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(54) **Peristaltic pump having an adaptive variable speed control**

(57) A peristaltic pump (10), comprises a rotatable shaft (24) and a roller head (14) carrying a plurality of rollers (16) mounted to the shaft, adapted in use to displace fluid along a segment of a flexible fluid channel (26), wherein the speed of rotation of the rollers may be varied. An adaptive variable speed control is provided which may be configured to accelerate rotation of the pump through known minimum flow points, and to decelerate rotation of the pump through known maximum flow points responsive to a pressure sensor (126), and/or a position encoder (25), or based on a variable or pre-set pump pulsation profile.

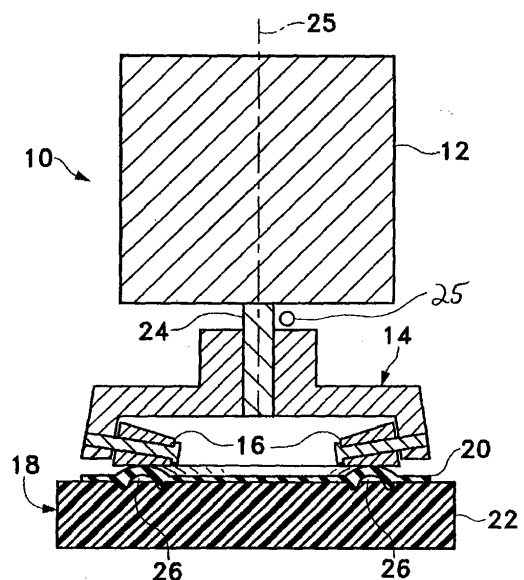


FIG. 2

Description

Background of the Invention

[0001] The present invention relates generally to peristaltic pumps and more specifically to peristaltic pumps used in ophthalmic surgical equipment.

[0002] Peristaltic pumps work by compressing or squeezing a length of flexible tubing (sometimes between a fixed race) using a rotating roller head. As the roller head rotates, the rollers stretch and pinch off a portion of the tubing and push any fluid trapped in the tubing between the roller in the direction of rotation. Peristaltic pumps are widely used in medical applications because of their predictable flow properties.

[0003] Many factors influence the efficiency of peristaltic pumps, for example, pump motor torque, pump speed and pump tube flexibility. The efficiency of a peristaltic pump is also dependent on how tightly the pump rollers crush the tubing against the pump race. If the tubing is not collapsed completely by the rollers, not all of the fluid will be pushed further down the tube. One characteristic of peristaltic pumps is that flow rate varies in a cyclical manner. As a roller begins to pinch off the pump tubing, flow rate is reduced to minimum and then is accelerated to a maximum as the roller continues to sweep along the pump tubing segment. The pressure moves in an inverse relationship to the flow (Pressure $\uparrow$ as Flow $\downarrow$ or Pressure $\downarrow$ as Flow $\uparrow$). As the next roller begins to pinch off the pump tubing, the cycle starts again. This cyclical variation in flow rate causes a cyclical variation in pressure within the fluid path, the effects of which can be observed as pressure pulsations at the operative site. Prior art peristaltic pumps have reduced the effects of these pulsations by increasing the number of pump rollers and/or by tapering the tubing, by introducing capacitance/compliance chambers into the aspiration line or by variable radius pumps. Increasing the number of rollers and/or the use of variable radius pumps increases the cost and complexity of the pumping mechanism. Compliance or capacitance chamber negatively affect the performance (such as vacuum rise time) of the pump.

[0004] Accordingly, a need continues to exist for a method of reducing pulsations in a peristaltic pump that can be implemented without adding unnecessary complexity or compliance to the pumping system.

Brief Summary of the Invention

[0005] The present invention improves upon prior art peristaltic pumps by providing a peristaltic pump having an adaptive pulsation profile.

[0006] Accordingly, one objective of the present invention is to provide a high efficiency peristaltic pump.

[0007] Another objective of the present invention is to provide a peristaltic pump that reduces pump pulsations.

[0008] Yet another objective of the present invention is to provide a peristaltic pump having an adjustable,

adaptive pulsation profile.

[0009] These and other advantages and objectives of the present invention will become apparent from the detailed description, drawings and claims that follow.

