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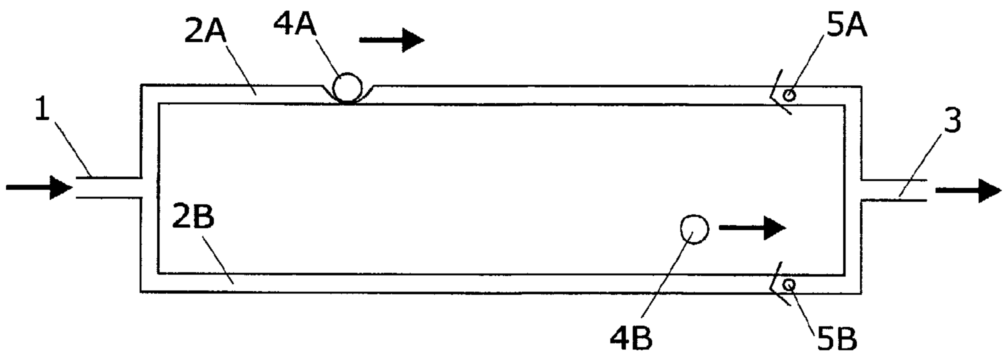
(54) Title: FLUID PUMP



(57) Abstract: A peristaltic pump comprising (i) two fluid flow tubes; (ii) two pressure members operable to urge fluid flow through the tubes, the pressure members being mounted on a common rotatable element and operating with a phase difference between their respective movement cycles; and (iii) a non-return valve in each tube downstream of its region of contact with the associated pressure member; wherein for each of the two tubes there is no more than one associated pressure member; the arrangement being such that the first valve opens at a differential fluid pressure corresponding to that at which the second pressure member releases the second tube and (b) the second valve opens at a differential fluid pressure corresponding to that at which the first pressure member releases the first tube, so that the opening of the first valve coincides with cessation of flow in the second tube.

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Fluid pump

Field of the invention

This invention relates to a fluid pump of the peristaltic type, to assemblies forming part of the pump, to apparatus incorporating it and to a method for its operation.

Background to the invention

A peristaltic pump is a form of positive displacement pump for generating fluid flow through a deformable tube. The tube is "pinched" usually by a succession of pressure exerting elements such as rollers, which progress along a length of the tube pushing fluid ahead of them. The rollers are typically mounted around the edge of a rotor so that each contacts the fluid tube in turn as the rotor turns, pressing it for instance against a backing plate so as to cause the required flow constriction. Factors affecting the fluid flow include the number of rollers mounted on the rotor and the angle(s) between them, the contact angle between the rollers and the fluid tube, the degree of pressure which each roller is able to exert against the tube, the speed of rotation of the rotor and the nature of the tube (for instance, its diameter and its deformability).

Peristaltic pumps can deliver a moderately accurate fluid flow particularly at relatively low flow rates. They operate without associated flow control valves, allowing their use with for instance relatively viscous fluids or fluids with particulate content.

Significant pulsations in flow can result from the operation of a conventional peristaltic pump. The output flow exhibits a series of troughs corresponding to the parts of the cycle where each roller loses contact with the tube. In extreme cases, a trough may result in a temporary cessation, or even reversal, of flow. One known method of reducing the flow variation is to operate two peristaltic pumps in parallel and combine their outputs so that flow can be averaged across the two. Preferably the pumps are operated with a phase offset so that the peaks in flow rate through one of the pumps coincide, at least partially, with the troughs of the other. An incoming fluid flow may then be split between two separate tubes which are acted on by the respective pumps, the flows through the two tubes being subsequently recombined. In a variation of this system the two pumps are incorporated into a single assembly, for instance with two sets of pressure rollers appropriately positioned on a single rotor or with a single set of rollers pinching the two tubes against diferentially shaped backing plates.

The overall flow output from such a system exhibits a generally sinusoidal variation with time. However the flow variation is a smaller fraction of the average flow rate because maxima in one tube can partially compensate for minima in the other.

The absence of flow control valves in a peristaltic pump means that in order to maintain flow pressure, at least some degree of constriction must be maintained at some point along each fluid tube at all times. In other words, at least one roller must pinch the tube before previous roller(s) have completely lost contact with it.

This in turn can cause problems associated with stretching of the fluid tube. As they pinch the tube, the rollers tend to cause upstream stretching and downstream compression. Since each roller contacts the tube before the previous one leaves, the stretching is cumulative until the longitudinal force applied by the rollers is balanced by stretch in the tube. This stretching further distorts flow, due to the variation in tube aperture along the region of roller contact.

Improved forms of peristaltic pump, which avoid or at least mitigate the above described problems, would therefore be desirable.

Statements of the invention

According to a first aspect of the present invention there is provided a fluid pump comprising a fluid flow tube; a pressure member operable to exert a variable pressure against a contact region of the tube so as to urge fluid present in the tube to flow through it; and a valve, in fluid communication with the tube and downstream of the contact region, which is operable to prevent or at least reduce reverse fluid flow through the tube.

In the present context, the terms "upstream" and "downstream" refer to the normal, desired, direction of fluid flow through the tube due to the action of the pressure member. "Reverse" flow means flow in a downstream to upstream direction, eg, from the valve back towards the contact region of the tube.

The pump is of the peristaltic type and may in many respects be analogous in construction and operation to known peristaltic pumps. However, according to the invention, a valve is incorporated into the fluid flow downstream of the region of pressure application, to reduce or more preferably prevent back flow. To our knowledge this has not previously been done in a peristaltic pump. If reverse fluid flow is prevented, there is no need to maintain a constant constriction in the system. A single pressure member may therefore be used rather than a series, and the fluid flow tube may be completely released from the pressure member in between contact periods. This in turn allows the tube to recover from the stretching and deforming effects of its contact with the pressure member, so that tube stretch may be non-cumulative and have a reduced effect on flow output.

The use of fewer pressure members generally means that for a given volume of pumped fluid, there will be fewer fluctuations in flow rate. Moreover the reduction in tube stretching can allow more accurate and reliable fluid volumes to be displaced through the pump.

In the context of the present invention, a fluid flow tube is a conduit through which fluid can flow and which has sufficient flexibility and/or deformability that the pressure member can be used, in known fashion, to generate flow in it. Conventional rubber or plastics tubing for instance made of silicone rubber, Santoprene™, EPDM or Viton™ may be used.

The pump of the present invention may comprise more than one fluid flow tube, preferably two or more. Each tube may be provided with a separate respective pressure member operable to exert a variable pressure against a contact region of that tube so as to urge fluid to flow through it, and/or a separate respective valve, in fluid communication with that tube and downstream of its contact region, to prevent or at least reduce reverse fluid flow through it. Such pressure members and valves are preferably independently operable, to allow independent fluid flow through each of the tubes.

The or each tube may be provided with more than one associated pressure member, operable together to apply a desired pressure profile as do the rotor-mounted pressure rollers of conventional peristaltic pumps. However, as explained above, the provision of the valve makes it possible to operate with only one pressure member per fluid flow tube, with continuous pressure application being unnecessary.

Where the pump comprises two or more tubes, their fluid outputs are preferably combinable downstream of the valve(s). A pump according to the invention thus preferably comprises a connector for combining the fluid outputs of two or more fluid flow tubes, downstream of the valve(s), and preferably also a fluid outlet conduit for the resultant combined fluid flow.

The pump may also include a connector upstream of the pressure member contact region(s), conveniently with a fluid inlet conduit, in an arrangement such that a single fluid flow may be divided, upstream of the pump, into two or more separate flows through two or more tubes within the pump.

The or each pressure member may be for example a pressure roller of conventional construction and operation. Typically it will be brought into contact with a region of the fluid flow tube for a period of time, during which contact period it creates a constriction in the tube which restricts or prevents fluid flow in that region. The constriction should travel along the tube in the direction of fluid flow during the contact period, due to a corresponding movement of the pressure member longitudinally with respect to the tube. The degree of constriction, ie, the amount of pressure exerted, may vary during the contact period, for instance increasing to a maximum and then reducing until finally the pressure member moves out of contact with the tube. In this way, a "pulse" of pressure may be applied temporarily to the tube, to generate a corresponding pulse of fluid flow. Preferably the pressure member is operable to apply a series of such pulses at spaced, suitably regularly spaced, intervals.

The pressure member may conveniently be mounted on a rotatable element (suitably at or towards its periphery, or at least non-centrally), for instance via a cam or other intermediate component to ensure a desired pattern of movement as the rotatable element turns.

Where the pump comprises more than one pressure member, whether associated with a single or with more than one fluid flow tube, they may be mounted at appropriate positions on a common driveable (again typically rotatable) element.

