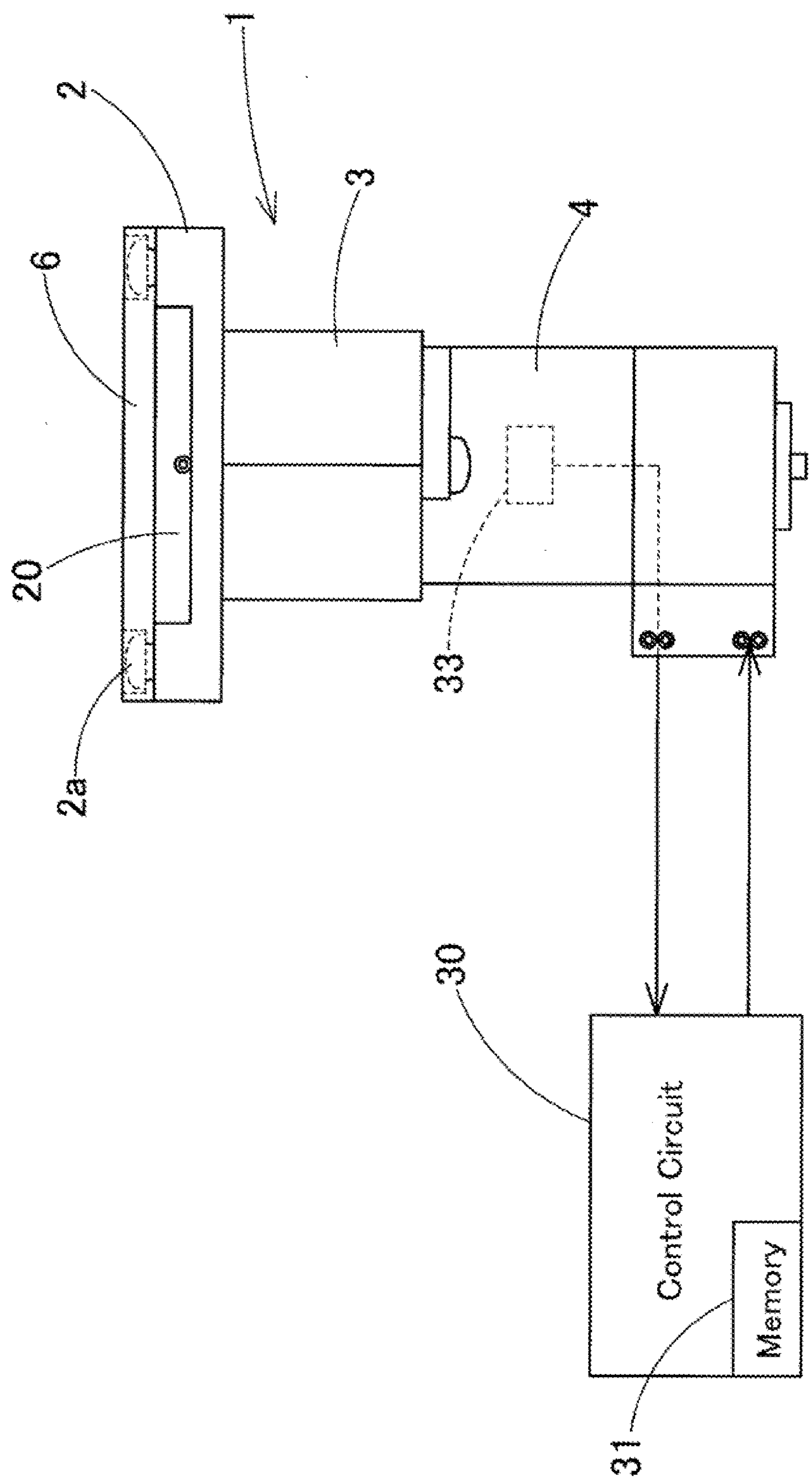
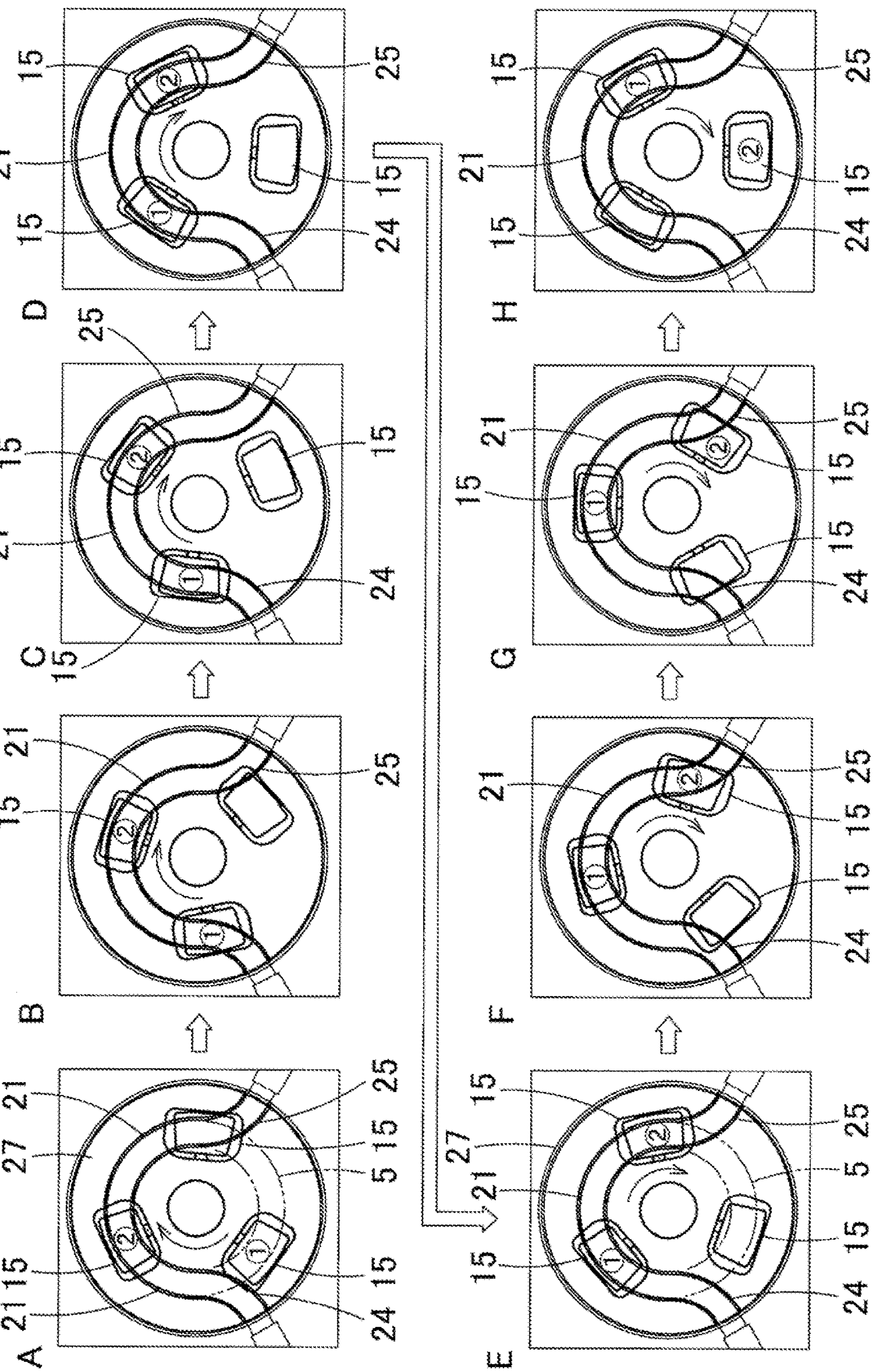


FIG. 16



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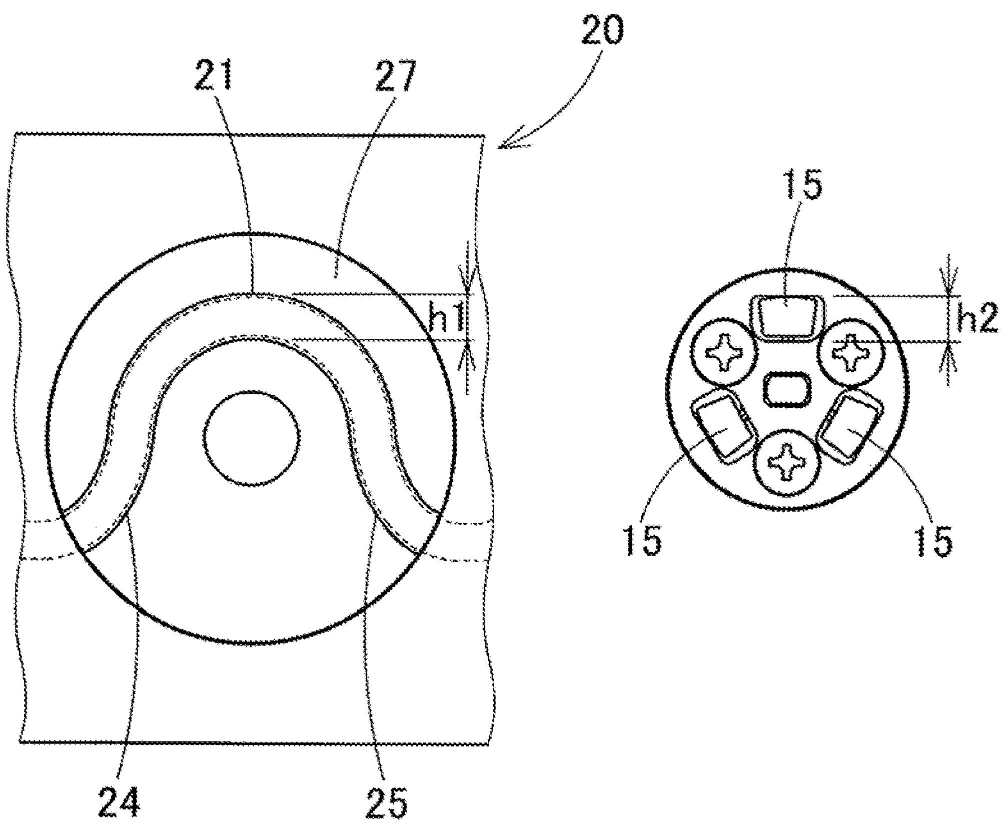