Brief Description of the Drawings

[0010]

FIG. 1 is a perspective view of a surgical console that may be used with the present invention.

FIG. 2 is a cross-sectional view of one embodiment of a peristaltic pump of the present invention.

FIG. 3 is a plot of pump pressure/outflow over time for prior art peristaltic pumps.

FIG. 4 is a plot of pump pressure/outflow over time for the peristaltic pump of the present invention.

FIG. 5 is a schematic representation of the pump of the present invention.

Detailed Description of the Invention

[0011] As best seen in FIG. 2, in one embodiment of the present invention, pump 10 of the present invention generally includes pump motor 12, roller head 14, containing one or more rollers 16. Pump 10 is used in combination with cassette 18 having elastomeric sheet 20 applied to the exterior of relatively rigid body or substrate 22. Pump motor 12 preferably is a stepper or D.C. servo motor. Roller head 14 is attached to shaft 24 of motor 12 so that motor 12 rotates roller head 14 in a plane generally normal to the axis of shaft 24, and the longitudinal axes of rollers 16 are generally radial to the axis of shaft 24. Shaft 24 may contain shaft position encoder 25.

[0012] With respect to cassette 18, sheet 20 contains molded fluid channel 26 that is generally planar, arcuate in shape (within the plane) and having a radius approximating that of rollers 16 about shaft 24. Sheet 20 may be made of any suitably flexible, easily molded material such as silicone rubber or thermoplastic elastomer. Sheet 20 is attached or bonded to substrate 22 by any suitable technique such as adhesive, heat fusion or mechanical crimping. Substrate 22 preferably is made of a material that is rigid with respect to sheet 20, such as a rigid thermoplastic, and may be made by any suitable method, such as machining or injection molding.

[0013] As best seen in FIG. 5, pump 10 of the present invention may form part of console 112. Console 112 generally contains pump 10 that is in fluid communication with aspiration line 120 and aspiration exhaust line 134. Aspiration line 120 is connected to surgical handpiece 122 on one end and end 118 of aspiration line 120 opposite handpiece 122 is connected to pump 10 so as to draw fluid through handpiece 122. Aspiration line 120 is intersected between handpiece 122 and 118 by aspiration vent line 124. In fluid communication with aspiration line 120 is sensor 126, which may be one of a variety of invasive or non-invasive pressure or flow sensors well-

known in the art. Exhaust line 134 and vent line 124 drain aspirated fluid into reservoir 128 contained within or on cassette 18. Reservoir may additionally drain into drain bag 129, which may also be contained within or on cassette 18.

[0014] As best seen in FIGS. 3 and 4, the flow/pressure of peristaltic pumps plotted against time has characteristic peaks and valleys. Each peak and valley corresponds to a pump roller displacing fluid from a currently engaged pump segment. The minimum point (valley) corresponds to a roller just pinching off the pump segment (thus momentarily reducing flow), the maximum (peak) corresponds to flow being accelerated to a maximum rate. As seen in FIG. 3, prior art pumps can have large flow/pressure discrepancies between the peaks and valleys, by way of example only, on the order of 10-15 mm Hg.

[0015] Pump 10 of the present invention has an adaptive variable speed control to accelerate rotation of rollers 16 on roller head 14 through known minimum flow (maximum pressure) points, and slow down rotation of rollers 16 on roller head 14 through known maximum flow (minimum pressure) points. This acceleration/deceleration profile can be adaptive; in other words, can vary depending upon cassette 18 and/or the surgical parameters set by the user. For example, a set of pressure data versus roller 16 position can be recorded by surgical console 112 using sensor 126 and encoder 25 during initial priming or other pre-operational tests of cassette 18. This data can be used to derive a pump speed profile required to achieve a desired pressure/flow profile. The derived profile can be used to control the speed of pump 10 during use. In addition, pressure data and position of roller 16 can be continually monitored during use, and this data can be used adaptively to vary the pump speed to achieve and maintain a desired pressure/flow profile during surgery. Further, console 112 can be programmed with a variety of pressure/flow profiles previously generated so as to optimize the pressure/flow profile for a particular cassette type or surgical technique. The proper pressure/flow profile can be manually selected by the user, or console 118 may automatically boot up such optimum pressure/flow profile by automatic identification of the cassette (e.g. barcode or RFID). All of these features can be implemented on commercially available surgical equipment using software commands well within a person skilled in the art.