Additionally or alternatively, a pressure member may be associated with more than one fluid flow tube, the tubes being positioned and supported in a manner which allows the pressure member to act upon each at an appropriate point in its movement cycle.

Movement of the pressure member(s) may be driven by any suitable drive means, for instance involving an electrically powered motor. Their operation may be under automatic or semi-automatic control; the pump may therefore comprise, or be used with, a control means such as a microprocessor. Again, if there is more than one pressure member, their movement may be driven by a common drive means and/or controlled by a common control means.

In the pump of the present invention, the or each valve is a fluid flow control valve which preferably completely prevents reverse fluid flow; in other words, it is preferably a "non-return" or "one way" valve.

The or each valve is preferably operable to allow forward fluid flow (in an upstream to downstream direction) only above a threshold differential fluid pressure (ie, the pressure difference between the upstream and downstream valve regions). In this way, movement of a pressure member against its associated fluid tube can be made to contribute to the overall pump output only when the fluid pressure in that tube is sufficient to open the associated valve.

Suitable valves incorporate a moveable element biassed to seal shut the region of fluid flow, where a given upstream fluid pressure (typically referred to as the "cracking pressure") is able to overcome the biassing force and urge the moveable element out of contact with the sealing region. For example, the moveable element may be a ball, urged by a spring into contact with a deformable gasket or other compliant element in the region of fluid flow.

Alternatively, the moveable element may be a tongue or flap made from a resilient material such as rubber, biassed (eg, by virtue of its natural resilience) into sealing contact with an internal fluid flow region of the valve. Such a tongue or flap may be associated with a spring or other biassing means to increase the fluid pressure needed to overcome the seal.

The moveable element may be constituted by a region of a flexible diaphragm, which diaphragm may serve to provide a valve sealing function in more than one region for respective fluid conduits. Local displacement and/or deformation of the diaphragm can be influenced by differential fluid pressures and in turn provide the desired fluid flow control in an associated fluid flow conduit.

Two or more such valves, in particular of the sprung ball type, may be used together to achieve the desired overall function.

Preferably the valve has a relatively low opening or "cracking" differential pressure (for example, of 10 kPa or below) and seals effectively in the reverse direction with minimum fluid movement. Sprung-ball valves with compliant valve seats are particularly suitable. A valve with a low cracking pressure is preferably used in association with a relatively stiff fluid flow tube – a suitable tube might be made, for instance, from rubber of between

50 and 60 Shore, and typically have a bore of between 1 and 5 mm and a wall thickness of between 1 and 3 mm.

It is preferred that the valve be positioned to give a minimal flow tube volume between the point of release of the tube by its associated pressure member and the valve. This aids priming. Before the tube is filled with a substantially incompressible liquid to be pumped, it is commonly gas (eg, air) filled. In circumstances where there may be back pressure applied downstream of the valve, or where the valve exhibits a significant cracking pressure, this gas has to be pressurized to open the valve. If the gas is not compressed sufficiently and the valve does not open, then there will be no net flow of gas since the compression may be released when the pressure member releases the flow tube. In this case, the gas cannot be purged from the tube and fluid will not be pumped. The degree of compression of the gas trapped between the pressure member constriction and the valve depends on its proportional volume change. As the constriction moves along the tube, the enclosed volume reduces to a minimum in the instant before the constriction is removed. The valve is thus preferably positioned close to where the constriction is removed so that the enclosed volume is compressed by the largest degree.

Thus if V_1 is taken to be the enclosed fluid tube volume between the first point of constriction of the tube and the valve, and V_2 the volume between the point where the constriction leaves and the valve, then ideally the ratio of V_1:V_2 is relatively large, for instance 5 or greater.

The valve is ideally an integral part of the pump of the present invention, upstream of the intended pump output.

Where the pump comprises more than one fluid flow tube, each with a respective pressure member, the pressure members are conveniently operable out of phase with one another, preferably in a complementary fashion so that higher flow rate periods in one tube compensate, at least partially, for lower flow rate periods in one or more other tubes. In other words, the contact periods for each of the pressure member/tube pairs, and in particular the points at which maximum and/or minimum tube constrictions are applied, do not correspond temporally. There may be overlap in periods during which fluid flow is either present or absent in the respective tubes, although ideally the pressure members are operable so that there is little or no overlap in the periods for which fluid flow is allowed through the respective tubes.

The duration of the contact periods, and the pressures applied during those periods, may differ from pair to pair.

Yet more preferably, the pressure members are operable with a phase difference between their respective movement cycles of 360°/n for an n-tube arrangement.

A preferred embodiment of the invention comprises first and second pressure members associated with first and second fluid flow tubes respectively, the two pressure members being operable to exert pressure on their respective tubes out of phase with one another, more preferably in anti-phase (ie, 180° phase difference between their respective movement cycles). This can conveniently be achieved by mounting the pressure members on a common rotatable element, preferably diametrically opposite one another.

Such an embodiment is again preferably operable so as to provide little or no overlap between the periods during which fluid flow occurs in the first and second tubes. This can conveniently be achieved using first and second pressure regulated valves associated respectively with the first and second tubes. Such valves open only above a predetermined fluid pressure; the opening of the first valve may therefore be arranged to coincide with cessation of flow in the second tube (due to its release by the second pressure member) and vice versa. In other words, the differential cracking pressure of the first valve is preferably chosen, together with other features of the pump such as the nature of the fluid flow tube and the geometry of its support and its associated pressure members, to correspond with the pressure at which the second pressure member releases the second tube. Similarly the differential cracking pressure of the second valve is preferably chosen to correspond with the pressure at which the first pressure member releases the first tube. Such a fluid flow pattern differs from that in a more conventional two-tube peristaltic pump arrangement in that, due to the presence of the non-return valves, there need be little if any overlap of the periods of allowed fluid flow through the two tubes. As a result, flow variations in the net pump output can be significantly reduced.

In general, the output from a pump according to the invention may be significantly more uniform than that achievable using prior art peristaltic pumps. Ideally, the net output exhibits variations in fluid flow rate of less than 30 %, more preferably less than 20 % or 10 % or 5 %, of the desired average level.

A pump according to the invention suitably comprises a support for the one or more fluid flow tubes, in which the pressure member(s) and their associated drive means may also be located. This support may for example take the form of a cradle shaped to accommodate a rotor which carries the pressure member(s), and ideally provides a backing member against which the tube(s) may be urged when contacted by the pressure member(s). Guide means, such as for instance tracks in the support and/or guiding rollers associated with moving parts of the pump, may be included to ensure that the tube(s) and pressure member(s) maintain their desired relative positions.

A second aspect of the present invention provides a pump sub-assembly for use as part of a pump according to the first aspect, the sub-assembly comprising a moveable pressure member (preferably with drive means for driving its movement); a support for a fluid flow tube against which, thus supported, the pressure member is operable to exert a variable pressure so as to urge fluid present in the tube to flow through it; and a non-return valve in fluid communication with a thus supported tube, downstream (in use) of the region of contact of the pressure member with the tube.

Preferred features of such a sub-assembly may be as described in connection with the pump of the first aspect of the invention. In particular, it preferably comprises upstream and/or downstream connectors for one or more fluid flow tubes, and optionally an inlet and/or outlet conduit in fluid communication with the relevant connector(s). The valve may be provided as part of a downstream connector.

The sub-assembly may be fitted with one or more, preferably replaceable, fluid flow tubes prior to use. It may be provided in combination with one or more suitable tubes.

An alternative pump sub-assembly, in accordance with a third aspect of the invention and again for use as part of a pump according to the first aspect, comprises one or more moveable pressure members (preferably with associated drive means); and a support for one or more fluid flow tubes against which, thus supported, the pressure member(s) is or are operable to exert a variable pressure, wherein for each supportable tube there is no more than one associated pressure member operable to exert pressure on that tube.

Preferred features of this sub-assembly may be as described in connection with the first and second aspects of the invention. It preferably comprises a support for two fluid flow tubes, and two pressure members. It may in particular include one or more non-return valves.

According to a fourth aspect of the present invention, there is provided a fluid flow tube assembly for use in a pump according to the first aspect of the invention and/or a pump sub-assembly according to the second or third aspect. The tube assembly comprises a fluid flow tube, suitable for use in a peristaltic type pump, and a non-return valve in fluid communication with the tube. The valve preferably allows fluid flow only above a threshold fluid pressure.