FIG. 18A

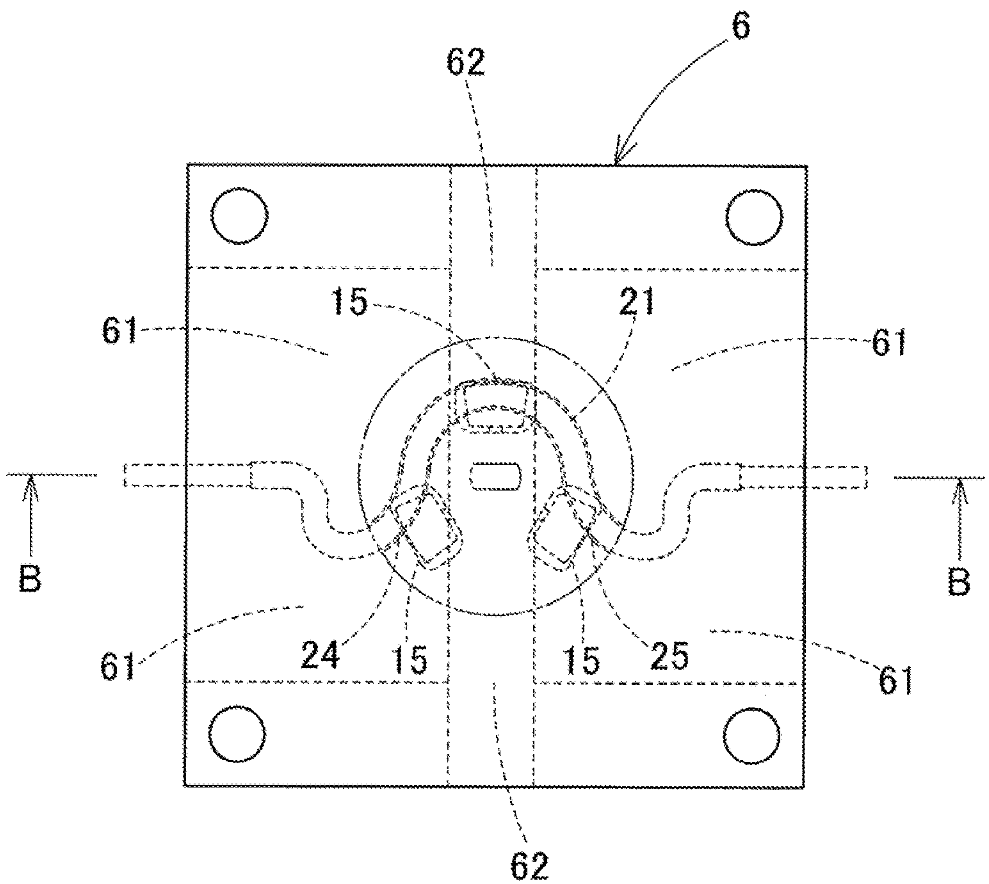


FIG. 18B

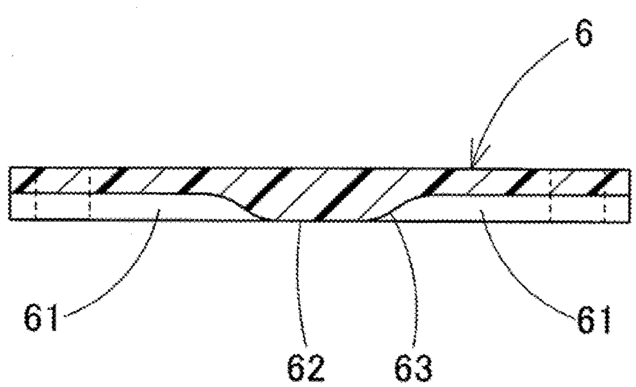


FIG. 19

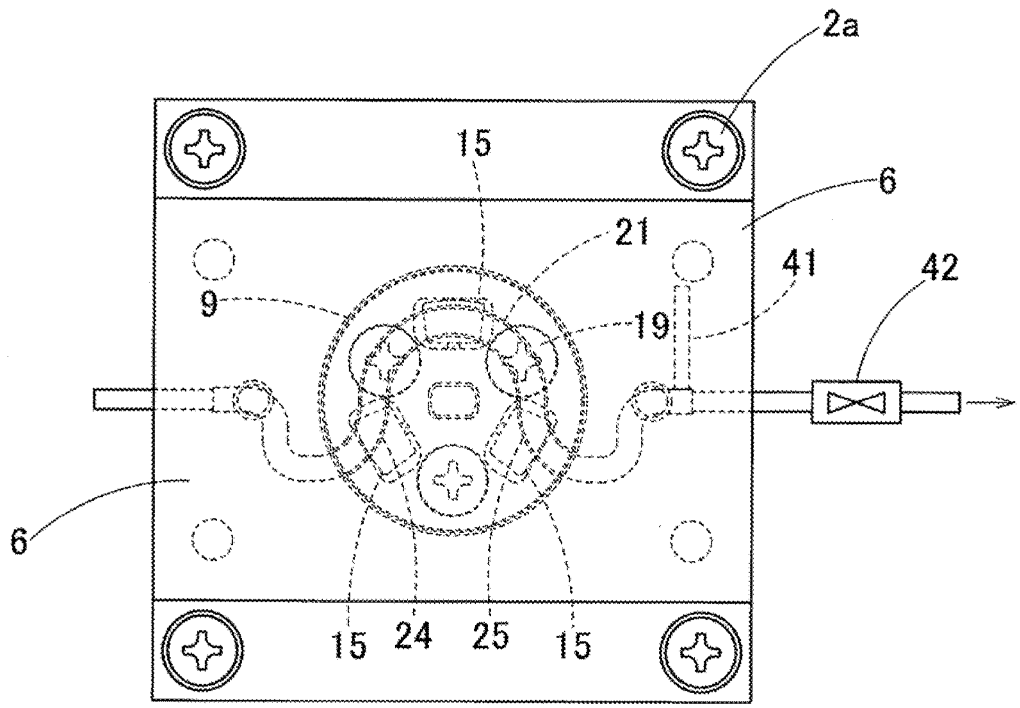


FIG. 20

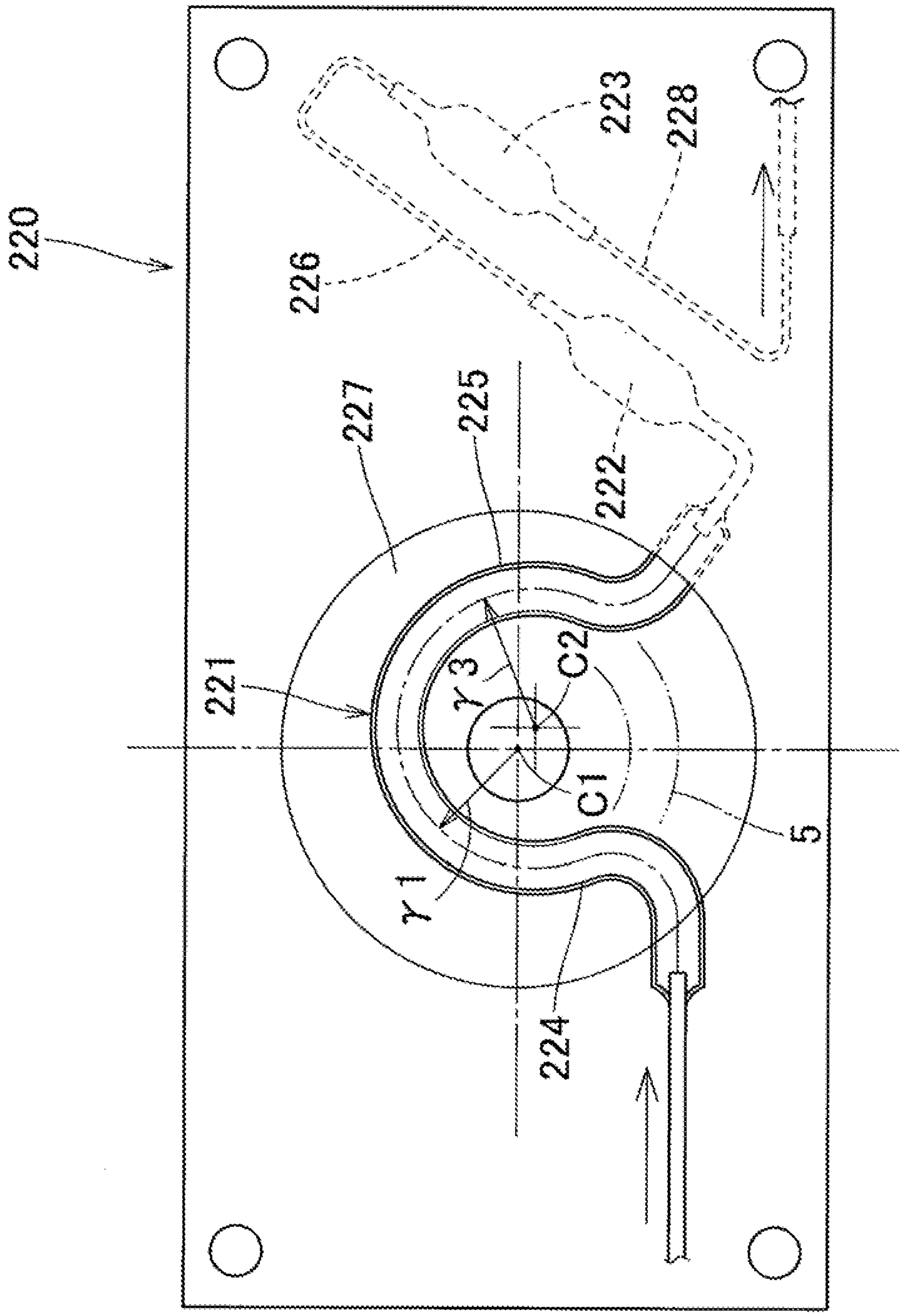


FIG. 21

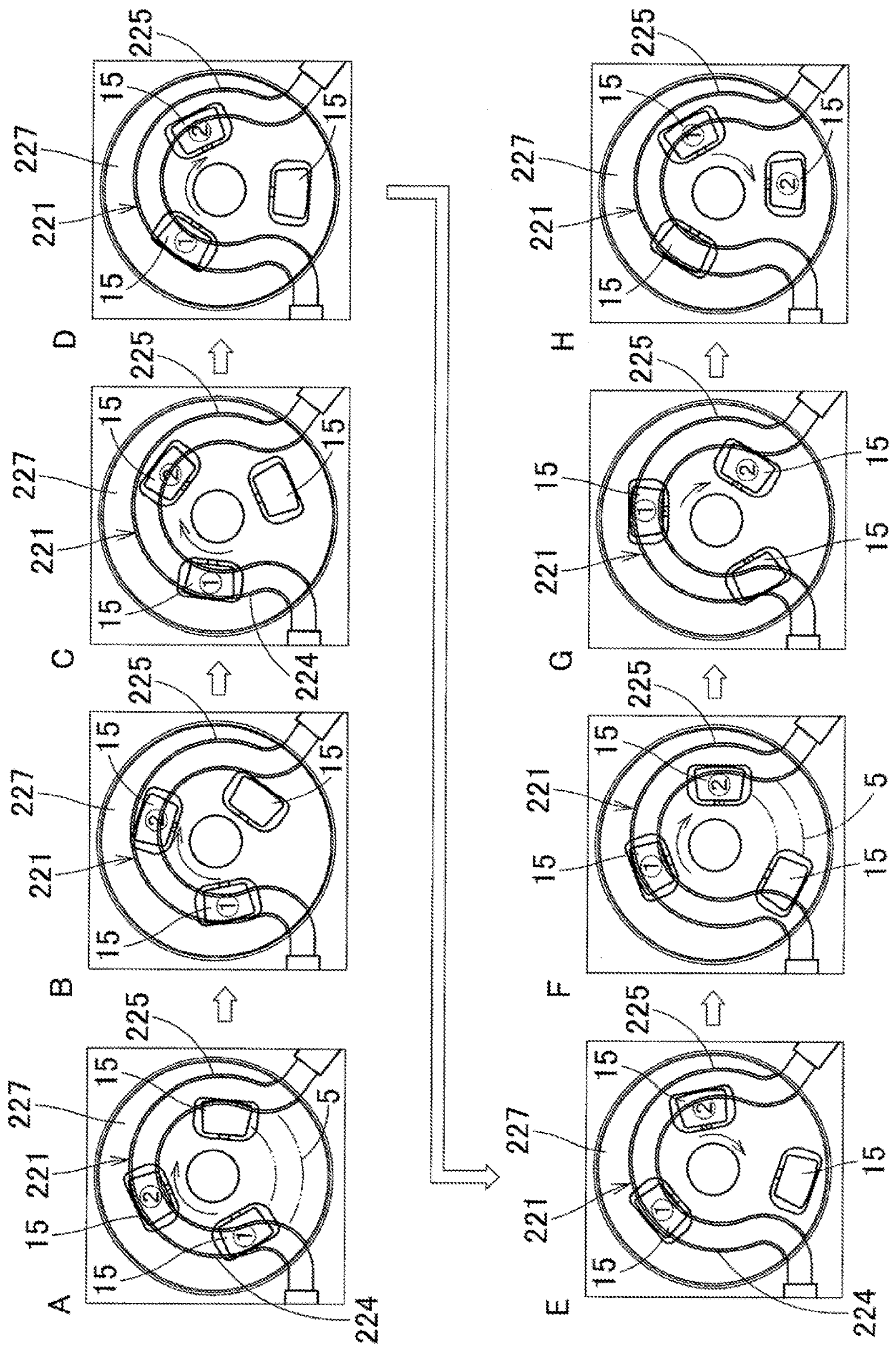


FIG. 22A

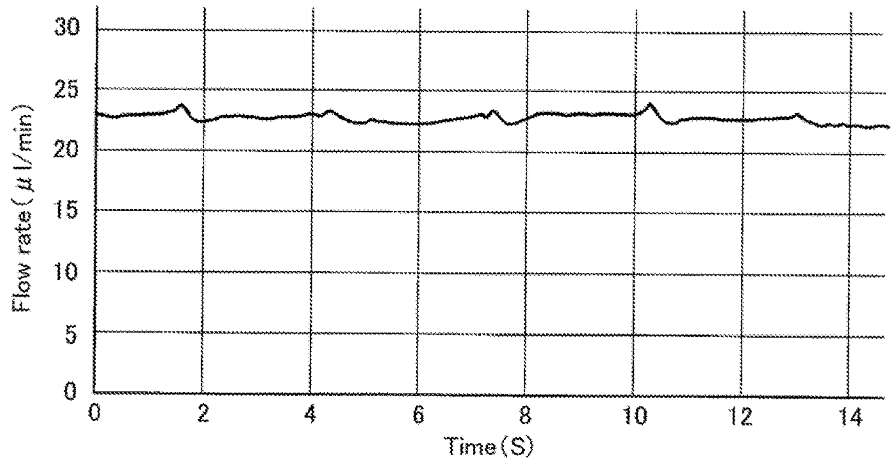


FIG. 22B

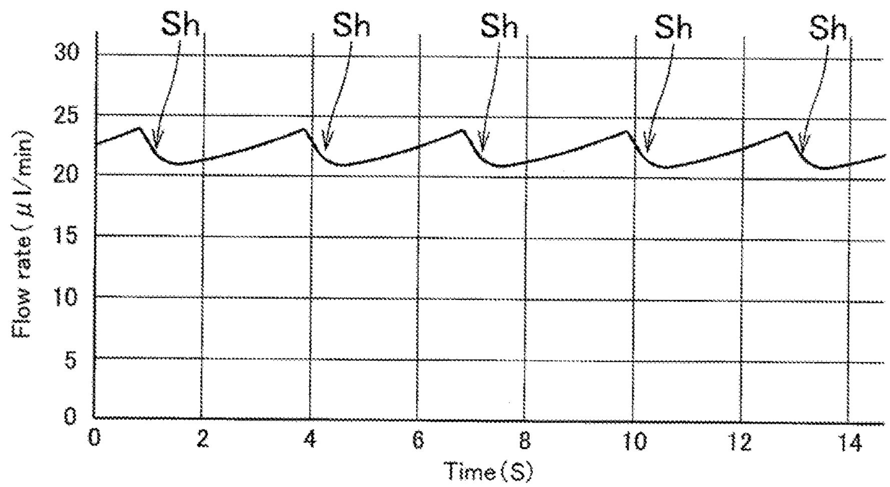
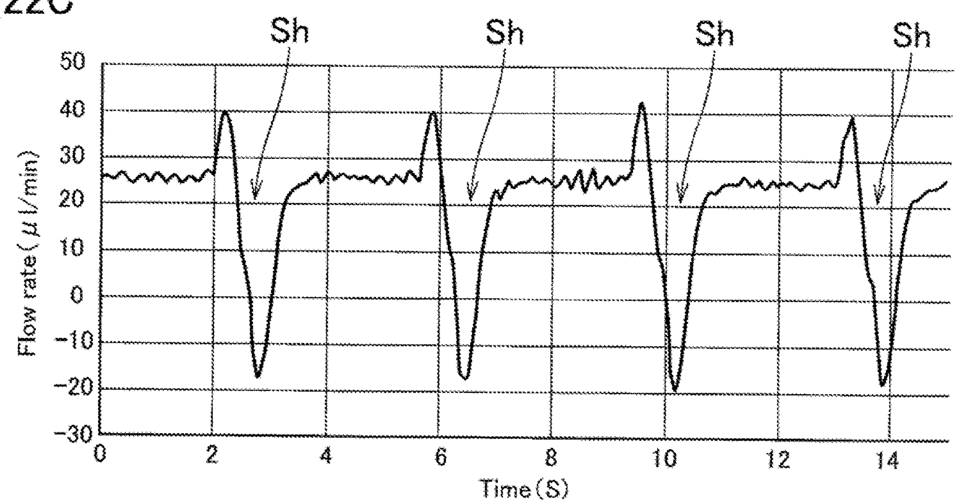


FIG. 22C



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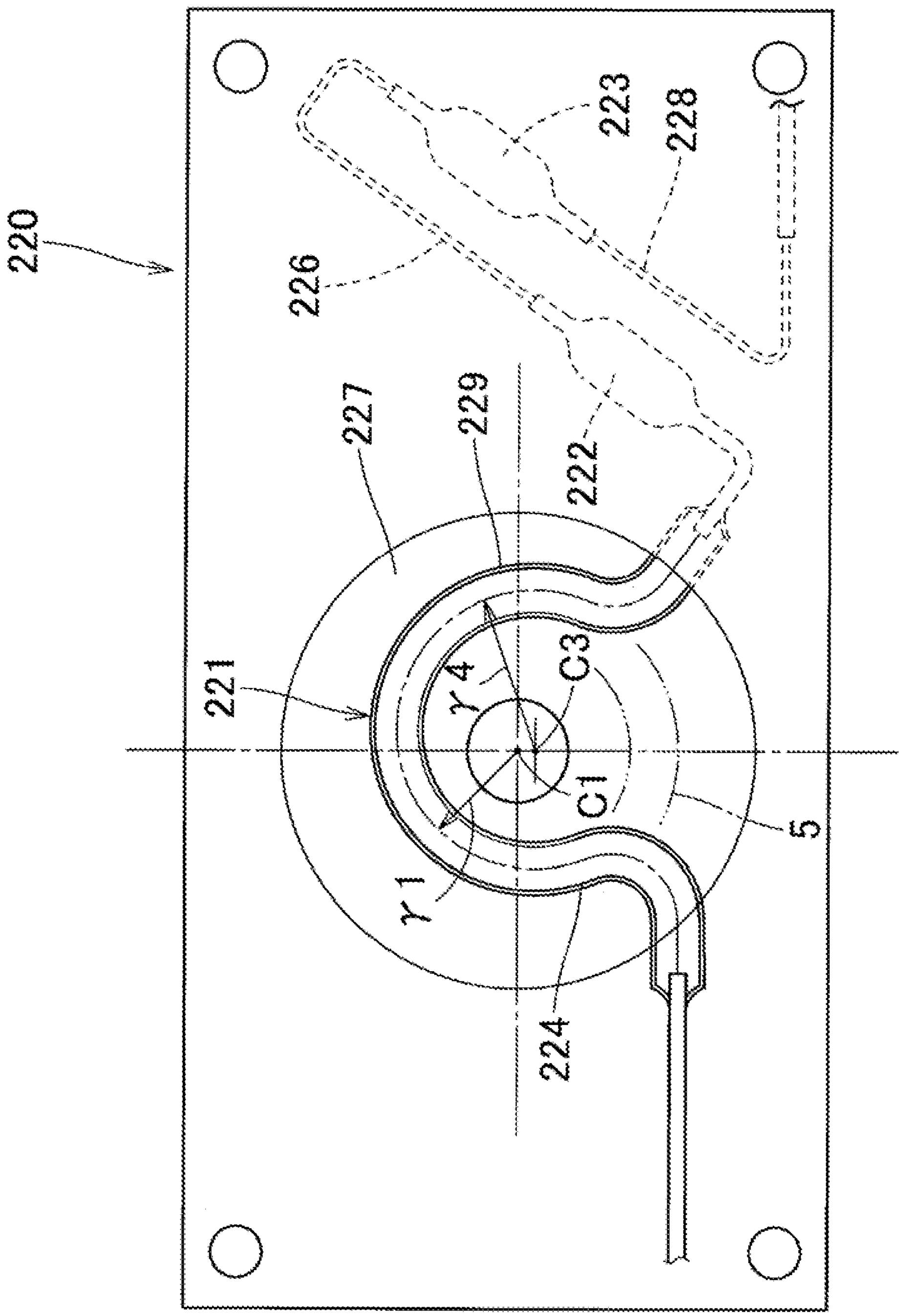


FIG. 24

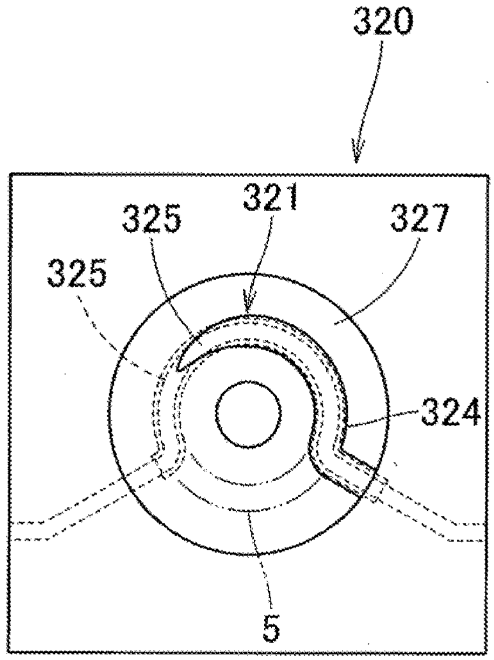


FIG. 25

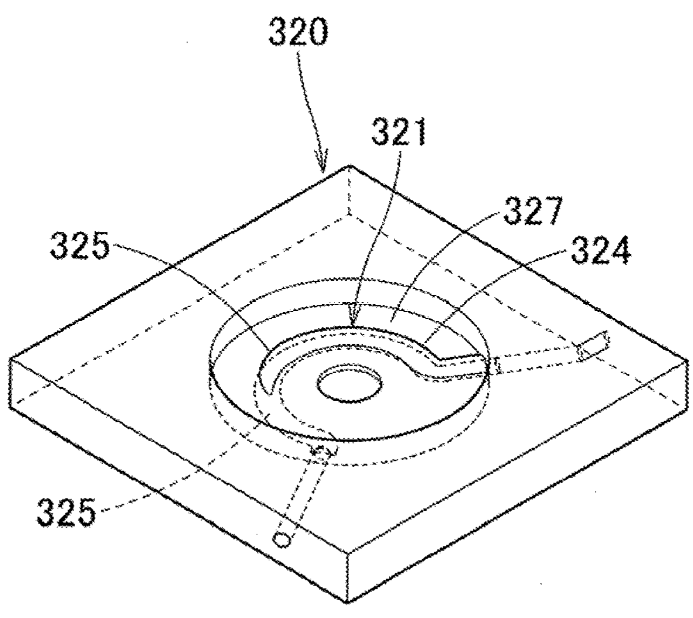
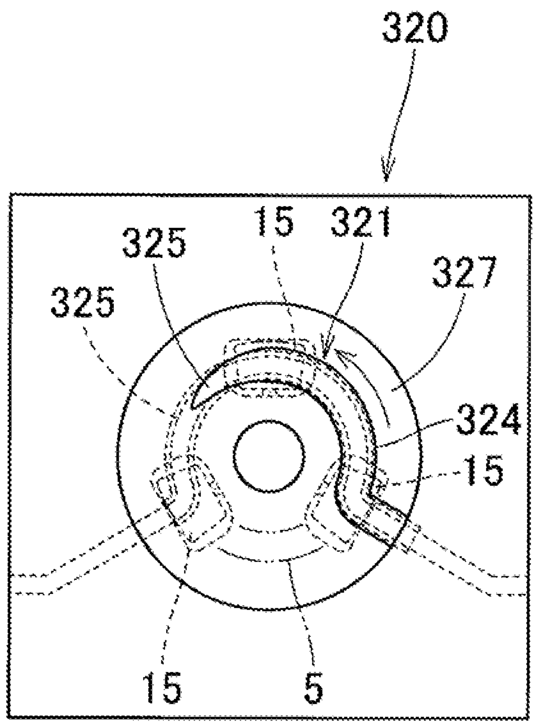


FIG. 26



PERISTALTIC PUMP DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a peristaltic pump device which is used at the time of flowing micro-fluid such as a culture solution or various types of reagents into a microfluidic flow path, to perform cell culturing, reagent screening, chemical analysis, and the like, and in particular, to a peristaltic pump device which is capable of effectively reducing pulsation when sending fluid.

2. Description of Related Art

[0002] Conventionally, a peristaltic pump in which a plurality of rollers are rotatably-pivotally supported on a circular rotor, and the outer circumferential surfaces of the respective rollers on the rotor are pressed against a tube, to send a fluid in the tube while rotating the rotor, has been known by JP No. 2004-92537 A, etc.

[0003] This type of conventional peristaltic pump is configured such that a circular rotor which is rotary-driven by a motor rotatably-pivotally supports a plurality of rollers on its outer circumferential portion, and the spindles of the respective rollers are disposed parallel to the rotary shaft of the rotor, and during rotation of the rotor, the outer circumferential surfaces of the respective rollers are pushed against a tube (flexible conduit tube), and the rollers on the rotor are sequentially pressed against the tube to rotationally move, to send a liquid.