[0016] Alternatively, sensor 126 may be used to predict minimum and maximum flow/pressure points based on the speed of motor shaft 12 so that encoder 25 is not necessary.

[0017] As best seen in FIG. 4, which is plotting on the same scale as FIG. 3, optimization of the pressure/flow profile can result in greatly attenuated peak to valley pressure variations, for example, on the order of a 3 to 1 reduction.

[0018] This description is given for purposes of illustration and explanation. It will be apparent to those skilled

in the relevant art that modifications may be made to the invention as herein described without departing from its scope or spirit. For example, the present invention is also applicable to more conventional peristaltic pumps that stretch a length of tubing over the roller head.

Claims

1. A peristaltic pump (10), comprising a rotatable shaft (24) and a roller head (14) carrying a plurality of rollers (16) mounted to the shaft, adapted in use to displace fluid along a segment of a flexible fluid channel (26), **characterized by**,
an adaptive variable speed control configured to accelerate rotation of the pump through known minimum flow points, and to decelerate rotation of the pump through known maximum flow points.
2. The peristaltic pump of claim 1, further comprising means (126) to monitor fluid pressure and/or flow caused by the rollers (16) over time, so as to derive a pump speed profile required to achieve a desired pressure/flow profile, or so as to predict said minimum and maximum flow points.
3. The peristaltic pump of claim 1 or claim 2, further comprising means (25) to monitor the shaft (24) or roller (16) position over time.
4. The peristaltic pump of claim 1, wherein the acceleration and deceleration of the peristaltic pump is based on a pump pulsation profile, the pump pulsation profile being determined during initial priming or other pre-operational test of the peristaltic pump.
5. The peristaltic pump of claim 1, wherein the acceleration and deceleration of the peristaltic pump is based on a pump pulsation profile, the pump pulsation profile being continually determined during operation of the peristaltic pump.
6. The peristaltic pump of claim 1, wherein the acceleration and deceleration of the peristaltic pump is based on a pump pulsation profile, the pump pulsation profile being set by a user of the peristaltic pump.
7. The peristaltic pump of claim 1, wherein the acceleration and deceleration of the peristaltic pump is based on a pump pulsation profile, the pump pulsation profile being determined by automatic recognition of a cassette (18) comprising the segment of a flexible fluid channel (26), being used with the peristaltic pump.
8. A surgical console (112), comprising:
 - (a) a peristaltic pump (10), the peristaltic pump

having a shaft (24) and a roller head (14) carrying a plurality of rollers (16) mounted to the shaft, adapted in use to displace fluid along a segment of a flexible fluid channel (26);

(b) a position encoder (25) associated with the pump for establishing the location of the shaft (24) or the rollers (16); 5

(c) a sensor (126) for determining a pressure generated in an aspiration line (120) by the peristaltic pump; and 10

(d) an adaptive variable speed control, responsive to the position encoder (25) and the pressure sensor (126) to accelerate rotation of the pump rollers (16) through known minimum flow points, and to decelerate rotation of the pump rollers (16) through known maximum flow points. 15

9. The surgical console of claim 8, wherein the adaptive variable speed control is configured to cause acceleration and deceleration of the peristaltic pump (10) based on a pump pulsation profile, the pump pulsation profile being determined during initial priming or other pre-operational test of the peristaltic pump. 20

10. The surgical console of claim 8, wherein the adaptive variable speed control is configured to cause acceleration and deceleration of the peristaltic pump (10) based on a pump pulsation profile, the pump pulsation profile being continually determined during operation of the peristaltic pump. 25 30