Again, preferred features of the fourth aspect of the invention may be as described in connection with the first, second and third aspects. In particular, the tube assembly preferably comprises more than one (more preferably two) fluid flow tubes. It also preferably comprises more than one (preferably two) non-return valves, which are more preferably associated one with each of one or more tubes such that flow through those tubes may be individually controlled by their respective valves.

Where the tube assembly has more than one tube, it preferably also comprises means for combining the fluid flows from two or more of them, conveniently at a single outlet. It suitably also comprises a fluid inlet and means for dividing fluid flow at that inlet between two or more of its fluid flow tubes. The fluid inlet and/or outlet conveniently take the form of connectors, connectable to external fluid conduits.

A fifth aspect of the present invention provides apparatus incorporating a fluid pump according to the first aspect, a pump sub-assembly according to the second or third aspect or a fluid tube assembly according to the fourth.

A sixth aspect provides a method of operation of a peristaltic pump of the type described above, wherein the fluid flow tube is not subjected to a continuous constriction by its associated pressure member(s) but is allowed one or more "recovery" periods between intervals of pressure member contact. Preferred aspects of this method, in particular where the pump comprises more than one fluid flow tube and/or pressure member, may again be as described above in connection with the other aspects of the invention.

The present invention will now be described by way of example only and with reference to the accompanying illustrative drawings, of which:

Fig 1 illustrates the fluid flow through a pump in accordance with the present invention;

Figs 2 to 5 are plan views of a pump in accordance with the invention, showing different phases of its operation;

Fig 6 is a plan view of a pump analogous to that of Figs 2 to 5;

Fig 7 corresponds to a section along the line VII-VII in Fig 3, but taken 180° further on in the pump cycle;

Figs 8A to 8C illustrate typical variations in fluid flow rate with time through various parts of a pump such as that of Figs 2 to 5;

Figs 9 and 10 are sections through valves for use in a pump according to the invention;

Fig 11 is a plan view of part of the Fig 10 valve;

Fig 12 is a section through part of an alternative valve analogous to that of Fig 10; and

Fig 13 is a section through a valve assembly for use in a pump according to the invention.

All figures are schematic.

Detailed description

Referring firstly to Fig 1, fluid enters a typical pump in accordance with the present invention via an inlet conduit 1 and is then divided between two parallel tubes 2A and 2B. It should be noted that in this context the term "parallel" is used as in an electrical circuit, to denote a flow pattern rather than an exact geometric arrangement of hardware. Flow from the two parallel tubes is combined at the downstream end of the pump into the outlet conduit 3.

The pump includes two pressure rollers 4A and 4B, associated respectively with the tubes 2A and 2B and which, in use, provide a moving constriction in each of the tubes so as to urge fluid flow through them in the direction shown. The arrangement and operation of the pressure rollers may be as in a conventional peristaltic pump. In Fig 1, however, the tubes 2A and 2B have been shown "unrolled" for clarity, whereas in a typical pump according to the invention they would be arranged around a rotor carrying the two pressure rollers.

Positioned in the two tubes, downstream of their regions of contact with the pressure rollers but upstream of the common outlet conduit 3, are non-return valves 5A and 5B. In a preferred embodiment of the invention, these valves allow fluid flow only when the upstream fluid pressure exceeds the downstream pressure by a small amount.

The peristaltic pump shown in Figs 2 to 5 comprises two fluid flow tubes 10, 11 positioned one behind another and hence only the front one 10 of which is visible in the figures. These are connectable by an upstream connector 12 to a main fluid inlet conduit and by a downstream connector 13 to a main fluid outlet conduit, in the same manner as in the Fig 1 system. The tubes are supported in a U-shaped "cradle" 14, the semi-circular lower portion of which is shaped to accommodate a rotor as described below and has a centre corresponding to that of the rotor. The tubes follow the periphery of the rotor, both having similar positions with respect to its angular movement.

Fluid flow is induced in the tubes 10, 11 by the pressure rollers 15, 16 respectively. These are mounted, via specially shaped swivel plates 17, 18 respectively, towards the periphery of a rotor plate 19. A spring 20, passing through the centre of the rotor plate, links the two swivel plates and helps to bias the pressure rollers into contact with the fluid flow tubes at the appropriate points in their movement cycles. Tying the swivel plates together in this way helps ensure that equal forces are applied to the two pressure rollers.

The swivel plates are identical in shape and are positioned diametrically opposite one another on the rotor plate.

Idle rollers 21, 22, also mounted on the rotor plate, guide (but do not pinch) the tubes 10, 11 to help achieve consistency of operation and avoid "kinks".

The shape of the swivel plates 17, 18 ensures that as the rotor plate turns, the pressure rollers 15, 16 move periodically into contact with their respective fluid flow tubes, "pinching" the tubes against the cradle 14 and thus causing periodic pulses of fluid flow.

For example, in the Fig 2 position there is no constriction in, and hence no fluid flow induced in, the "front" tube 10. As the rotor turns (anti-clockwise as seen in the figures), the Fig 3 position is reached in which the pressure roller 15 has begun to constrict the tube 10. The roller continues to move along the tube, the constriction moving with it, to the position shown in Fig 4 and then to that of Fig 5. During this progression, the shape and position of the swivel plate 17 causes the roller to move closer to the cradle 14 and hence to exert increasing pressure against the tube 10, until the maximum constriction is achieved in the Fig 5 position.

The pinching effect of roller 15 on tube 10 effects closure of the bore of the tube at some rotor position such as that shown in Fig 3. The movement of the swivel plates and the pressure applied via them from the spring are arranged to provide a consistent closure effect (and hence fluid flow) despite variations in the material of the tube, its dimensions and changes in its properties induced by pump operation, temperature variations, wear or ageing. A highly predictable position for closure could be achieved using a steep ramp at the entry to the cradle 14, however this could also cause undesirably high rotor torques and tube wear and it is therefore generally preferred to limit the steepness of the entry ramp.

As the rotor plate reaches a position around 180° from that shown in Fig 3, the constriction on the tube 10 is released. Again, a predictable position for release is desirable so that uniform flow may be achieved reliably. At the exit of the semi-circular portion of cradle 14, a steeper ramp may be acceptable since the effect on torque is to aid, rather than retard, rotation. Since sufficient torque has to be supplied to the rotor plate to overcome friction as well as the effect of the spring 20, extra torque to aid rotation is normally acceptable (in contrast to the retarding effect of a steep ramp at the cradle entry). Consequently, the cradle shape may be asymmetrical between its entry and exit ramps. As the rotor plate moves beyond the point of release of the tube constriction, roller 15 moves away from tube 10 since the corresponding swivel plate 17 reaches its own limit of movement.

The movement of the pressure roller 16 against the "back" tube 11 is the same as but 180° behind that of the front roller 15. Roller 16 pinches tube 11 during the period when roller 15 is not in contact with tube 10. Each complete turn of the rotor plate causes a single pulse of pressure to, and hence a single pulse of fluid flow in, each tube.

The inner surface of the cradle 14 is provided with tracks for location of the tubes 10 and 11 and to help guide movement of the rollers. The cradle needs to be appropriately shaped to ensure that the pressure rollers pinch the tubes at the appropriate positions in their cycle, ensuring minimum pulsation in the overall fluid flow downstream of the pump (ie, at connector 13). During a single turn of the rotor plate 19, one of the pressure rollers enters its associated cradle track and as it moves along that track it displaces a fixed volume of fluid through its associated flow tube. When this pressure roller reaches the end of the track, the other pressure roller then enters the beginning (upstream end) of its own track and displaces fluid in the other flow tube. This results in a continuous net pumping action.

Thus, at any given point in the operating cycle there is generally only one pressure roller "pinching" a fluid flow tube. There may however be a relatively short overlap period when both pressure rollers are in contact with their respective tubes and "handing over" the pumping action – the duration of this overlap period is affected by the cradle profile and the tube diameters.

The internal surface of the cradle 14 has additional arcuate cut-out portions (labelled 23, 24 in Fig 6) at the lead-in and lead-out ends of the active length of its tube supporting track. These portions have a slightly greater radius than the main part of the track, and thus help to minimise the peak torque demanded of the motor used to drive the rotor plate, as described above.

The rotor plate may be driven under the control of an electronic circuit. One or more sensors (eg, optical position sensors alignable with features such as slots on the rotor plate) may be provided to monitor movement of the pump components and/or the pump output, and conveniently to provide feedback to the pump controls. Such sensors also allow movement to be stopped at any desired point in the cycle, for instance at a point where both tubes are constricted to at least some degree so as to minimise fluid leakage when the pump is not operating.