[0004] However, this type of peristaltic pump is configured such that a plurality of rollers are provided on a rotor, and a liquid is sent through a tube by rotationally moving a rotor while pressing the respective rollers against the tube, so that a flow rate of the liquid flowing inside the tube is inevitably pulsated.

[0005] Therefore, the peristaltic pump is provided with a sensor that detects a rotational position of the rotor, and when the rollers move by a predetermined rotation angle while pressing and crushing the tube, rotation of a rotor driving motor is controlled so as to minimize the pulsation of the flow rate of the liquid.

[0006] However, in the peristaltic pump described above, according to rotation of the rotor, when each roller separates from the tube that the roller pressed, due to a restoring force of the tube, a negative pressure is applied inside the tube and causes a phenomenon of a rapid decrease in flow rate. Therefore, the peristaltic pump described above has a problem in which, although the rotation of the roller driving motor is controlled to suppress pulsation of the liquid according to the rotational position of the rotor, it is still difficult to sufficiently reduce pulsation.

[0007] On the other hand, the applicant of the present invention proposed, in WO 2015/173926 A1, a peristaltic pump to send a liquid in a flow path by causing a circular arc shaped flow path to make a peristaltic motion by rotation of a rotor. In this peristaltic pump, a circular arc shaped flow path is formed as a microfluidic flow path inside a sheet-like microfluidic chip, and the rotor is pressed against the circular arc shaped flow path of the microfluidic chip, and the rotor is rotary-driven by a motor.