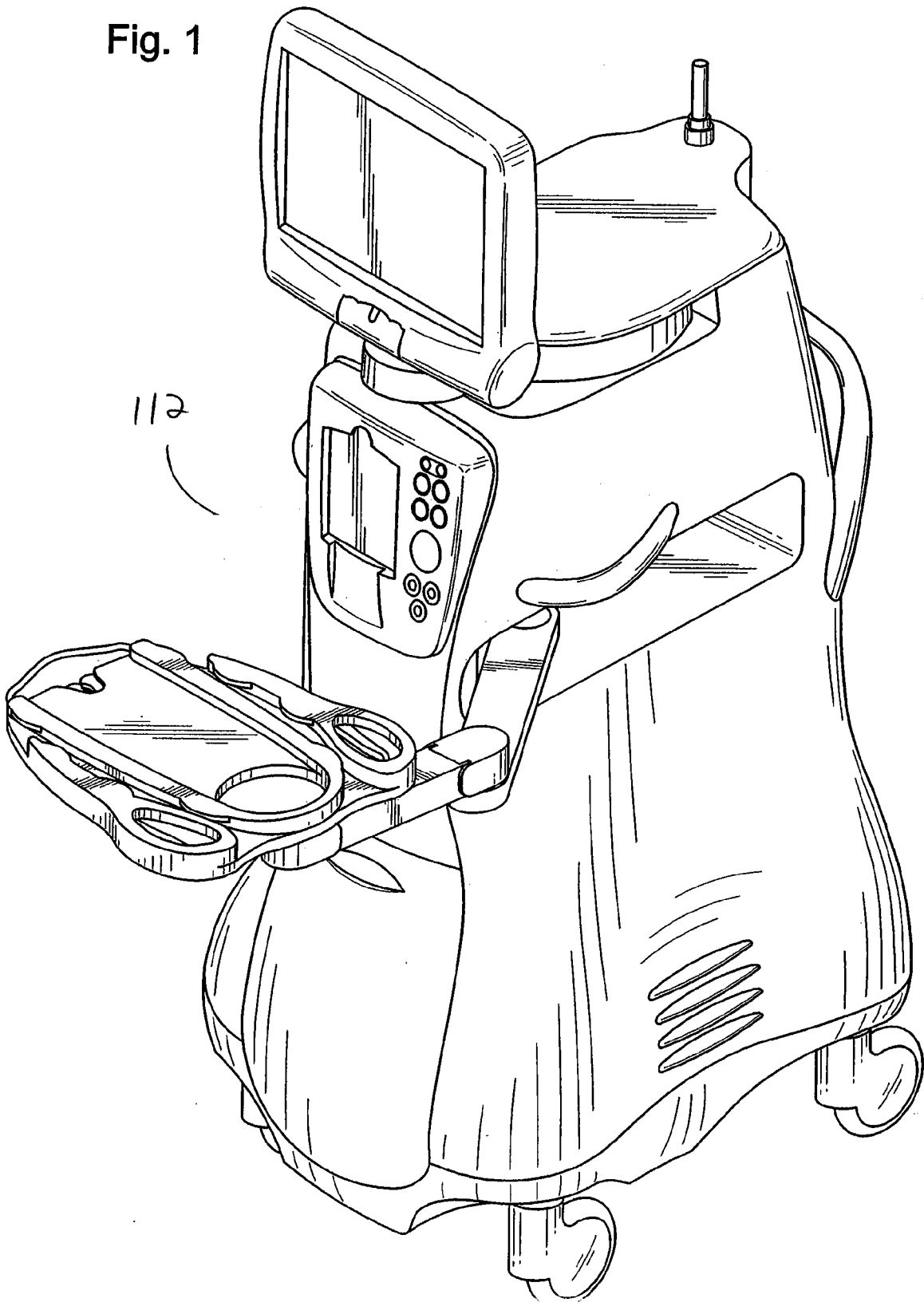
11. The surgical console of claim 1, wherein the adaptive variable speed control is configured to cause acceleration and deceleration of the peristaltic pump (10) based on a pump pulsation profile, the pump pulsation profile being set by a user of the console. 35

12. The surgical console of claim 1, wherein the adaptive variable speed control is configured to cause acceleration and deceleration of the peristaltic pump (10) based on a pump pulsation profile, the pump pulsation profile being determined by automatic recognition by the surgical console (112) of a cassette (18) comprising said segment of said flexible fluid channel (26), the console being adapted to receive the cassette and being adapted to cause the peristaltic pump to coact with the cassette. 40 45