Connectors 12 and 13 provide conduits through which fluid may pass between the tubes 10, 11 and the outside of the pump. The downstream connector 13 also incorporates two non-return valves (not shown in Figs 2 to 5), associated with the respective outputs of the tubes 10, 11. These eliminate back flow of fluid when a pressure roller is not in contact with its associated tube. They allow forward fluid flow only above a threshold pressure. Suitable forms of valve are described below in connection with Figs 9 to 13.

Fig 6 is a schematic plan view of a pump similar to (but a mirror image of) that shown in Figs 2 to 5, and like parts have the same reference numerals. Certain components have been omitted for clarity. In Fig 6, the positions of the swivel plate 17 and the pressure rollers 15, 16 at different points in their movement cycle are superimposed on one another. It can be seen that the swivel plate is able to rotate about the pin 30 which attaches it to the rotor plate 19, and is provided with a slot 31 to accommodate, as it rotates, the locating pin 36 (see below) for the idle roller 21. Conveniently, bearings are used between the rotor plate and each of the swivel plates to reduce friction in their relative movements.

The swivel plate 17 has two non-symmetrical arm-like portions generally labelled 32 and 33, each carrying a pin (34 and 35 respectively). The pressure roller 15 is rotatably mounted on pin 34. Pin 35 is for attachment to a spring (such as 20 in Figs 2 to 5).

The rotor plate also has fixed pins 36, 37 on which the idle rollers 21, 22 are rotatably mounted.

The central axle around which the rotor plate is driven is positioned where indicated at 38; torque is typically provided by the rotor shaft of a stepper motor, as seen in Fig 7.

Fig 7 shows schematically the cradle 14, the rotor plate 19, the swivel plates 17, 18, the pressure rollers 15, 16 and their respective locating pins 34, 40 and one of the idle rollers 21, 22. Also shown is a stepper motor 41, the drive shaft 42 of which imparts torque to the rotor plate. The two flexible tubes 10 and 11 are both, at this particular point in the pump cycle, at least partially compressed by their associated pressure rollers.

From Fig 7 it can be seen that the idle roller 22 has an approximately W-shaped cross-sectional profile incorporating two radial grooves to accommodate the two fluid tubes. Roller 21 has the same shape. Each pressure roller presents at one face a generally cylindrical profile which can "pinch" the associated fluid tube, and towards its other face is provided with an approximately V-shaped radial groove to accommodate the fluid tube on which it is not intended to exert pressure. The pressure rollers are mounted in opposite orientations to one another, the radial grooves in the idle rollers and in the two pressure rollers ensuring that each tube is only pinched at the appropriate time.

The two tubes 10, 11 are positioned inside the cradle 14 at a fixed distance from one another, aligned with the paths of the V-grooves in the rollers, to ensure that each of the pressure rollers can act against only one of the tubes.

The number and arrangement of pressure rollers, in particular their relative movements and the timings thereof, may be used to influence the overall fluid flow output from the pump. The pump described in connection with Figs 2 to 5 and 7, for instance, is preferably operated as illustrated in Fig 8, which shows the variation in flow rate with time in (Fig 8A) tube 10, (Fig 8B) tube 11 and (Fig 8C) a common outlet conduit downstream of the connector 13. Flow in tubes 10 and 11 is measured downstream of their associated non-return valves.

Here, there is very little overlap between the periods of flow in the two tubes, in contrast to the situation in conventional two-tube peristaltic pumps. Movement of a pressure roller along one of the tubes only contributes to the overall pump output when the pressure in that tube is sufficient to open its associated valve. If the contact angle (ie, the angle over which the roller contacts the tube during its movement cycle) is arranged appropriately, release of the first tube can be made to coincide accurately with the opening of the valve in the second. This valve opening would typically happen shortly after the pressure roller had sealed the second tube. However, at high outlet pressures, the roller might need to move further along the second tube to build sufficient pressure to open its valve. A suitable contact angle therefore depends on the desired overall outlet pressure and the nature (in particular, elasticity and diameter) of the tubes. At higher outlet pressures, there is a reduced flow at the overlap point whereas at lower outlet pressures there is increased flow at the overlap.

Fig 8C shows the net overall output of the pump when operated in this way, which exhibits significantly lower temporal variations than that of conventional peristaltic pump arrangements.

Figs 9 to 13 show non-return valves suitable for use in a pump according to the invention, such as in the connector 13 of the Fig 2 to 5 pump.

The Fig 9 valve comprises a shuttle 50 which carries an O-ring seal 51. The shuttle and seal are biassed by spring 52 into sealing contact with a "neck" region 53 of the valve, thus preventing fluid flow. Sufficient upstream fluid pressure, as indicated by the arrow, can overcome the spring force, urge the shuttle out of contact with the neck region and allow fluid flow. Item 54 is the valve body, item 55 the spring keeper. In valves of this type, the compliant sealing element (in this case 51) may be carried by the moveable element (here, the shuttle) or it may alternatively be provided as a fixed element in the valve body.

The valve shown in Figs 10 and 11 comprises a flexible rubber membrane 60 located across the open ends of fluid inlet conduits 61, 62 which are provided in a lower block 63. Above each of the conduits, the membrane provides cut-out flaps 64, 65 respectively – see Fig 11, which is a plan view of the membrane 60 with the lower block and inlet conduits shown by dotted lines.

The membrane flaps are urged by springs 66, 67 respectively into sealing contact with the upper surface of the block 63, in the regions of the inlet conduits. Only when the fluid pressure in one of the conduits is great enough to overcome the associated spring force is the membrane flap lifted from the block 63 in that region, allowing fluid to flow into the central cavity 68 defined in the upper valve block 69, and thence to the common valve outlet conduit 70.

This form of valve could thus be used to control fluid flow in two separate tubes connected to the conduits 61 and 62, and to combine the outputs from the two tubes.

Fig 12 shows a modification to the Fig 10 valve arrangement, in which the surface of block 63 is specially profiled in the region of the inlet conduit 61, to provide a radial raised "rim" 71 which contacts the membrane flap 64. This arrangement copes better when the fluid passing through the valve contains particulates. It can also effect better sealing particularly at low spring force, since the force is concentrated onto a smaller area of the membrane – the valve may thus provide efficient sealing yet have a relatively low cracking pressure.

The valve assembly of Fig 13 incorporates two valves of the type shown in Fig 9, shown schematically as 80 and 81, in a common manifold 82. Inlet connectors 83 and 84, with associated seals 85, 86 respectively, allow the assembly to be connected to two fluid flow tubes such as 10 and 11 in the Fig 2 pump. Outlet connector 87 allows the flow through the two valves to be combined into a single fluid conduit downstream of the pump. The assembly may thus be used as the connector 13 in the Fig 2 pump.

A pump such as those described above may be provided in the form for instance of a sub-assembly including the cradle, motor and moving parts such as the rotor plate and rollers. A tube assembly in accordance with the fourth aspect of the invention (incorporating fluid flow tubes and their connectors, and integrated non-return valves) may then be located in the sub-assembly prior to use, and removed and replaced if necessary.

The pumps of the invention may be of use in a wide range of systems and may be incorporated into any apparatus through which a fluid needs to be pumped, particularly where accuracy and uniformity of flow rate are important. The pumps may be particularly well suited to the delivery of relatively low fluid flow rates but with relatively high accuracy, uniformity and control.

They may in particular be used in apparatus for carrying out fluid-phase chemical assays, for instance as described in our co-pending international patent application no. PCT/GB01/05158.

Claims

1. A fluid pump comprising :

(i) first and second fluid flow tubes;

(ii) first and second pressure members operable on the first and second fluid flow tubes respectively so that each exerts a variable pressure against a contact region of its associated tube so as to urge fluid present in the tube to flow through it, the first and second pressure members being mounted on a common rotatable element and operating with a phase difference between their respective movement cycles; and

(iii) first and second valves, in fluid communication with the first and second fluid flow tubes respectively, each of which valves is positioned downstream of the contact region of its associated tube and is operable to prevent or at least reduce reverse fluid flow through that tube and to allow forward fluid flow only above a threshold differential fluid pressure;

wherein for each of the first and second fluid flow tubes there is no more than one associated pressure member operable to exert pressure on that tube;

the arrangement being such that, in use, the first valve opens at a differential fluid pressure corresponding to that at which the second pressure member releases the second tube and (b) the second valve opens at a differential fluid pressure corresponding to that at which the first pressure member releases the first tube, so that the opening of the first valve coincides with cessation of flow in the second tube.

2. A pump according to claim 1, additionally comprising control means for controlling movement of the first and second pressure members, a sensor to

monitor the movement of one or more components of the pump and means for providing feedback from the sensor to the control means.