[0008] This peristaltic pump is configured such that, on the flat surface of the rotor perpendicular to a rotary shaft of the rotor, three rollers are held so as to be pressed to touch the circular arc shaped flow path, to freely rotate on the flat surface, and the circular arc shaped flow path in the microfluidic chip swells out of a flat surface of the microfluidic chip to be formed into a circular arc shape such that its cross section becomes a substantially mountain shape, and is disposed along a rotational trajectory of the rollers, a cover is attached to cover the circular arc shaped flow path from the opposite side of the rollers, and when the rotor is rotary-driven by the motor, the rollers rotate while pressing their outer circumferential surfaces against the circular arc shaped flow path on the flat surface, to send a liquid in the circular arc shaped flow path.

[0009] However, this peristaltic pump can send a liquid by pressing and crushing the circular arc shaped flow path with very small loading by the rollers, so that the rotational load of the rotor can be reduced and the motor can be downsized, and further, by detaching the cover, the microfluidic chip can be easily replaced, however, the fluid is still pulsated, and it is difficult to reduce the pulsation.

SUMMARY OF THE INVENTION

[0010] An object of the present invention is to provide a peristaltic pump device capable of reducing pulsation when sending a fluid to be sufficiently small. The object of the present invention can be attained by a peristaltic pump device configured as described below.

[0011] That is, a peristaltic pump device according to the present invention includes a base that includes a cover member and a chip housing portion formed inside, a sheet-like microfluidic chip housed inside the chip housing portion and has a circular arc shaped flow path formed inside, and a micro peristaltic pump to a tip end portion of which a rotor rotatably-pivotally supporting a plurality of rollers is attached so as to be rotary-driven by a motor, and which is fixed to the base by pressing the rollers against the circular arc shaped flow path, wherein on a flat surface perpendicular to a rotary shaft of the rotor, the plurality of rollers are pivotally supported at even angular intervals to freely rotate in pressure-contact with the circular arc shaped flow path on the flat surface, the circular arc shaped flow path of the microfluidic chip is formed into a circular arc shape by swelling out of a surface of the microfluidic chip, and disposed along a rotational trajectory of the plurality of rollers, and a discharge flow path is formed such that the rollers gradually separate from the discharge flow path on a discharge side of the circular arc shaped flow path when the rollers rotate.

[0012] Here, the present invention can be configured such that the discharge flow path on the discharge side of the circular arc shaped flow path is formed by being curved such that a radius of curvature of a circular arc portion is larger than a radius of curvature of a rotational trajectory of the rollers and smaller than 1.5 times the radius of curvature of the rotational trajectory of the rollers, and a circular arc center of the discharge flow path deviates to an arc opening side from a center of the rotary shaft of the rotor.

[0013] Here, the present invention can be configured such that the discharge flow path is formed into a circular arc shape by partially swelling out of a surface of the microfluidic chip, and gradually embedded inside the microfluidic chip toward a discharge end to cause the swelling-out portion to gradually disappear, and the rollers gradually separate from the swelling-out discharge flow path when the rollers rotate.

[0014] According to this peristaltic pump device of the present invention, when each roller of the rotor presses and crushes the circular arc shaped flow path formed in the microfluidic chip to discharge a fluid, the roller moves to gradually separate from the discharge flow path of the circular arc shaped flow path so as to gradually end pressing.

[0015] Therefore, when the roller separates from the discharge flow path, a negative pressure is gradualy applied inside the discharge flow path by a restoring force of the microfluidic chip. Thus, a rapid increase in flow rate and a subsequent rapid decrease in flow rate inside the discharge flow path are suppressed, and accordingly, the flow rate of the fluid to be sent out of the circular arc shaped flow path of the microfluidic chip is uniformized, and pulsation of the flow rate of the fluid can be reduced to be sufficiently small.

[0016] Here, it is preferable that a buffer chamber is provided in a flow path on a discharge side of the circular arc shaped flow path inside the microfluidic chip, and a narrowed portion is provided in a flow path on a discharge side of the buffer chamber. Accordingly, a buffer effect is generated in the discharge flow path, and pulsation of the discharge flow rate can be reduced to be smaller.

[0017] Here, in the peristaltic pump device described above, it is preferable that a control circuit to control a rotation speed of the motor is provided, and the control circuit is provided with a rotation sensor that detects a rotational position of the rotor and generates a detection signal indicating the rotational position, and a memory that stores in advance a rotational position of the rotor and rotation speed data of the motor corresponding to the rotational position.

[0018] In addition, it is preferable that the control circuit calculates a command rotation speed of the motor from data stored in the memory based on a detection signal transmitted from the rotation sensor, and controls rotation of the motor based on the command rotation speed to, in a stroke in which the rollers separate from the discharge flow path after pressing the discharge flow path to push out the fluid, increase the rotation speed of the rollers, and immediately after the rollers separate from the discharge flow path, reduce the rotation speed of the rollers to return the rotation speed to a normal speed.

[0019] With this configuration, in a stroke in which the rollers separate from the discharge flow path after pressing the discharge flow path to push out the fluid, the rotation speed of the rollers are temporarily increased, so that a decrease in discharge flow rate due to a negative pressure inside the discharge flow path caused by a restoring force of the microfluidic chip immediately after the rollers separate from the discharge flow path is suppressed, and pulsation of the discharge flow rate can be reduced to be smaller. Thus, by the peristaltic pump device of the present invention, pulsation at the time of sending a fluid can be reduced to be sufficiently small.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] FIG. **1**A and FIG. **1**B are perspective views showing a first embodiment of a micro peristaltic pump of a peristaltic pump device of the present invention.

[0021] FIG. **2** is a plan view of the same micro peristaltic pump.

[0022] FIG. **3** is a sectional view taken along the line II-III in FIG. **2**.

[0023] FIG. **4** is a perspective view of the micro peristaltic pump viewed from below.

[0024] FIG. **5** is a left side view of the micro peristaltic pump.

[0025] FIG. **6** is a bottom view of the same micro peristaltic pump.

[0026] FIG. **7** is a plan view showing a state where a cover member and a microfluidic chip are detached.

[0027] FIG. **8** is a sectional view taken along the line VIII-VIII in FIG. **7**.

[0028] FIG. **9**A is a perspective view of a lower surface side of the microfluidic chip, and FIG. **9**B is a perspective view viewed from a flat surface side.

[0029] FIG. **10**A is a bottom view of the microfluidic chip, and FIG. **108** is a side view of the same.

[0030] FIG. **11** is a sectional view taken along the line XI-XI in FIG. **10**.

[0031] FIG. **12**A is a perspective view of a rotor, and FIG. **12**B is a perspective view viewed from a bottom surface side.

[0032] FIG. **13**A is a plan view showing a relationship between a cover member and a circular arc shaped flow path, a rotor, and FIG. **138** is a sectional view taken along the line B-B in FIG. **13**A.

[0033] FIG. **14** is a bottom view of the microfluidic chip, showing a radius of curvature r1 of the circular arc shaped flow path and a radius of curvature r2 of an outward discharge flow path.

[0034] FIG. **15** is an entire configuration diagram including a control circuit of the peristaltic pump device.

[0035] FIG. **16** is an explanatory view showing operation of the peristaltic pump device.

[0036] FIG. **17** is an explanatory view showing a relationship between a flow path width of the circular arc shaped flow path and a length in an axial direction of a roller.

[0037] FIG. **18**A is a plan view showing a relationship between a cover member and a circular arc shaped flow path, a rotor according to another embodiment, and FIG. **188** is a sectional view taken along the line B-B in FIG. **18**A.

[0038] FIG. **19** is a plan view showing the cover member, the circular arc shaped flow path, the rotor, and a discharge side flow path of another embodiment.

[0039] FIG. **20** is a bottom view of a microfluidic chip of a peristaltic pump device according to a second embodiment.

[0040] FIG. **21** is an explanatory view showing operation of the same peristaltic pump device.

[0041] FIG. **22**A is a graph showing a discharge flow rate change when pulsation is minimized by performing rotation speed control of a rotor, FIG. **22**B is a graph showing a flow rate change of the same peristaltic pump when the rotation speed control is not performed, and FIG. **22**C is a graph showing a flow rate change of a conventional peristaltic pump device as a comparative example.

[0042] FIG. **23** is a plan view of a microfluidic chip of another embodiment.

[0043] FIG. **24** is a bottom view of a microfluidic chip of a peristaltic pump device according to a third embodiment.

[0044] FIG. **25** is a bottom perspective view of the same microfluidic chip.

[0045] FIG. **26** is a bottom view showing a relationship between the same microfluidic chip and a rotor.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0046] Hereinafter, the present invention is described based on embodiments shown in the drawings. The present invention is not limited to the embodiments. All modifications within requirements of the claims or equivalents regarding the requirements shall be included in the scope of the claims.

[0047] FIG. **1** to FIG. **17** show a peristaltic pump device according to a first embodiment, and this peristaltic pump device includes, as shown in FIG. **15**, a base **2** that houses a microfluidic chip **20**, a micro peristaltic pump **1** that is fixed to a lower portion of the base **2** and drives a rotor **10** by a motor **4**, and a control circuit **30** that controls a rotation speed of the motor **4**.

[0048] To an upper portion of the micro peristaltic pump **1**, the rotor **10** to be driven by the motor **4** is attached, and on a horizontal surface of the rotor **10**, three rollers **15** are pivotally supported radially at intervals, and the three rollers **15** are pressed against a circular arc shaped flow path **21** formed inside a concave portion **27** of the microfluidic chip **20**, and the rotor **10** and the rollers **15** are rotated to send a liquid at a micro flow rate.

[0049] In the micro peristaltic pump **1**, schematically, a circular arc shaped flow path **21** is formed as a microfluidic flow path inside a sheet-like microfluidic chip **20**, three rollers **15** of the rotor **10** are pressed against the circular arc shaped flow path **21** of the microfluidic chip **20**, the rotor **10** is rotary-driven by the motor **4**, and the circular arc shaped flow path **21** is caused to make a peristaltic motion by rotation of the three rollers **15** to send a liquid in the flow path. As shown in FIG. **1**, the motor **4** is fixed upward to an attaching portion **3** provided on a lower portion of the base **2**.

[0050] The base **2** is configured such that a plate-like portion is formed integrally with an upper portion of the attaching portion **3**, and a substantially square chip housing portion **8** is formed in the plate-like portion in order to function as a holder which houses the microfluidic chip **20**. The attaching portion **3** is provided downward in an extended condition on the lower side of the plate-like portion, and the motor **4** is attached upward to the attaching portion **3**. An opening portion is formed so as to open downward in the attaching portion **3**, and an output shaft side of the motor **4** is inserted into the opening portion from below, to be fixed. A substantially rectangular chip housing portion **8** is formed, as a sheet-like space, so as to open into the upper side, in the top surface of the plate-like portion of the base **2**. A circular opening portion **9** is formed in the center of the chip housing portion **8**, and an upper portion of the rotor **10** shown in FIG. **12** is inserted into the circular opening portion **9** from below.

[0051] As shown in FIG. **3**, an output shaft **4*a*** of the motor **4** is provided upward, and a spring holding portion **13** is fixed to the output shaft **4*a*** so as to cover it from above. The rotor **10** having a turned-down cup shape (FIG. **12**) is attached onto the spring holding portion **13** from above so as to cover it via a coil spring **14**. The coil spring **14** is mounted between its flange portion **13*a*** and the rotor **10** onto the outer circumference of the spring holding portion **13**.

[0052] The rotor **10** is biased upward with respect to the spring holding portion **13**, that is, the output shaft **4*a*** of the motor **4** by this coil spring **14**. A shaft-like tip end portion **13*b*** serving as a rotary shaft of the rotor **10** is provided in an extended condition at the upper portion of the spring holding portion **13**, and the tip end portion **13*b*** of the spring holding portion **13** is, as the rotary shaft, fitted into an odd-shaped hole provided in the center of the rotor **10**, to be coupled to the rotor **10**.

[0053] The spring holding portion **13** is coupled to the output shaft **4*a*** by fitting the output shaft **4*a*** of the motor **4** into its central shaft hole, to transmit the rotary-driving force of the motor **4** to the rotor **10** via the spring holding portion **13**, thereby the rotor **10** rotates. As the motor **4**, for example, an extremely compact DC motor or stepping motor which has a built-in reduction machine is used, and its output shaft **4*a*** is rotary-driven at low speed.