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Fig. 1



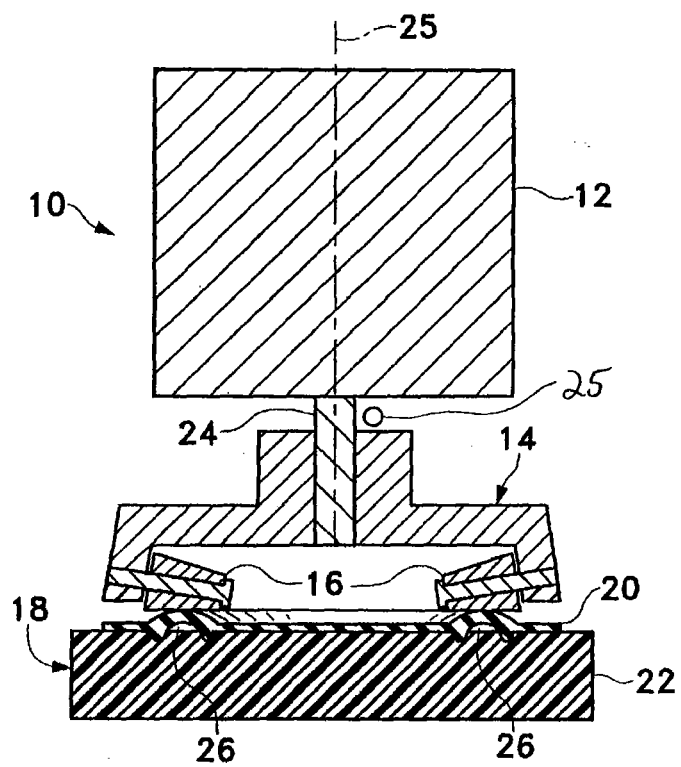
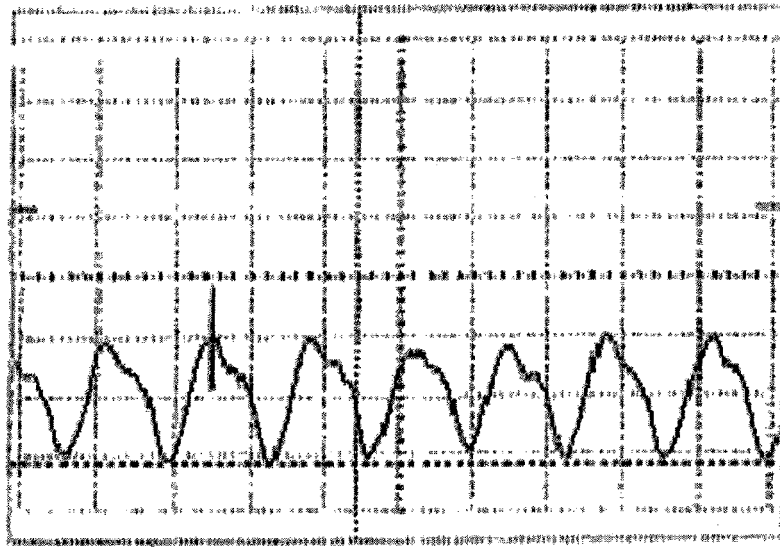