3. A pump according to claim 2, wherein the sensor is an optical position sensor.

4. A pump according to claim 2 or claim 3, wherein the control means comprises a microprocessor.

5. A pump according to any one of the preceding claims, wherein the first and second pressure members operate to exert pressure on their respective fluid flow tubes in anti-phase (ie, with a 180° phase difference between their respective movement cycles).

6. A pump according to claim 5, wherein the first and second pressure members are mounted diametrically opposite one another on the common rotatable element.

7. A pump according to any one of the preceding claims, additionally comprising a support for the first and second fluid flow tubes, the support being in the form of a U-shaped cradle which provides a backing member against which the tubes may be urged when contacted by their associated pressure members.

8. A pump according to claim 7, wherein the internal surface of the cradle has additional arcuate cut-out portions at the lead-in and lead-out ends of its tube supporting region, the cut-out portions each having a radius greater than that of the main part of the tube supporting region.

9. A pump according to claim 7 or claim 8, wherein the cradle is asymmetrical in shape between the lead-in and lead-out ends of its tube supporting region.

10. A pump according to any one of the preceding claims, wherein the first and second pressure members comprise first and second pressure rollers respectively.

11. A pump according to any one of the preceding claims, comprising n fluid flow tubes each having an associated pressure member, the n pressure members being mounted on a common rotatable element and operating with a phase difference between their respective movement cycles of 360°/n, where n is greater than 2.

12. A pump according to any one of the preceding claims, wherein the threshold differential pressure of at least one of the valves is 10 kPa or below.

13. A pump according to any one of the preceding claims, wherein at least one of the valves comprises a ball or other moveable element, biassed into contact with a compliant element in the region of fluid flow.

14. A pump according to any one of the preceding claims, wherein at least one of the valves is positioned such that the ratio $V_1:V_2$ is 5 or greater, where V_1 is the flow tube volume between the valve and the first point of constriction of its associated fluid flow tube by the relevant pressure member, and V_2 is the flow tube volume between the valve and the point of release of the tube by the pressure member.

15. A pump according to any one of the preceding claims, comprising means for combining the fluid outputs from the first and second fluid flow tubes downstream of their associated valves.

16. A pump according to any one of the preceding claims, comprising a fluid inlet and means for dividing fluid flow at the inlet between the first and second fluid flow tubes.

17. A pump according to any one of the preceding claims, which comprises a pressure member associated with more than one fluid flow tube, said tubes being positioned and supported in a manner which allows the pressure member to act upon each at an appropriate point in its movement cycle.

18. A pump according to any one of the preceding claims, the net output from which exhibits variations in fluid flow rate of less than 20 % of the desired base level.

19. A pump according to claim 18, the net output from which exhibits variations in fluid flow rate of less than 10 % of the desired base level.

20. A fluid pump substantially as herein described with reference to the accompanying illustrative drawings.

21. A pump sub-assembly for use as part of a fluid pump according to any one of the preceding claims, the sub-assembly comprising :

(I) first and second moveable pressure members mounted on a common rotatable element and operating with a phase difference between their respective movement cycles;

(II) a support for first and second fluid flow tubes against each of which, thus supported, the first and second pressure members respectively are operable to exert a variable pressure so as to urge fluid present in the relevant tube to flow through it; and

(III) first and second valves in fluid communication respectively with first and second thus supported tubes, each of which valves is positioned downstream (in use) of the region of contact of its associated tube with the relevant pressure member;

wherein for each of the first and second fluid flow tubes, in use, there is no more than one associated pressure member operable to exert pressure on that tube;

the arrangement being such that, in use, the first valve opens at a differential fluid pressure corresponding to that at which the second pressure member releases the second tube and (b) the second valve opens at a differential fluid pressure corresponding to that at which the first pressure member releases the first tube, so that the opening of the first valve coincides with cessation of flow in the second tube.

22. A pump sub-assembly according to claim 21, additionally comprising control means for controlling movement of the first and second pressure members, a sensor to monitor the movement of one or more components of the pump and means for providing feedback from the sensor to the control means.

23. A pump sub-assembly according to claim 22, wherein the sensor is an optical position sensor.

24. A pump sub-assembly according to any one of claims 21 to 23, additionally comprising a support for first and second fluid flow tubes, the support being in the form of a U-shaped cradle which provides a backing member against which the tubes may be urged when contacted by their associated pressure members, the internal surface of the cradle having additional arcuate cut-out portions at the lead-in and lead-out ends of its tube supporting region, each of which cut-out portions has a radius greater than that of the main part of the tube supporting region.

25. A pump sub-assembly according to claim 24, wherein the cradle is asymmetrical in shape between the lead-in and lead-out ends of its tube supporting region.

26. A pump sub-assembly substantially as herein described with reference to the accompanying illustrative drawings.

27. Apparatus incorporating a fluid pump according to any one of claims 1 to 20, or a pump sub-assembly according to any one of claims 21 to 26.

28. A method of operating a peristaltic fluid pump according to any one of claims 1 to 20, wherein :

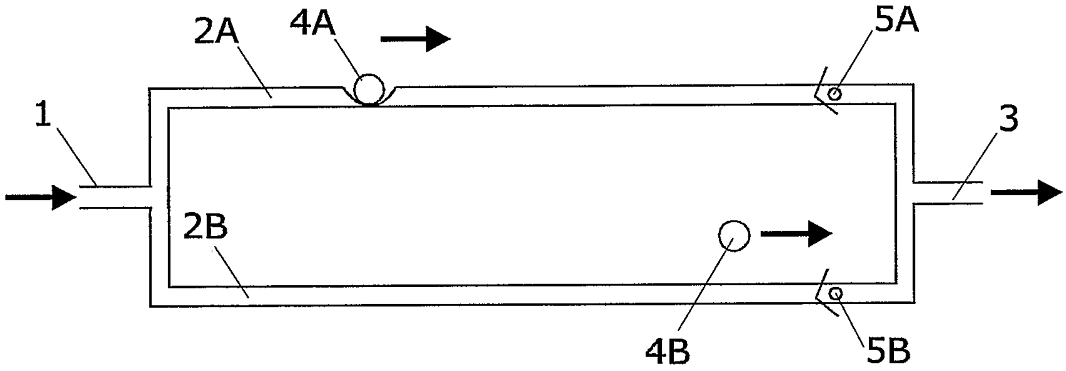
A) each of the first and second pressure members is operated to exert a variable pressure against a contact region of its associated fluid flow tube so as to urge fluid present in that tube to flow through it, there being a phase difference between the movement cycles of the first and second pressure members;

B) neither the first nor the second fluid flow tube is subjected to a continuous constriction by its associated pressure member but is allowed one or more "recovery" periods between intervals of pressure member contact; and

C) the first valve opens at a differential fluid pressure corresponding to that at which the second pressure member releases the second tube and (b) the second valve opens at a differential fluid pressure corresponding to that at which the first pressure member releases the first tube, so that the opening of the first valve coincides with cessation of flow in the second tube.

29. A method according to claim 28, wherein the pump comprises n fluid flow tubes and their associated pressure members are operated with a phase difference between their respective movement cycles of 360°/n.

30. A method of operating a peristaltic fluid pump, the method being substantially as herein described with reference to the accompanying illustrative drawings.