[0054] As shown in FIG. **15**, rotation of the motor **4** is accurately controlled by the control circuit **30** according to a rotational position of the rotor **10**. For this control, to the motor **4**, a rotation sensor **33** that detects rotation of the output shaft **4*a***, that is, the rotor **10** and generates a detection signal is attached. The rotation sensor **33** is configured by using, for example, a photointerrupter, a magnetic sensor, or the like, and outputs a detection signal at a predetermined rotation angle position. The rotation sensor **33** may be a sensor that detects a rotation angle position in addition to an origin position, or a sensor that only detects an origin position of the rotor **10**, and in this case, the control circuit **30** calculates rotation angle data based on the origin position according to rotary-driving of the motor **4**.

[0055] The control circuit **30** consists of a microcomputer, and controls the rotation speed of the motor **4** so as to suppress pulsation of the discharge flow rate of the micro peristaltic pump **1** based on a motor control program stored in advance. For this control, in the memory **31** of the control circuit **30**, the rotation angle of the rotor **10** and command rotation speed data are stored in advance as, for example, table data. When the motor **4** is driven, the control circuit **30** determines a command rotation speed based on a detection signal (rotation angle signal) input from the rotation sensor **33** and controls driving of the motor **4** based on the command rotation speed, and property performs speed control to, in particular, when each roller **15** on the rotor **10** reaches the outward discharge flow path **25** of the microfluidic chip **20**, at the timing of separation of the roller **15** from the outward discharge flow path **25**, rapidly increase or gradually reduce the rotation speed of the rotor **10** such that an increase and a decrease in flow rate at the time of fluid discharge are suppressed.

[0056] The coil spring **14** mounted to the spring holding portion **13** is a spring having extremely low spring force, and when the rotor **10** is pushed from above, the rotor **10** is slightly pushed up by the weak spring force from the spring force of the coil spring **14**, to provide upward loading to the rotor **10**. In addition, the rotor **10** may be biased upward by using a plate spring, etc., in place of the coil spring.

[0057] The rotor **10** is, as shown in FIGS. **8** and **12**, formed such that a circular flat surface portion **11** is provided on the upper portion of a cylindrical portion **12**, and three retention holes **17** are formed in the flat surface portion **11**, and the above-described rollers **15** serving as free-rotating bodies are rotatably-pivotally supported in the respective retention holes **17**. A cover portion **11*a*** is attached to the flat surface portion **11** with three attaching screws **19** so as to cover the three rollers **15**, and the respective rollers **15** in the retention holes **17** are rotatably-pivotally supported with roller spindles **15*a***, to be attached. The three retention holes **17**

provided in the flat surface portion **11** are formed at angular intervals of 120 degrees, and the rollers **15** are rotatabty-pivotally supported with the roller spindles **15***a* radially installed in the respective retention holes **17**. Holes with diameters smaller than those of the retention holes **17** are formed in the cover portion **11***a*, and as shown in FIG. **8**, the upper portions of the respective rollers **15** are exposed so as to slightly protrude from these holes.

[0058] Because the three rollers **15** are disposed at angular intervals of approximately 120 degrees on the rotor **10**, and the three rollers **15** at intervals of 120 degrees touch the circular arc shaped flow path **21** formed within an angular range of approximately 240 degrees at the microfluidic chip **20**, to rotate, it is in a state in which the two rollers **15** always press and crush the circular arc shaped flow path **21** during rotation, thereby it is possible to improve the seal performance of the pump.

[0059] The roller spindles **15***a* of the rollers **15** are radially disposed in planar view as shown in FIG. **7**, and are held in a sloped manner so as to be lower on their outer circumferential portions and higher on their inner circumferential portions as shown in FIG. **8**. Further, the roller **15** is formed into a circular truncated cone shape, and its outer circumferential surface is formed in a sloped manner so as to be thinner on the inner circumferential side, and thicker on the outer circumferential side as in FIG. **8**. Thereby, the three rollers **15** are installed so as to keep their upper outer circumferential surfaces horizontal to the flat surface of the flat surface portion **11** on the flat surface portion **11** of the rotor **10** as shown in FIGS. **3** and **8**.

[0060] In this way, because the rollers **15** radially installed on the flat surface portion **11** are formed into the circular truncated cone shapes, their roller spindles **15***a* are pivotally supported in a sloped manner and the upper outer circumferential surfaces of the respective rollers **15** are horizontal to the flat surface portion **11**, to slightly protrude, when the three rollers **15** touch the circular arc shaped flow path **21** in the microfluidic chip **20** thereon, to rotate, the circumferential velocities of the inner circumferential portions and the outer circumferential portions are made the same. Further, a radius of the rotational trajectory **5** (FIG. **14**) of these three rollers **15** is set to be the same as the radius of the circular arc shaped flow path **21** in the microfluidic chip **20**.

[0061] Further, as shown in FIG. **3**, the rollers **15** are pivotally supported while leaving spaces between the rollers and bottom surfaces of the retention holes **17** such that the outer circumferential surfaces of the rollers **15** do not touch the bottom surfaces of the retention holes **17**. Accordingly, when the rotor **10** rotates, the rotational load of the rollers **15** can be minimized, and the rollers **15** can be rotated with a minimum load. Further, as shown in FIG. **17**, a flow path width h1 of the circular arc shaped flow path **21** and a width h2 in the axial direction of the roller **15** are formed to be substantially the same. Accordingly, the widths h2 in the axial directions of the rollers **15** enable the rollers **15** to roll while pressing and crushing the circular arc shaped flow path **21**, and are minimum, so that when the rollers **15** press the outward discharge flow path **25** to discharge a fluid, the fluid can be gradually discharged, and pulsation of the discharge flow rate can be reduced.

[0062] On the other hand, inside the base **2** into which the rotor **10** is inserted from below, as shown in FIG. **3**, a chip housing portion **8** having a rectangular plate shape is formed, and the microfluidic chip **20** is housed inside the chip housing portion **8** such that the circular arc shaped flow path **21** in the concave portion **27** is on the bottom surface side. At an upper portion of the base **2**, as shown in FIG. **1**, a plate-like cover member **6** is fixed with fixing screws **2***a* so as to cover the top surface of the microfluidic chip **20**, that is, the portion of the circular arc shaped flow path **21** from the top surface on the opposite side of the rollers **15**. The cover member **6** is formed of a hard transparent synthetic resin, and it is possible to observe a state inside the microfluidic chip **20** through the cover member **6**. Further, the cover member **6** may be fixed by using a retainer such as fixation clips in place of the fixing screws **2***a* for fixing the cover member **6**.

[0063] As shown in FIG. **13**, the cover member **6** is formed to have a flat portion **62** and a concave portion **61** on its inner surface on the microfluidic chip **20** side. The concave portion **61** of the cover member **6** is provided at a discharge side portion curved outward of the circular arc shaped flow path **21**, that is, a portion corresponding to the outward discharge flow path **25**, and provided, as shown in FIG. **13**, at a portion where touching the circular arc shaped flow path **21** by each roller **15** ends to discharge a fluid. Here, the outward discharge flow path **25** is a flow path portion curved outward such that the circular arc shaped flow path **21** separates from the portion of the rotational trajectory **5** of the rollers **15** and is led outward as shown in FIG. **14**.

[0064] On an inner surface excluding the concave portion **61** of the cover member **6**, as shown in FIG. **13**, a flat portion **62** is provided. A boundary portion between the flat portion **62** and the concave portion **61** is continuously formed of a gently-curved surface **63** without a level difference. That is, the concave portion **61** formed on the inner surface of the cover member **6** is formed at a position corresponding to the discharge flow path of the circular arc shaped flow path **21**, and the concave portion **61** is formed such that pressing on the circular arc shaped flow path **21** by the rollers **15** is gradually dissipated or reduced in the discharge flow path. Accordingly, when each roller **15** reaches a position in the vicinity of the outward discharge flow path **25** of the circular arc shaped flow path **21**, the pressing force applied to the flow path is reduced, and an increase and a decrease in discharge flow rate to be easily occurred when the roller **15** reaches the outward discharge flow path **25** of the circular arc shaped flow path **21** can be suppressed.

[0065] In order to reduce pulsation of the discharge flow rate of the fluid, on the inner surface of the cover member **6** covering the outward discharge flow path **25**, the concave portion **61** may be provided to reduce a pressing force of the rollers **15** to be applied to the outward discharge flow path **25**, and an intake flow path **24** does not necessarily have to be covered by the concave portion **61** of the cover member **6** for reduction in pulsation. However, as shown in FIG. **18**, on the inner surface of the cover member **6** covering the intake flow path **24** as well, if the concave portion **61** is provided to reduce a pressing force of the rollers **15** to be applied to this portion, for example, even during use in a state where the motor **4** is reversely rotated and the rotor **10** is rotated in a direction opposite to the forward direction shown in FIG. **16** to reverse the fluid sending direction, as in the case of forward rotation, pulsation of the discharge flow rate of the fluid can be reduced.

[0066] The microfluidic chip **20** is, as shown in FIGS. **9**, **10**, and **11**, formed to be rectangular sheet-like from a polymeric elastic body which is soft transparent synthetic resin such as PDMS or silicone resin. A circular concave portion **27** is formed in the center of the bottom surface of the microfluidic chip **20**, and the circular arc shaped flow path **21** is formed in the concave portion **27**. A radius of the circular arc shaped flow path **21** is the same as the radius of the rotational trajectory **5** of the three rollers **15** on the rotor **10**, and the rollers **15** accurately roll on and presses the lower surface of the circular arc shaped flow path **21**. As shown in FIG. **17**, a width (flow path width h1) in the transverse direction of the circular arc shaped flow path **21** is formed to be the same as a length h2 in the axial direction of the roller **15**.

[0067] As shown in FIG. **10**, on the left of the circular arc shaped flow path **21**, an intake flow path **24** to take-in a fluid is formed as a portion where the rotating rollers **15** start to press the circular arc shaped flow path **21**, and on the right of the circular arc shaped flow path **21**, the outward discharge flow path **25** to discharge the fluid is formed as a portion where pressing on the circular arc shaped flow path **21** by the rotating rollers **15** ends. These intake flow path **24** and outward discharge flow path **25** are portions where the circular arc shaped flow path **21** separates from the rotational trajectory **5** of the rollers **15** as described above, and are gently curved and continued from the circular arc shaped flow path **21**. That is, the intake flow path **24** as an intake side neighboring portion of the circular arc shaped flow path **21** and the outward discharge flow path **25** as a discharge side neighboring portion are formed so as to, herein, as shown in FIG. **14**, have a radius of curvature r2 substantially the same as a radius of curvature r1 of the rotational trajectory **5** of the rollers **15**, and separate from the rotational trajectory **5** of the rollers **15** by gentle curving.

[0068] Here, by curving the outward discharge flow path **25** outward at the radius of curvature r2 as a gentle curvature, larger than ½ of the radius of curvature r1 of the rotational trajectory **5** of the rollers **15** of the rotor **10**, and smaller than 2 times the radius of curvature r1, an increase and a decrease in discharge flow rate can be suppressed. Accordingly, as shown in FIG. **16**F, the outward discharge flow path **25** where pressing on the circular arc shaped flow path **21** by the rollers **15** ends is formed such that pressing on the outward discharge flow path **25** by the rollers **15** is gradually ended to suppress an increase and a decrease in discharge flow rate of the fluid. If the radius of curvature r2 of the outward discharge flow path **25** is set to be equal to or smaller than ½ of the radius of curvature r1 of the rotational trajectory **5**, the effect of suppressing pulsation of the discharge flow rate of the fluid becomes smaller.

[0069] In order to reduce pulsation of the discharge flow rate of the fluid, the outward discharge flow path **25** is formed to be gently curved and continued from the circular arc shaped flow path **21**, and the intake flow path **24** does not necessarily have to be gently curved for reduction in pulsation. However, as shown in FIG. **14**, if the intake flow path **24** is also formed to extend at a radius of curvature r2 substantially the same as the radius of curvature r1 of the rotational trajectory **5** of the rollers **15**, to separate from the rotational trajectory **5** of the rollers **15** by gentle curving, for example, at the time of use in a state where the fluid sending direction is inverted by rotating the rotor **10** in a direction opposite to the forward direction in FIG. **16** by reversely rotating the motor **4**, pulsation of the discharge flow rate of the fluid can be reduced even during the reverse rotation as well as during forward rotation.

[0070] As shown in FIG. **13**, the circular concave portion **27** is formed on the bottom surface at the center of the main body of the microfluidic chip **20**, an upper portion of the rotor **10** is inserted into this circular concave portion **27** from below, and the rollers **15** rotate while pressing and crushing the circular arc shaped flow path **21** on the rotational trajectory **5** of the rollers. The intake flow path **24** on the intake side of the circular arc shaped flow path **21** and the outward discharge flow path **25** on the discharge side separate from the circular arc shaped flow path **21** and are extended to the outside of the concave portion **27**, and a tube-like flow path to flow micro-fluid is formed up to a marginal portion of the inside of the microfluidic chip **20**. Further, as shown in FIG. **9**, connecting pipes (stainless steel pipes or the like) **26** for external connection are connected to the end marginal portions of the circular arc shaped flow path **21**.