FIG. 2

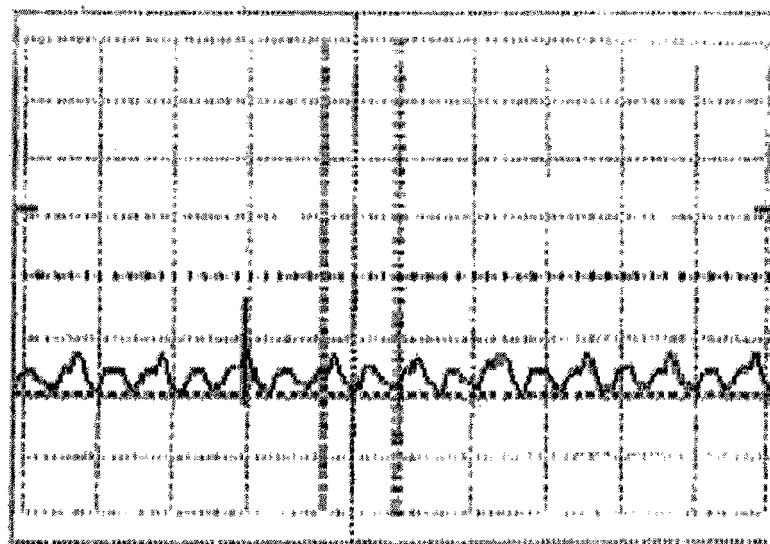
Pressure↓/Flow↑



Time

FIG. 3

Pressure↓/Flow↑



Time

FIG. 4

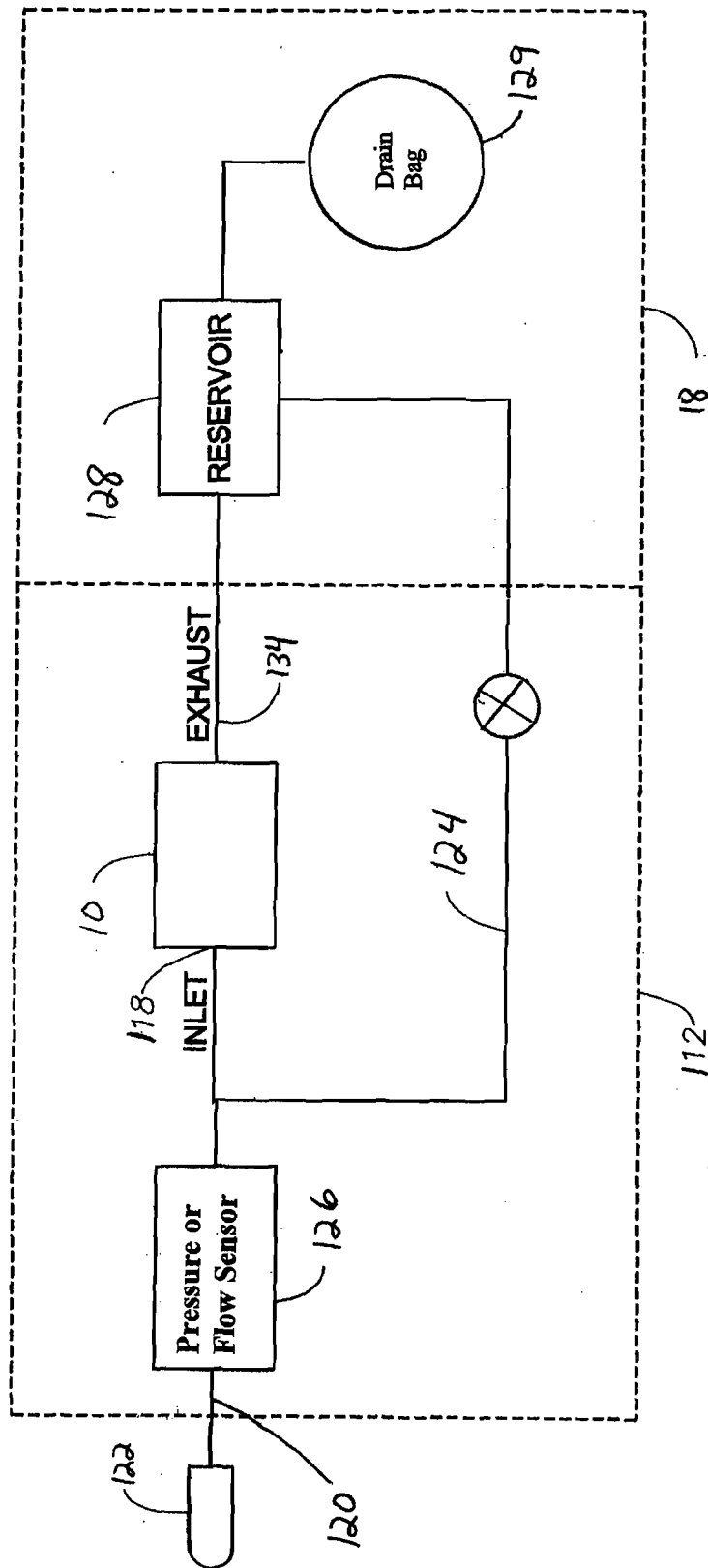


FIG. 5



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Application Number
EP 07 10 3180

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Place of search Munich		Date of completion of the search 20 April 2007	Examiner Gnüchtel, Frank
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Place of search Munich		Date of completion of the search 20 April 2007	Examiner Gnüchtel, Frank
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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