2A
4A
5A
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2B
4B
5B

Fig 1

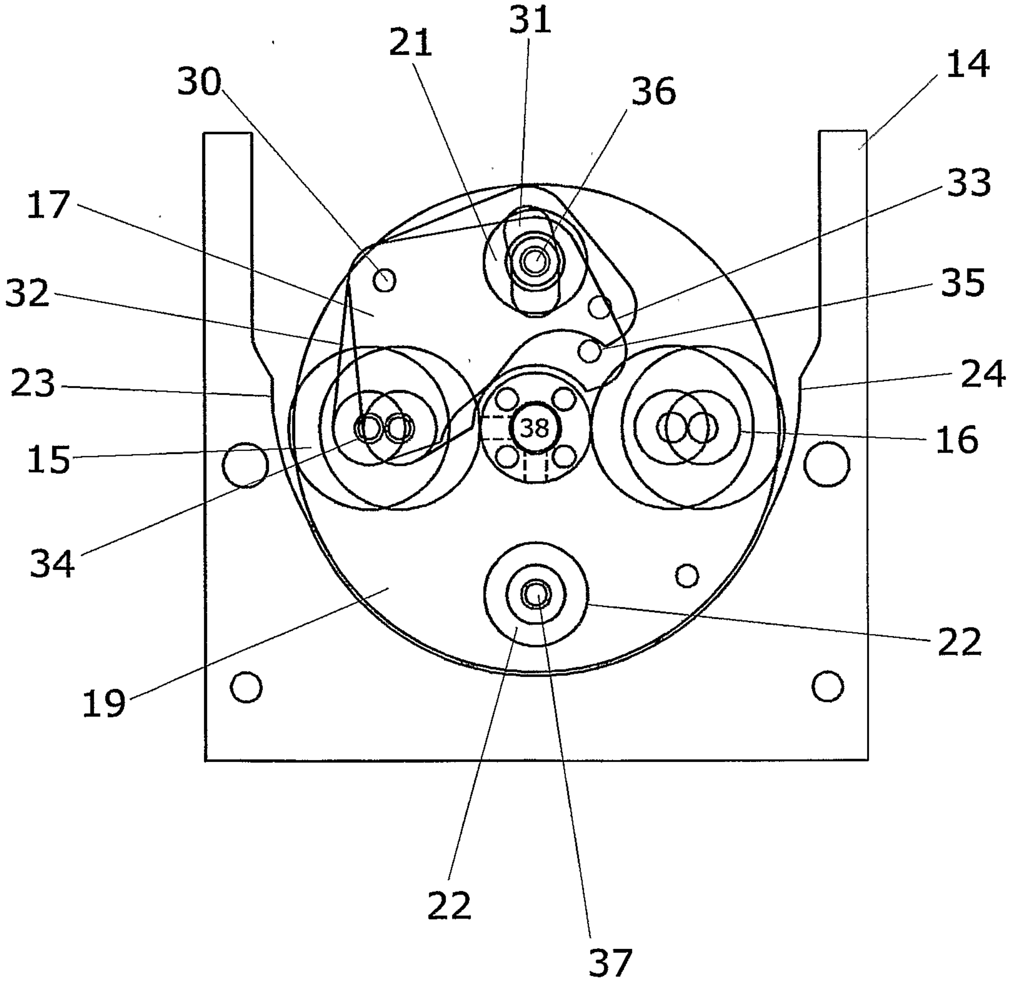
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Fig 6