[0071] As shown in FIG. **11**, the circular arc shaped flow path **21** of the microfluidic chip **20** is formed on the bottom surface such that its cross section swells out to be a mountain shape downward, and the top surface of the circular arc shaped flow path **21** is a flat shape, thereby it is possible for the rollers **15** to make a rolling motion while satisfactorily crushing the circular arc shaped flow path **21** even with low pressing-loading.

[0072] The microfluidic chip **20** of such a shape may be manufactured such that, at the time of manufacture, for example, by using two polymeric elastic sheets (sheet such as a PDMS) having the same thickness, the lower sheet is superposed onto the upper sheet, and the lower sheet is molded to form the circular concave portion **27** on the bottom surface, and the two sheets are further molded and bonded so as to form the circular arc shaped flow path **21** in the concave portion **27**. At that time, the circular arc shaped flow path **21** in the concave portion **27** is manufactured by bonding so as to cause a part of the lower thinner second elastic sheet **23** to bow into a circular arc shape such that the cross section of the flow path swells out to be a mountain shape. Thereby, as shown in FIG. **11**, the portion of the circular arc shaped flow path **21** which serves as a pump portion in the microfluidic chip **20** is to be conjugated under the thicker first elastic sheet **22** so as to cause the thinner second elastic sheet **23** to bow into a circular arc shape.

[0073] As a concrete example of the microfluidic chip **20**, for example, as shown in FIG. **11**, the first elastic sheet **22** with a thickness of approximately 1.1 mm and the second elastic sheet **23** are superposed and bonded, to manufacture the microfluidic chip **20**. In that case, when a depth of the concave portion **27** of the pump portion is set to approximately 0.8 mm, a thickness of the second elastic sheet **23** of the pump portion is to be approximately 0.3 mm, and the circular arc shaped flow path **21** has a thickness of the outer layer on its swelling-out side of approximately 0.1 mm, and a height width of a space in the circular arc shaped flow path **21** of approximately 0.1 mm.

[0074] In this way, because the circular concave portion **27** is formed on the lower surface of the second elastic sheet **23**, and the circular arc shaped flow path **21** is formed in the concave portion **27**, it is possible to form the circular arc shaped flow path **21** which may be crushed with extremely low pressing-loading by adjusting a depth of the concave portion **27**. That is, because it is possible to adjust the thickness of the outer layer of the circular arc shaped flow path **21** by changing the depth of the concave portion **27**, it is possible to manufacture the circular arc shaped flow path **21** so as to minimize loading at the time of pressing and crushing by the rollers **15** while keeping the durability of the circular arc shaped flow path **21** high.

[0075] In addition, in the above-described embodiment, the motor **4** is fixed upward from below the base **2**, the circular arc shaped flow path **21** for a peristaltic pump is provided in the lower surface of the microfluidic chip **20** housed in the chip housing portion **8** in the base **2**, and the rollers **15** for pressing are pivotally supported on the top surface of the rotor **10** which is rotary-driven by the motor **4**. However, the present invention may be configured such that those members are installed in the upside-down positions and forms, and the rollers on the lower surface of the rotor which are installed on the upper side of the circular arc shaped flow path are pressed against the circular arc shaped flow path formed in the top surface of the microfluidic chip **20**, and the rotor is rotary-driven by the motor which is installed so as to set its output shaft downward.

[0076] Further, the shape of the microfluidic chip **20** housed in the chip housing portion **8** is rectangular as shown in FIG. **9**. However, the shape of the microfluidic chip **20** may be square or triangular. Further, the microfluidic chip **20** may be configured such that the respective chip members are formed as chip modules, and as a chip module which uses those chip modules in combination.

[0077] Next, the using mode and the operation of the micro peristaltic pump device of the above-described configuration will be described. This micro peristaltic pump is used at the time of flowing micro-fluid such as a culture solution or various types of reagents into the flow path of the microfluidic chip **20**, to perform cell culturing, reagent screening, chemical analysis, and the like.

[0078] The microfluidic chip **20** to be used is housed such that the fixing screws **2***a* on the pump top surface are taken off to detach the cover member **6**, and as shown in FIG. **8**, the chip housing portion **8** in the base **2** is opened, and the circular arc shaped flow path **21** in the concave portion **27** of the microfluidic chip **20** is set on the downside at a predetermined position inside the chip housing portion **8**. In this way, because it is possible to simply and easily set the microfluidic chip **20** by merely detaching the cover member **6**, in the case where the microfluidic chip **20** is replaced in each culturing or analysis, it is possible to very easily replace the chip, and easily use the microfluidic chip to be disposable.

[0079] When the microfluidic chip **20** is set in the chip housing portion **8**, the cover member **6** is attached to a predetermined position, and the cover member **6** is fixed with the fixing screws **2***a*, the circular arc shaped flow path **21** in the concave portion **27** of the microfluidic chip **20** touches the three rollers **15** on the rotor **10**, to be pressed and crushed, and the rotor **10** compresses the coil spring **14** to be slightly pushed down. Although the pressing-loading applied to the rollers **15** at this time is extremely low, because the outer layer of the circular arc shaped flow path **21** swelling out to be a mountain shape is extremely thin, and the non-pressed side of the circular arc shaped flow path **21** is a flat shape, as shown in FIG. **3**, the outer layer of the circular arc shaped flow path **21** touched by the rollers **15** are easily crushed with the low loading.

[0080] In this state, when the motor **4** starts, the rotor **10** rotates in a clockwise direction in FIG. **16**, the three rollers **15** move as shown in A to H in FIG. **16** while rolling, and the three rollers **15** at intervals of 120 degrees freely rotate on the rotational trajectory **5** while sequentially pressing and crushing the circular arc shaped flow path **21**, to move along the circular arc shaped flow path **21**. At this time, in A to E in FIG. **16**, the roller **15** (**2**) rolls to push out the fluid inside the circular arc shaped flow path **21**, and the fluid is accordingly sent out of the outward discharge flow path **25**.

[0081] Then, when the roller **15** (**2**) reaches the outward discharge flow path **25**, as shown in F to G in FIG. **16**, the roller **15**(**2**) gradually separates from the outward discharge flow path **25**. At this time, the fluid to be sent out of the outward discharge flow path **25** is sent by a pushing-out operation of the roller **15** (**1**) positioned in front of the roller **15** (**2**), and the roller **15** (**2**) rolls to gradually separate from the outward discharge flow path **25** and release pressing, to push the fluid out of the outward discharge flow path **25**. This is because the outward discharge flow path **25** is shaped to deviate from the rotational trajectory **5** of the rollers while gently curving. In addition, at this time, the roller **15**(**2**) presses the outward discharge flow path **25** in a state where the pressing force is made weaker by the concave portion **61** of the cover member **6** than on an intermediate portion. Therefore, the flow rate of the fluid to be discharged from the outward discharge flow path **25** is avoided from rapidly increasing.

[0082] At the timing of separation of the rollers **15** from the outward discharge flow path **25**, the control circuit **30** performs control to rapidly increase the rotation speed of the motor **4** for only a short period of time. When the roller **15** (**2**) separates from the outward discharge flow path **25** in G of FIG. **16**, the pressed and crushed outward discharge flow path **25** restores and causes a negative pressure to be generated inside the flow path, so that the flow rate easily rapidly decreases. At this time, the rotation speed of the motor **4** is rapidly increased for only a short period of time, and the roller **15** (**1**) as the next roller on the upstream side (non-rotating side) of the separated roller **15** is also rapidly accelerated.

[0083] Therefore, due to rapid pressing by the roller **15** (**1**), the discharge flow rate is increased to compensate for the decrease in flow rate caused by the negative pressure, and the rapid decrease in flow rate accompanying the negative pressure inside the flow path when the roller **15** separates from the outward discharge flow path **25** is suppressed. After the rapid acceleration for a short period of time, the rotation speed of the motor **4** is immediately returned to a normal speed.

[0084] In this way, the roller **15** (**2**) completely separates from the outward discharge flow path **25**, and in H of FIG. **16**, the fluid is sent out of the outward discharge flow path **25** by the roller **15** (**1**), and a substantially constant discharge flow rate is maintained.

[0085] Then, when the roller **15** (**1**) reaches the outward discharge flow path **25**, in the same manner as described above, the roller **15** (**1**) gradually separates from the outward discharge flow path **25**, and at this time, the outward discharge flow path **25** is pressed in a state where the pressing force is weakened by the concave portion **61** of the cover member **6**. In addition, at the separation timing of the roller **15** (**1**), the control circuit **30** performs speed control to rapidly increase the rotation speed of the motor **4** for a short period of time. Accordingly, the decrease in flow rate caused by the negative pressure generated when the roller **15** (**1**) separates from the outward discharge flow path **25** is compensated for by the acceleration control of the roller **15** as the next roller on the upstream side of the roller **15** (**1**), and a rapid decrease in flow rate of the fluid to be discharged from the outward discharge flow path **25** is accordingly suppressed, and a substantially constant discharge flow rate is maintained.

[0086] In this way, the outward discharge flow path **25** where pressing on the circular arc shaped flow path **21** by each roller **15** ends is curved at a gentle curvature, and the outward discharge flow path **25** is covered by the concave portion **61** of the cover member **6**, so that the roller **15** gradually separates from the outward discharge flow path **25** of the circular arc shaped flow path **21**, and pressing on the outward discharge flow path **25** by the roller **15** is weakened. Therefore, a rapid increase in flow rate of the fluid when pushing the fluid out of the outward discharge flow path **25** that was pressed and crushed by the roller **15** is suppressed, and further, control is performed such that, at the timing when each roller finishes touching the circular arc shaped flow path **21** and separates therefrom, the rotation speed is rapidly increased for a short period of time, and accordingly, a change in flow rate to be sent out of the circular arc shaped flow path of the microfluidic chip, in particular, pulsation of the fluid flow rate due to a negative pressure when each roller **15** separates from the circular arc shaped flow path **21**, can be suppressed to be small.

[0087] FIG. **19** shows a peristaltic pump device of another embodiment. This peristaltic pump device is provided with a buffer chamber **41** in a flow path on the discharge side of the circular arc shaped flow path **21**, and a narrowed portion **42** is connected to a flow path on the discharge side of the buffer chamber **41**, and configured such that a fluid is sent out through the narrowed portion **42**. The buffer chamber **41** is formed as a flow path having a closed tip end, and as the narrowed portion **42**, for example, a micro needle valve is used.

[0088] With this configuration, when the roller **15** presses the circular arc shaped flow path **21** to discharge the fluid, a fluid pressure on the discharge side is increased by the narrowed portion **42**, and the fluid compresses air inside the buffer chamber **41** and flows into the buffer chamber. Thereafter, the fluid is gradually discharged at a small flow rate through the narrowed portion **42**, and the increase in fluid pressure in the outward discharge flow path **25** is absorbed by the buffer chamber **41**. Therefore, the change in discharge flow rate of the fluid when the roller **15** separates from the outward discharge flow path **25** of the circular arc shaped flow path **21** is absorbed by the buffer chamber **41** and the narrowed portion **42**, and pulsation of the discharge flow rate is reduced to be smaller.

[0089] FIG. **20** to FIG. **23** show a peristaltic pump device of a second embodiment, and FIG. **20** shows a microfluidic chip **220** of the same. In the plan views shown in FIG. **20**, FIG. **21**, and FIG. **23**, the lines showing internal flow paths, etc., which do not appear in the plan view of the microfluidic chip **220** are shown by solid lines for easy understanding.

[0090] The microfluidic chip **220** is formed to be rectangular sheet-like from a polymeric elastic body which is soft transparent synthetic resin such as PDMS or silicone resin. A circular concave portion **227** is formed in the center of the main body of the microfluidic chip **220**, and a circular arc shaped flow path **221** is formed in the concave portion **227**. A radius of the circular are shaped flow path **221** is the same as the radius of the rotational trajectory **5** of the three rollers **15** (FIG. **7**) on the rotor **10** (FIG. **7**), and the rollers accurately roll on and press a lower surface of the circular arc shaped flow path **221**. A width in the transverse direction of the circular arc shaped flow path **221** is the same as the length in the axial direction of the roller **15**.

[0091] As shown in FIG. **20**, on the left of the circular arc shaped flow path **221**, an intake flow path **224** to take-in a fluid is formed as a portion where the rotating roller **15** (FIG. **7**) starts to press the circular arc shaped flow path **221**, and on the right of the circular arc shaped flow path **221**, a discharge flow path **225** to discharge a fluid is formed as a portion where the rotating roller **15** presses the circular arc shaped flow path **221** to push out a fluid. This discharge flow path **225** is formed by being curved such that a radius of curvature r3 of a circular arc portion of the discharge flow path **225** is larger than the radius of curvature r1 of the rotational trajectory of the rollers **15** and smaller than 1.5 times the radius of curvature r1 of the rotational trajectory of the rollers **15** to cause the circular arc shaped flow path **221** to gradually separate from the rotational trajectory **5** of the rollers **15**.

[0092] Further, as shown in FIG. **20**, the circular arc center C2 of the discharge flow path **225** is formed to deviate to a circular arc opening side (discharge side on the lower right in FIG. **20**) from the rotary shaft center C1 of the rotor **10**. Accordingly, the discharge flow path **225** is shaped such that it separates from the rotational trajectory **5** of the rollers **15** by gentle curving, and when the rollers **15** rotate, the rollers **15** gradually deviate from the discharge flow path **225**.

[0093] It is also possible that, as shown in FIG. **23**, the discharge flow path shaped to separate from the rotational trajectory **5** of the rollers **15** by gentle curving is formed such that the circular are center C3 of the discharge flow path **229** deviates from the rotary shaft center C1 of the rotor **10** to the lower side in FIG. **23** that is the circular arc opening side. The discharge flow path **229** is formed by being curved such that a radius of curvature r4 of the circular arc portion is larger than the radius of curvature r1 of the rotational trajectory of the rollers **15** and smaller than 1.5 times the radius of curvature r1 of the rotational trajectory of the rollers **15**. Accordingly, like the discharge flow path **225** shown in FIG. **20**, the discharge flow path **229** is shaped such that it separates from the rotational trajectory **5** of the rollers **15** by gentle curving, and when the rollers **15** rotate, the rollers **15** gradually deviate from the discharge flow path **229**. Here, in a case where the discharge flow path **225** or **229** is formed by being curved such that the radius of curvature r3 of the discharge flow path **225** or the radius of curvature r4 of the discharge flow path **229** is smaller than the radius of curvature r1 of the rotational trajectory **5** of the rollers **15**, or equal to or larger than 1.5 times the radius of curvature r1, when the rollers **15** rotate, it is difficult for the rollers **15** to rotate so as to gradually deviate or separate from the discharge flow path **225** or **229**. Therefore, the effect of suppressing pulsation of the discharge flow rate of the fluid becomes smaller.

[0094] As shown in FIG. **20**, inside the microfluidic chip **220**, a connecting pipe for external connection (stainless steel pipe, etc.) is connected to an end portion of the intake flow path **224** on an intake side of the circular are shaped flow path **221**. The discharge flow path **225** on the discharge side enters the inside of the microfluidic chip **220** from the concave portion **227** and is communicatively connected to a buffer chamber **222** provided inside the microfluidic chip **220**.

[0095] Inside the microfluidic chip **220**, two buffer chambers **222** and **223** are formed, a narrowed portion **226** is connected between the buffer chamber **222** and the buffer chamber **223**, a narrowed portion **228** is connected to an output side of the buffer chamber **223**, and an output side of the narrowed portion **228** is communicatively connected to a discharge port not shown in the drawings. Cross-sectional areas of the buffer chambers **222** and **223** are formed to be larger than those of a standard flow path and narrowed portions **226** and **228**, and generate a buffer effect for a change in flow rate of the discharge fluid.

[0096] Accordingly, the fluid to be discharged from the peristaltic pump is discharged from the discharge flow path **225** of the circular arc shaped flow path **221** through the buffer chamber **222**, the narrowed portion **226**, the buffer chamber **223**, and the narrowed portion **228**, and pulsation of the discharge flow rate in the peristaltic pump is greatly absorbed by the buffer chambers **222** and **223** and the narrowed portions **226** and **228** connected in series.

[0097] The microfluidic chip **220** can be manufactured such that, in the same manner as described above, for example, by using two polymeric elastic sheets (sheet such as a PDMS) having the same thickness, the lower sheet is superposed onto the upper sheet, and the lower sheet is molded to form the circular concave portion **227**, and the two sheets are further molded and bonded so as to form the circular are shaped flow path **221** in the concave portion **227**. At that time, the circular arc shaped flow path **221** in the concave portion **227** is bonded so as to cause a part of the lower thinner second elastic sheet to bow into a circular arc shape such that the cross section of the flow path swells out to be a mountain shape.

[0098] Thereby, the portion of the circular arc shaped flow path **221** which serves as a pump portion in the microfluidic chip **220** is to be conjugated under the thicker first elastic sheet so as to cause the thinner second elastic sheet to bow into a circular arc shape. In this microfluidic chip **220**, as described above, the circular arc shaped flow path **221** is formed in the circular concave portion **227**, and the discharge flow path **225** thereof is shaped to separate from the rotational trajectory **5** of the rollers **15** such that when the rollers **15** rotate, the rollers **15** gradually deviate from the discharge flow path **225** or the discharge flow path **229** (FIG. **23**).

[0099] The graph shown in FIG. **22**B shows a change in discharge flow rate measured in the peristaltic pump provided with the microfluidic chip **220** configured as described above. This graph of FIG. **22**B shows a change in discharge flow rate when the rotor **10** is driven by rotating the motor **4** at a constant speed and the three rollers **15** revolve while crushing the circular arc shaped flow path **21** to send a fluid. The graph of FIG. **22**C shows a change in discharge flow rate of a standard peristaltic pump conventionally generally used (a peristaltic pump structured to discharge a fluid by sequentially pressing and crushing a circular arc shaped tube by a plurality or rollers).

[0100] The graph of FIG. **22**C shows that the flow rate increases at the timing Sh when the plurality of rollers separate from the circular arc shaped flow path, and immediately after that, the discharge flow rate rapidly greatly decreases. This phenomenon is caused by a negative pressure generated inside the tube when, after the roller presses and crushes the tube to push out the fluid, at the timing Sh when the roller separates from the tube, the crushed tube swells up due to its elastic restoring force.

[0101] On the other hand, in the peristaltic pump having the above-described configuration provided with the microfluidic chip **220**, as shown in the graph of FIG. **22**B, the respective rollers **15** rotate to gradually separate from the discharge flow path **225**, and on the discharge side of the microfluidic chip **220**, two buffer chambers **222** and **223** and narrowed portions **226** and **228** are provided, so that at the timing Sh of separation of each roller **15**, although the discharge flow rate changes upward and downward, such upward and downward changes are reduced, and this proves that pulsation of the discharge flow rate is suppressed.

[0102] The rotor **10** including the rollers **15** is rotary-driven by the motor **4**, and the rotation speed of the motor **4** is controlled by the control circuit **30** as shown in FIG. **15**.

[0103] The control circuit **30** consists of a microcomputer, and based on a motor control program stored in advance, the control circuit **30** controls the rotation speed of the motor **4** so as to suppress pulsation of the discharge flow rate of the micro peristaltic pump **1**. For this operation, in the memory **31** of the control circuit **30**, the rotation angle of the rotor **10** and command rotation speed data are stored in advance as, for example, table data. The rotation angle and the command rotation speed data are measured by conducting a performance test of a peristaltic pump manufactured by way of trial, and data optimal for reduction in pulsation is stored in the memory **31**.

[0104] That is, for the peristaltic pump device configured as described above, a performance test is conducted while the discharge flow rate is measured, and at this time, the rotation speed of the motor **4** is controlled such that the rotation speed of the rotor **10** is rapidly increased at the timing Sh of a great decrease in discharge flow rate to make the discharge flow rate substantially constant. The rotation speed data at this time is stored as command rotation speed data in the memory **31** in association with the rotation angle of the rotor **10**.

[0105] When driving the motor **4**, the control circuit **30** storing the command rotation speed data determines a command rotation speed based on a detection signal (rotation angle signal) input from the rotation sensor **33**, and controls driving of the motor **4** based on the command rotation speed. In the rotation control of the motor **4**, when each roller **15** on the rotor **10** reaches the discharge flow path **225** of the microfluidic chip **220**, the rotation speed of the rotor **10** is rapidly increased at the timing Sh when the roller **15** separates from the discharge flow path **225**, and immediately after that, the rotation speed is returned to the normal speed. Accordingly, pulsation of the discharge flow rate is greatly reduced as shown in the graph of FIG. **22**A.

[0106] Next, operation of the peristaltic pump device configured as described above is described. As shown in FIG. **8**, in the same manner as described above, the microfluidic chip **220** to be used is housed such that the cover member **6** of the base **2** is detached and the top surface of the chip housing portion **8** is opened, and the circular arc shaped flow path **221** in the microfluidic chip **220** is set on the downside at a predetermined position inside the chip housing portion **8**.

[0107] When the microfluidic chip **220** is set in the chip housing portion **8**, the cover member **6** is attached to a predetermined position, and the cover body member **6** is fixed with the fixing screws **2***a*, the circular arc shaped flow path **221** in the concave portion **227** of the microfluidic chip **220** touches the three rollers **15** on the rotor **10**, to be pressed, and the rotor **10** compresses the coil spring **14** to be slightly pushed down. Although the pressing-loading applied to the rollers **15** at this time is extremely low, because the outer layer of the circular arc shaped flow path **221** swelling out to be a mountain shape is extremely thin, and the non-pressed side of the circular arc shaped flow path **221** is a flat shape, the outer layer of the circular arc shaped flow path **221** touched by the rollers **15** are easily crushed with the low loading.

[0108] In this state, when the motor **4** starts, the rotor **10** rotates and the three rollers **15** revolve in a clockwise direction in FIG. **21**. At this time, as shown in A to H of FIG. **21**, the three rollers **15** move while rolling, and the respective rollers **15** at intervals of 120 degrees freely rotate while sequentially pressing and crushing the circular arc shaped flow path **221** from the intake flow path **224** to the discharge flow path **225** side, and the rollers **15** revolve on the rotation trajectory **5**.

[0109] At this time, in A to B of FIG. **21**, the roller **15** (**2**) rolls to push the fluid out of the circular arc shaped flow path **221** and the fluid is discharged from the discharge flow path **225**, and then, in C to F of FIG. **21**, the width of the discharge flow path **225** pressed and crushed by the roller **15** (**2**) is gradually reduced, and in G of FIG. **21**, the roller **15** (**2**) separates from the discharge flow path **225**. At this time, in the discharge flow path **225**, elastic sheets are restored due to their elastic force, and a negative pressure is applied inside, however, at the same time, the rotation speed of the rotor **10** is increased, so that the roller **15** (**1**) on the upstream side (non-rotating side) of the roller **15** (**2**) acts to rapidly push the fluid out.

[0110] Accordingly, the decrease in discharge flow rate caused by the negative pressure generated inside the discharge flow path **225** is effectively compensated for, and pulsation at the timing Sh of separation of the roller **15** from the discharge flow path **225** is greatly reduced by the control to temporarily increase the rotation speed of the rotor **10** and then immediately return it to the normal speed.

[0111] FIG. **22**A shows a graph of a change in discharge flow rate measured when a performance test was conducted for the peristaltic pump device having the above-described configuration provided with the microfluidic chip **220** by operating the control circuit **30** to control the rotation speed of the motor **4**. This FIG. **22**A shows that upper and lower peaks of the discharge flow rate are greatly reduced and pulsation is greatly reduced by performing control such that the rotation speed of the rollers **15** is temporarily increased at the timing Sh of separation of each roller **15** from the discharge flow path **225**, and immediately after that, the rotation speed is returned to the normal speed.

[0112] For this effect of reducing pulsation of the discharge flow rate, the discharge flow path **225** of the microfluidic chip **220** is shaped to gradually separate from the rotational trajectory of the rollers **15**, a buffer effect is produced by the buffer chambers **222** and **223** and the narrowed portions **226** and **228**, and the rotation speed of the motor **4** is controlled by the control circuit **30** to be temporarily increased at the timing Sh and then immediately returned to the normal speed, and through these operations, upward and downward changes, that is, pulsation of discharge flow rate can be greatly reduced.

[0113] That is, comparing the graph A with the graphs B and C in FIG. **22**, in the graph of FIG. **22**B, as shown in FIG. **20**, the circular arc center of the discharge flow path **225** is formed to deviate from the rotary shaft center C1 of the rotor **10** to the discharge side, and when each roller **15** separates from the discharge flow path **225** after pressing and crushing it, the roller gradually separates from the discharge flow path, and by the buffer effect of the buffer chambers **222** and **223** and the narrowed portions **226** and **228** provided on the discharge side, the flow rate change at the timing Sh is reduced. Further, in the peristaltic pump device of the present embodiment, since the rotation speed of each roller **15** is controlled to temporarily increase at the timing Sh, as shown in the graph of FIG. **22**A, at the timing Sh of separation of each roller **15** from the discharge flow path **225**, upward and downward changes in discharge flow rate are greatly reduced and pulsation is greatly suppressed.