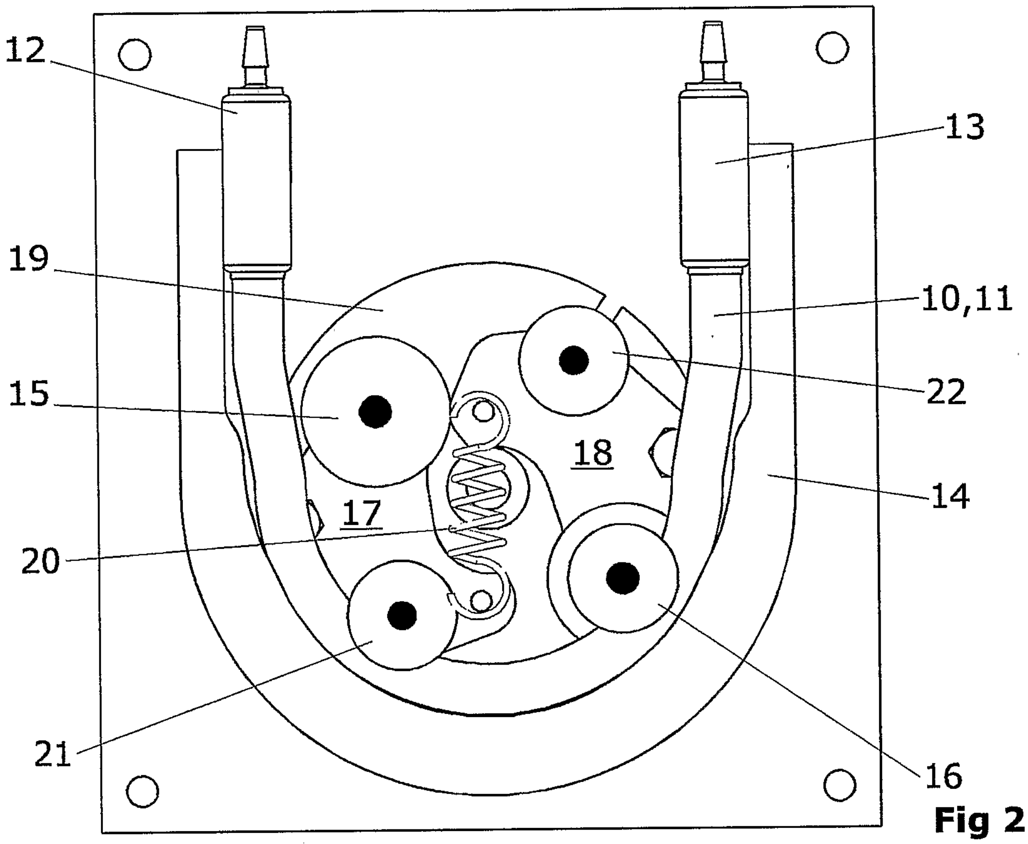

Fig 2

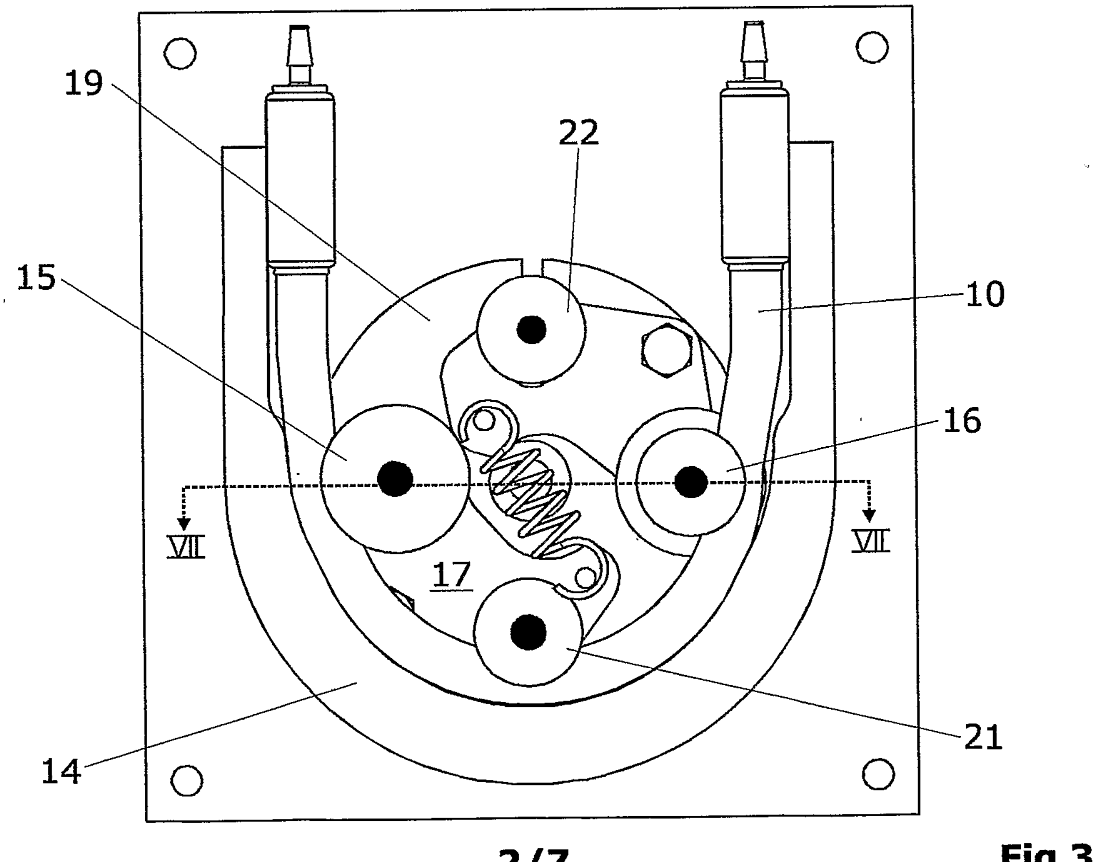

Fig 3

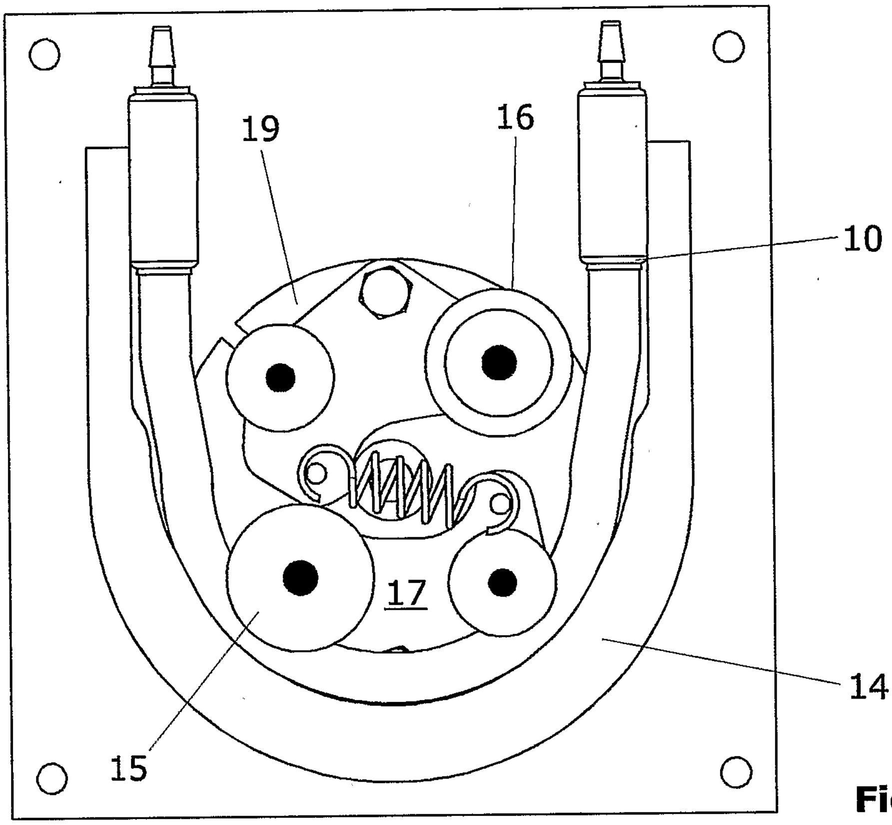

Fig 4

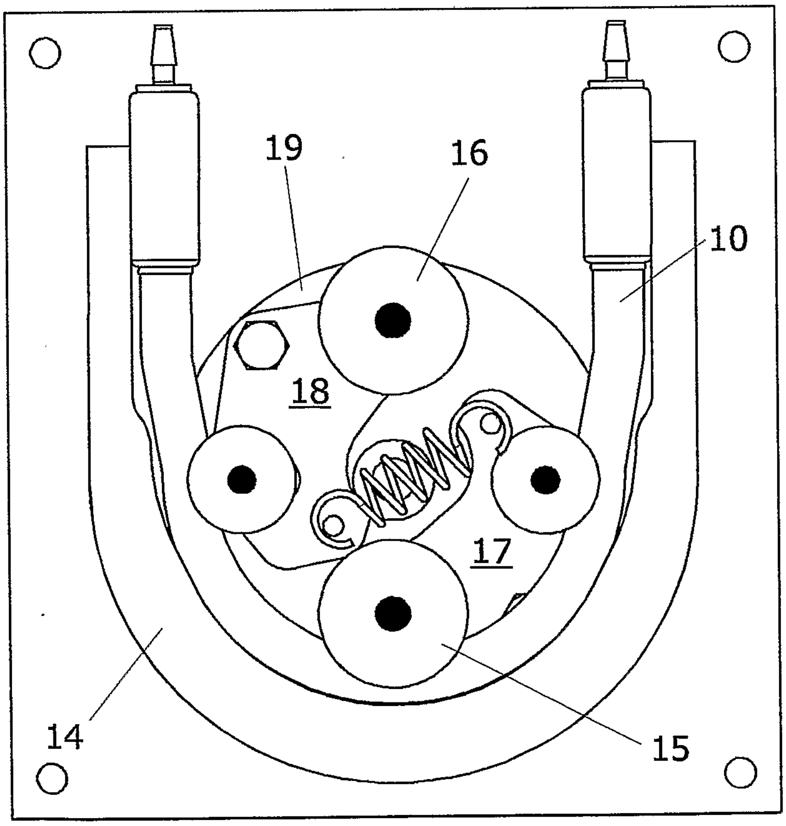

Fig 5

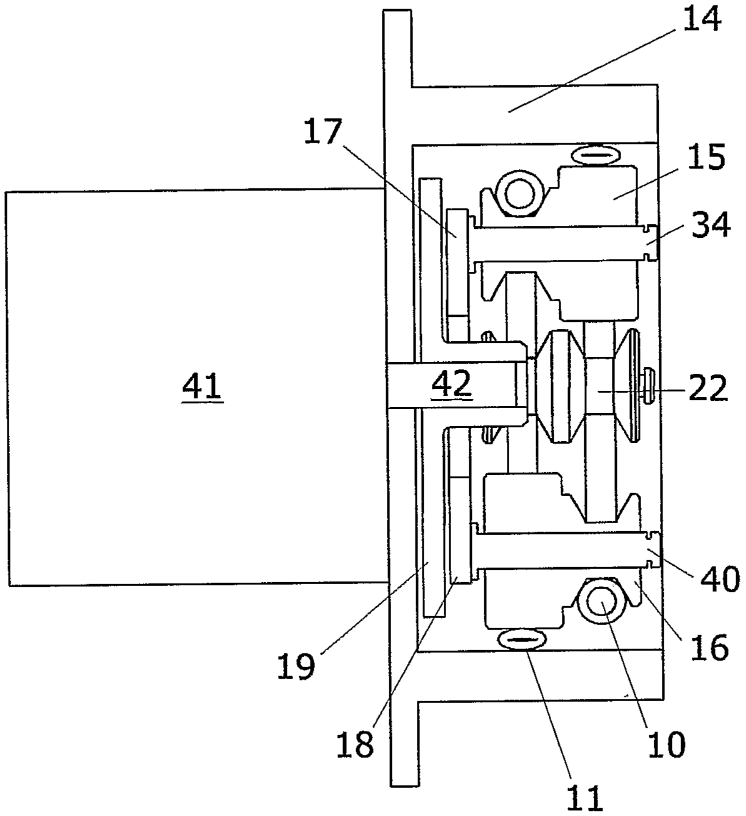

Fig 7

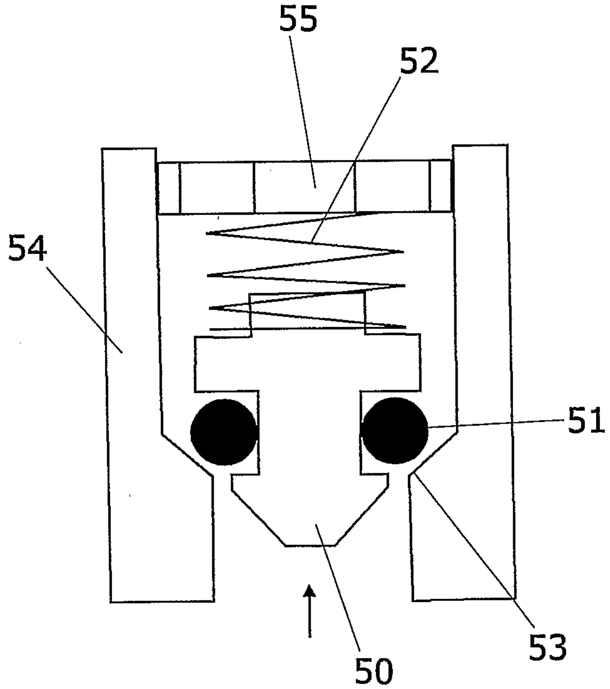

Fig 9

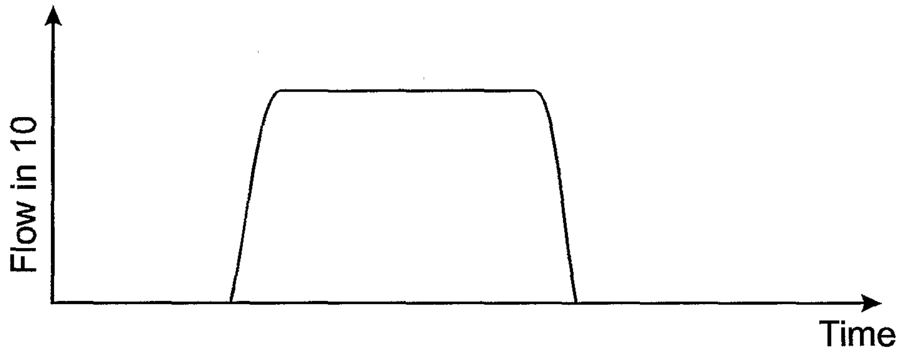

Fig 8A

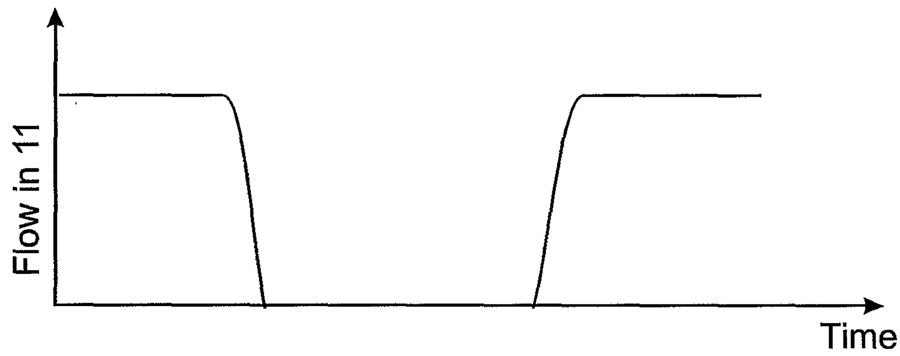

Fig 8B

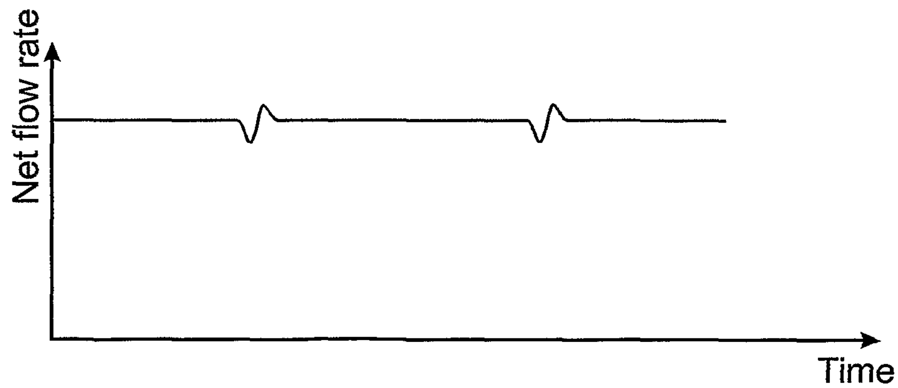

Fig 8C

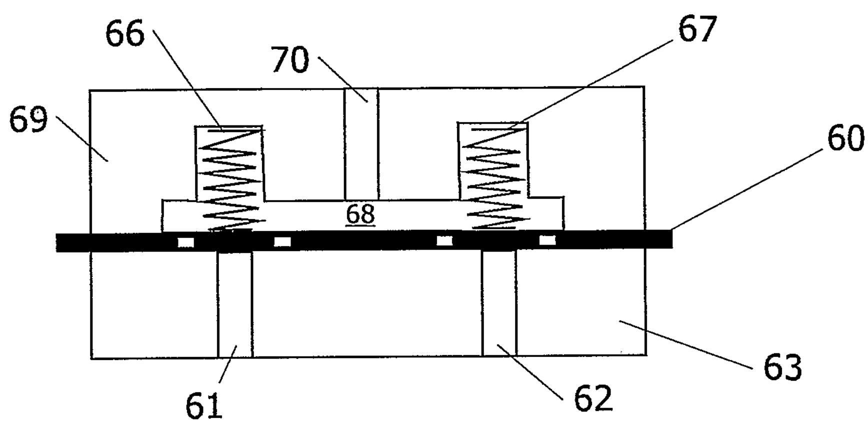

Fig 10

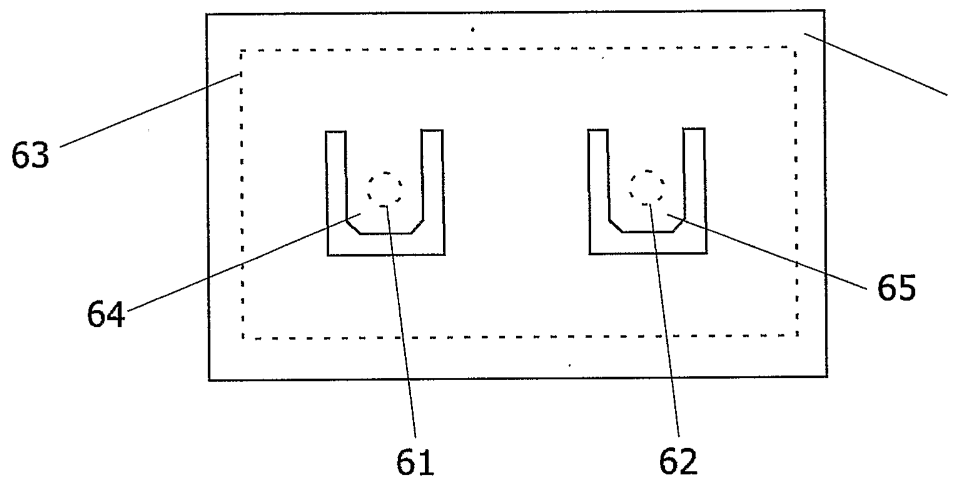

Fig 11

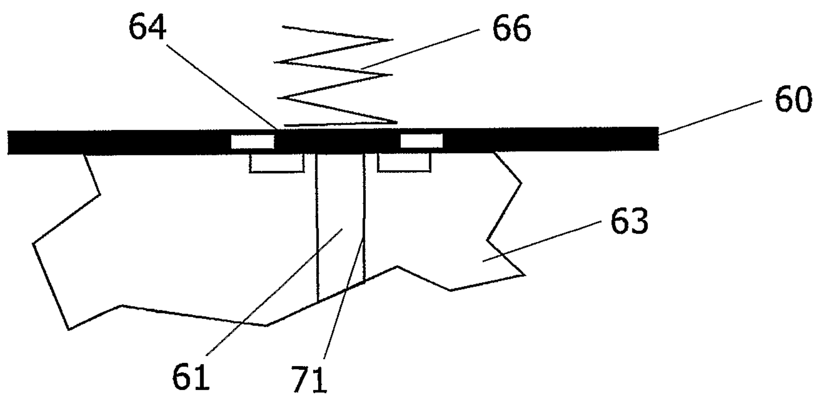

Fig 12

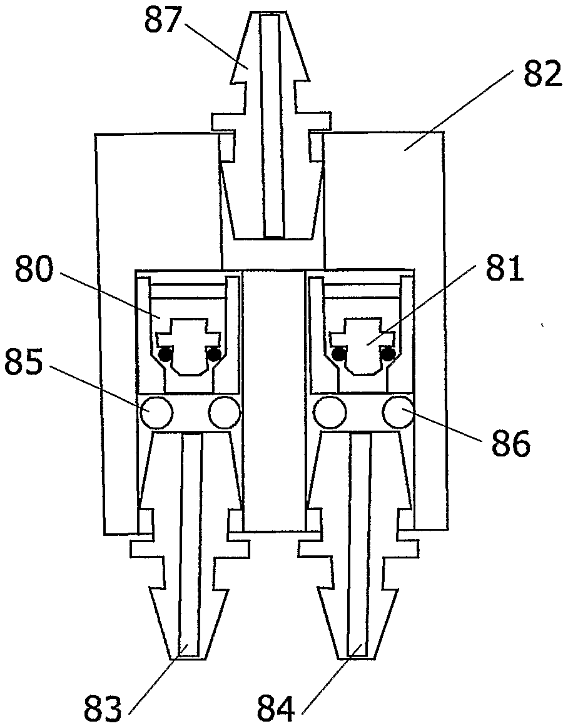

Fig 13

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 02/04818

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F04B43/12 F04B11/00

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 F04B

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 82 04291 A (GRAENDE PER OLOF;BORGSTROEM PER; MENTZ LARS AKE) 9 December 1982 (1982-12-09) page 3, line 3 -page 10, line 21 figures	1,5, 7-11,16, 20,21, 24-30
A	US 5 257 917 A (MINARIK DANIEL ET AL) 2 November 1993 (1993-11-02) abstract column 2, line 19 - line 34 column 6, line 32 - line 68 figures	1,5, 7-11,16, 17,20, 21,24-30

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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
10 January 2003	17/01/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Kolby, L

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	FR 2 595 765 A (MALBEC EDOUARD) 18 September 1987 (1987-09-18) abstract page 3, line 31 -page 6, line 3 figures	1,5, 7-11,16, 17,20, 21,24-30
A	GB 1 595 901 A (ICI LTD) 19 August 1981 (1981-08-19) abstract page 2, line 35 -page 3, line 12 figures	1,5, 7-11,16, 20,21, 24-30

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 02/04818

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