[0114] In this way, when the roller **15** separates from the discharge flow path **225** that the roller pressed, a negative pressure applied inside the discharge flow path **225** due to a restoring force of the microfluidic chip **220** is suppressed by sending-out of the fluid through the buffer chambers **222** and **223** and the narrowed portions **226** and **228** according to gradual separation of the roller **15** from the discharge flow path **225** and further controlling to temporarily increase the rotation speed of the rotor **10** at the timing of the negative pressure, and a rapid decrease in flow rate and a subsequent rapid increase are reduced. Accordingly, the flow rate of the fluid to be sent out of the circular arc shaped flow path **221** of the microfluidic chip **220** of the peristaltic pump is uniformized, and pulsation of the flow rate of the fluid can be reduced to be sufficiently small.

[0115] FIG. **24** to FIG. **26** show a microfluidic chip **320** of a third embodiment of the peristaltic pump device. In FIG. **24** to FIG. **26**, for convenience of description, a state where the inner surface of the microfluidic chip **320** is turned upward is shown, and the microfluidic chip **320** shown in the drawings is housed inside the chip housing portion **8** on the base **2** in a state turned inside out from the form shown in the drawings, to be used.

[0116] This microfluidic chip **320** is manufactured in the same manner as described above, for example, by using two polymeric elastic sheets (sheet such as a PDMS) having the same thickness, the lower sheet is superposed onto the upper sheet, and the lower sheet is molded to form a circular concave portion **327** at the center, and a circular arc shaped flow path **321** is further formed in the concave portion **327**.

[0117] At that time, the circular arc shaped flow path **321** in the concave portion **327** is manufactured by bonding so as to cause a part of the lower thinner second elastic sheet to bow into a circular arc shape such that the cross section of the flow path swells out to be a mountain shape. Thereby, the portion of the circular arc shaped flow path **321** which serves as a pump portion in the microfluidic chip **320** is to be conjugated under the thicker first elastic sheet so as to cause the thinner second elastic sheet to bow into a circular arc shape. The circular arc shaped flow path **321** is formed to have a flow path width substantially the same as a width in the axial direction of the rollers **15**, and a radius of curvature substantially the same as a radius of the rotation trajectory of the rollers **15**.

[0118] Further, in the circular arc shaped flow path **321**, a discharge flow path **325** on the discharge side of the circular arc shaped flow path swells out of a surface of the microfluidic chip **320** to be a circular arc shape, and be gradually embedded inside the microfluidic chip **320** toward a discharge end. That is, as shown in FIG. **24** to FIG. **26**, the circular arc shaped flow path **321** is configured such that an intake flow path **324** on the intake side swells out of the surface to be a circular arc shape, and the discharge flow path **325** gradually enters the inside of the microfluidic chip **320** toward its discharge end to cause the swelling-out portion to gradually disappear. Accordingly, as shown in FIG. **26**, when the roller **15** reaches the discharge flow path **325** during rotation, the roller gradually separates from the discharge flow path **325**.

[0119] In a state where the microfluidic chip **320** is housed inside the chip housing portion **8** of the base **2** described above, the rollers **15** of the rotor **10** described above rotate in a counterclockwise direction in FIG. **26**. Therefore, the right side in FIG. **26** serves as an intake-side flow path of the circular arc shaped flow path **321**, and the left side serves as a discharge flow path **325** of the circular arc shaped flow path **321**. As shown in FIG. **25**, the discharge flow path **325** is formed to be gradually embedded inside the microfluidic chip **320** toward the discharge end to cause the swelling-out portion to gradually disappear.

[0120] The present invention may be configured such that, in the same manner as described above, on the output port side of the discharge end of the discharge flow path **325**, buffer chambers **222** and **223** and narrowed portions **226** and **228** (FIG. **20**) are provided inside the microfluidic chip **320** and communicatively connected, although this configuration is not shown in the drawings. In addition, the present invention may also be configured such that the control circuit **30** shown in FIG. **15** is connected to the driving motor **4** and the motor **4** is controlled by the control circuit **30**.

[0121] The microfluidic chip **320** described above is housed in the chip housing portion **8** inside the base **2** in the same manner as described above, and when the motor **4** is started to rotary-drive the rotor **10**, the three rollers **15** revolve in a counterclockwise direction as shown in FIG. **26**, and while pressing and crushing the circular arc shaped flow path **321** of the microfluidic chip **320**, push a fluid out of the discharge flow path **325** to send the fluid.

[0122] When the rotor **10** is rotary-driven, the three rollers **15** rotationally move while pressing and crushing the circular arc shaped flow path **321**, freely rotate while sequentially pressing the flow path from the intake flow path **324** toward the discharge flow path **325** side, and revolve on the rotational trajectory **5** as shown in FIG. **26**.

[0123] Each roller **15** rolls to push the fluid out of the circular arc shaped flow path **321** and the fluid is discharged from the discharge flow path **325**, and when each roller **15** rolls on the discharge flow path **325** while pressing and crushing the discharge flow path, a pressing and crushing amount by the roller **15** gradually decreases toward the discharge end, and as a result, the roller **15** gradually separates from the discharge flow path **325**.

[0124] When the roller **15** separates from the discharge flow path **325**, the discharge flow path is restored due to an elastic force of the microfluidic chip **320** and a negative pressure is easily applied inside, however, a swelling-out sectional area of the discharge flow path **325** gradually decreases and enters the chip and the roller **15** gradually separates from the discharge flow path **325**, and at the same time of separation of the roller **15**, the rotation speed of the rollers **15** is controlled to temporarily increase to cause the roller **15** on the upstream side (non-rotating side) to rapidly push out the fluid, and then immediately returns to the normal speed.

[0125] By this control, the decrease in discharge flow rate caused by the negative pressure generated inside the discharge flow path **325** is compensated for, and pulsation of the flow rate that occurs at the timing of separation of the roller **15** from the discharge flow path **325** is greatly reduced by gradual separation of the roller **15** from the discharge flow path **325** and control to increase the rotation speed of the roller **15**. Further, by the buffer effect of the buffer chambers **222** and **223** and the narrowed portions **226** and **228** provided on the discharge side, pulsation of the discharge flow rate can also be effectively reduced. In this way, the flow rate of the fluid to be sent out of the circular arc shaped flow path **321** of the microfluidic chip **320** of the peristaltic pump is uniformized, and pulsation of the flow rate of the fluid can be reduced to be sufficiently small.

What is claimed is:

1. A peristaltic pump device comprising:

a base that includes a cover member, and a chip housing portion formed inside;

a sheet-like microfluidic chip housed inside the chip housing portion and has a circular arc shaped flow path formed inside; and

a micro peristaltic pump to a tip end portion of which a rotor rotatably-pivotally supporting a plurality of rollers is attached so as to be rotary-driven by a motor, and which is fixed to the base by pressing the rollers against the circular arc shaped flow path, wherein

on a flat surface perpendicular to a rotary shaft of the rotor, the plurality of rollers are pivotally supported at even angular intervals to freely rotate in pressure-contact with the circular arc shaped flow path on the flat surface,

the circular arc shaped flow path of the microfluidic chip is formed into a circular arc shape by swelling out of a surface of the microfluidic chip, and disposed along a rotational trajectory of the plurality of rollers, and

a discharge flow path is formed such that the rollers gradually separate from the discharge flow path on a discharge side of the circular arc shaped flow path when the rollers rotate.

2. The peristaltic pump device according to claim **1**, wherein the discharge flow path on the discharge side of the circular arc shaped flow path is formed by being curved such that a radius of curvature of a circular arc portion is larger than a radius of curvature of the rotational trajectory of the rollers and smaller than 1.5 times the radius of curvature of the rotational trajectory of the rollers, and a circular arc center of the discharge flow path deviates to an arc opening side from a center of the rotary shaft of the rotor.

3. The peristaltic pump device according to claim **1**, wherein the discharge flow path of the circular arc shaped flow path is formed into a circular arc shape by partially swelling out of a surface of the microfluidic chip, and formed so as to be gradually embedded inside the microfluidic chip toward a discharge end to cause the swelling-out portion to gradually disappear.

4. The peristaltic pump device according to claim **2**, wherein a buffer chamber is provided in a flow path on a discharge side of the circular arc shaped flow path inside the microfluidic chip, and a narrowed portion is provided in a flow path on a discharge side of the buffer chamber.

5. The peristaltic pump device according to claim **3**, wherein a buffer chamber is provided in a flow path on a discharge side of the circular arc shaped flow path inside the microfluidic chip, and a narrowed portion is provided in a flow path on a discharge side of the buffer chamber.

6. The peristaltic pump device according to claim **2**, wherein a control circuit to control a rotation speed of the motor is provided, and the control circuit is provided with a rotation sensor that detects a rotational position of the rotor and generates a detection signal indicating the rotational position, and a memory that stores in advance the rotational position of the rotor and rotation speed data of the motor corresponding to the rotational position.

7. The peristaltic pump device according to claim **3**, wherein a control circuit to control a rotation speed of the motor is provided, and the control circuit is provided with a rotation sensor that detects a rotational position of the rotor and generates a detection signal indicating the rotational position, and a memory that stores in advance the rotational position of the rotor and rotation speed data of the motor corresponding to the rotational position.

8. The peristaltic pump device according to claim **4**, wherein a control circuit to control a rotation speed of the motor is provided, and the control circuit is provided with a rotation sensor that detects a rotational position of the rotor and generates a detection signal indicating the rotational position, and a memory that stores in advance the rotational position of the rotor and rotation speed data of the motor corresponding to the rotational position.

9. The peristaltic pump device according to claim **5**, wherein a control circuit to control a rotation speed of the motor is provided, and the control circuit is provided with a rotation sensor that detects a rotational position of the rotor and generates a detection signal indicating the rotational position, and a memory that stores in advance the rotational position of the rotor and rotation speed data of the motor corresponding to the rotational position.

10. The peristaltic pump device according to claim **6**, wherein the control circuit is configured such that a command rotation speed of the motor from data stored in the memory is calculated based on a detection signal transmitted from the rotation sensor, and rotation of the motor is controlled based on the command rotation speed to, in a stroke in which the rollers separate from the discharge flow path after pressing the discharge flow path to push out the fluid, increase the rotation speed of the rollers, and immediately after the rollers separate from the discharge flow path, the rotation speed of the rollers is reduced to return the rotation speed to a normal speed.

11. The peristaltic pump device according to claim **7**, wherein the control circuit is configured such that a command rotation speed of the motor from data stored in the memory is calculated based on a detection signal transmitted from the rotation sensor, and rotation of the motor is controlled based on the command rotation speed to, in a stroke in which the rollers separate from the discharge flow path after pressing the discharge flow path to push out the fluid, the rotation speed of the rollers is increased, and immediately after the rollers separate from the discharge flow path, the rotation speed of the rollers is reduced to return the rotation speed to a normal speed.

12. The peristaltic pump device according to claim **8**, wherein the control circuit is configured such that a command rotation speed of the motor from data stored in the memory is calculated based on a detection signal transmitted from the rotation sensor, and rotation of the motor is controlled based on the command rotation speed to, in a stroke in which the rollers separate from the discharge flow path after pressing the discharge flow path to push out the fluid, increase the rotation speed of the rollers, and immediately after the rollers separate from the discharge flow path, the rotation speed of the rollers is reduced to return the rotation speed to a normal speed.

13. The peristaltic pump device according to claim **9**, wherein the control circuit is configured such that a command rotation speed of the motor from data stored in the memory is calculated based on a detection signal transmitted from the rotation sensor, and rotation of the motor is controlled based on the command rotation speed to, in a stroke in which the rollers separate from the discharge flow path after pressing the discharge flow path to push out the fluid, the rotation speed of the rollers is increased, and immediately after the rollers separate from the discharge flow path, the rotation speed of the rollers is reduced to return the rotation speed to a normal speed.

14. The peristaltic pump device according to claim **1**, wherein a concave portion is formed on an inner surface of the cover member, and the concave portion is formed at a position corresponding to the discharge flow path of the circular arc shaped flow path such that pressing on the circular arc shaped flow path by the rollers gradually decreases in the discharge flow path.

15. The peristaltic pump device according to claim **14**, wherein a buffer chamber is provided in a flow path on a discharge side of the circular arc shaped flow path inside the microfluidic chip, and a narrowed portion is provided in a flow path on a discharge side of the buffer chamber.

16. The peristaltic pump device according to claim **14**, wherein a control circuit to control a rotation speed of the motor is provided, and the control circuit is provided with a rotation sensor that detects a rotational position of the rotor and generates a detection signal indicating the rotational position, and a memory that stores in advance the rotational position of the rotor and rotation speed data of the motor corresponding to the rotational position.

17. The peristaltic pump device according to claim **15**, wherein a control circuit to control a rotation speed of the motor is provided, and the control circuit is provided with a rotation sensor that detects a rotational position of the rotor and generates a detection signal indicating the rotational position, and a memory that stores in advance the rotational position of the rotor and rotation speed data of the motor corresponding to the rotational position.

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