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(71) Applicant *(for all designated States except US)*: **GAMBRO LUNDIA AB** [SE/SE]; P.O. Box 10101, S-220 10 Lund (SE).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **OLDE, Bo** [SE/SE]; Läsvägen 20, S-224 67 Lund (SE). **JANSSON, Olof** [SE/SE]; Näktergalsgatan 33, S-235 38 Vellinge (SE).

(74) Agents: **BORNEGÅRD, Annette** et al.; P.O. Box 10101, S-220 10 Lund (SE).

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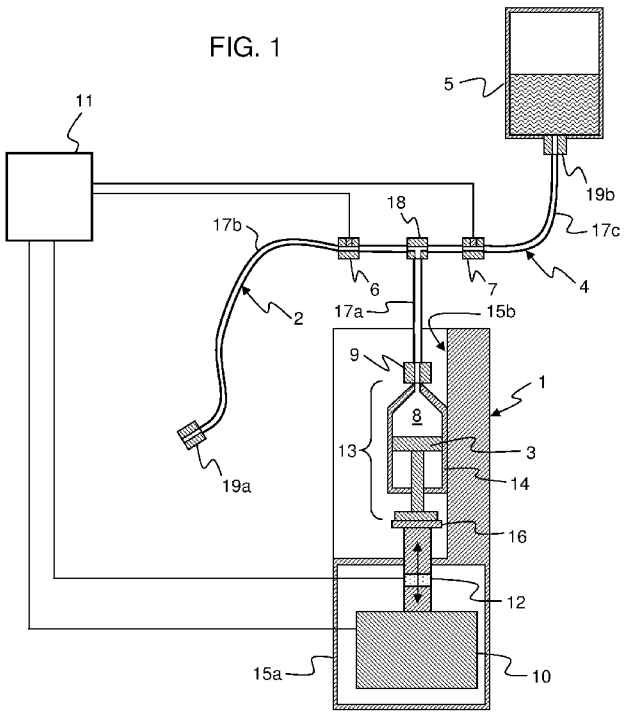
(54) Title: INFUSION SYSTEM AND METHOD OF INTEGRITY TESTING AND LEAK DETECTION

FIG. 1



(57) Abstract: An infusion system is controlled by driving a displacing element (3) in alternate fill and pump directions in a fluid chamber (8) to define a varying displacement volume, and by synchronously operating a valve arrangement (6, 7) to alternately open and close first and second fluid paths (4, 2) from the fluid chamber (8) to a source (5) and a connector (19a), respectively, such that an infusion liquid is repeatedly sucked into the fluid chamber (8) from the source (5) and pumped from the fluid chamber (8) through the connector (19a). The infusion system comprises a sensor (12) for generating a measurement signal representative of fluid pressure in the displacement volume. A controller (11) is connected to intermittently effect a system test, in which the valve arrangement (6, 7) is operated to close the second fluid path (2); the displacing element (3) is driven a given distance in the fill direction; and the measurement signal is obtained from the sensor (12) during at least part of the system test. The integrity of the infusion system is determined based on the measurement signal, e.g. by evaluating the temporal change in the measurement signal during and/or after the displacement. The system test may identify a shortage of infusion liquid in the source (5) or a leakage of air into the first fluid path (4).

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INFUSION SYSTEM AND METHOD OF INTEGRITY TESTING AND LEAK DETECTION

Technical Field

The present invention generally relates to infusion pumps such as those used for controlled delivery of fluid to a human or animal subject. More specifically, the invention relates to system tests and security measures to be performed during operation of infusion pumps.

Background art

Infusion pumps and systems are well-known in the art, for use in delivering or dispensing an infusion liquid or a prescribed medication to a patient through parenteral or intravenous administration.

A typical infusion pump includes a housing, which encloses a pump drive system, a fluid containment assembly, an electronics system and a power supply. The pump drive system typically includes a small electrical motor and drive train components such as gears, screws and levers that convert rotational motor motion to a translational movement of a plunger in a reservoir. The fluid containment assembly typically includes the reservoir with the plunger, tubing, and a catheter or infusion set to create an output fluid path for carrying infusion liquid from the reservoir to the body of the patient. The electronics system regulates power from the power supply to the motor. The electronics system may include programmable controls that operate the motor continuously or at periodic intervals to obtain a closely controlled and accurate delivery of infusion liquid over an extended period of time.

CA1067781 and US4137913 disclose an infusion pump in which the electronics system controls the motor to reciprocate the plunger back and forth in the reservoir in alternate fill and pump strokes. The reservoir is not only connected on an output fluid path to the body of the patient but also to a source of infusion liquid, via a line set that defines an input fluid path. A pair of valves are arranged to selectively open and close the input fluid path and the output fluid path, respectively, in synchronization with the reciprocating movement of the plunger. Thereby, infusion liquid is sucked into the reservoir via the input fluid path on a fill stroke, and infusion liquid is dispensed to the patient through the output fluid path on a pump stroke.

Generally, medical infusion systems should include an alarm system, which is designed to quickly and reliably detect and indicate any of a number of fault conditions of the infusion system. For example, the infusion system in CA1067781 and US4137913 includes a drop detector which monitors drop flow in a transparent drip chamber in the input fluid line. The drop detector includes a light source and a photocell arranged on opposite sides of the drip chamber. The alarm system is connected to the drop sensor to

ensure that drop flow occurs during the fill stroke and that no drop flow occurs during the pump stroke. Further, the system in CA10677881 and US4137913 includes an air detector, consisting of a combination of a light-emitting diode and a photocell detector, which is arranged to detect any air bubbles passing through the input or output fluid line. The alarm system is connected to the air detector to ensure that air is not infused into the patient.

It is realized that the complexity and cost of the overall infusion system is increased for each specialized detector that is included to detect a specific fault condition. Further, by including a number of specialized detectors, the number of potential points of failure for the overall system is actually increased, resulting in a potentially increased risk of system malfunction.

The prior art also comprises US2004/0247445 and US2009/0143727, which disclose a medical pump for use with a cassette having a pumping chamber. The medical pump includes a pumping element with a piston slider assembly which intermittently pressurizes the pumping chamber during a pumping cycle and has a piston head connected to a main body via a pressure sensor. During the pumping cycle, inlet and outlet valves in the cassette are controlled in synchronization with inlet and outlet strokes of the pumping element to ensure a unidirectional flow of feeding liquid from through the cassette. The pumping cycle consists of an fill phase, in which the inlet valve is opened and the outlet value is closed to draw the feeding liquid into the cassette via the inlet port, and a pumping phase, in which the inlet valve is closed and the outlet valve is opened to pump the feeding liquid out of the cassette via the outlet valve. During the pumping phase, the outlet valve is only opened after the pumping element has completed part of its output stroke, allowing a significant rise of pressure inside the cassette if the cassette is filled with feeding liquid. If the cassette is partly filled with air the pressure rise will be significantly lower. Thereby, it is proposed to detect presence of air in the cassette based on the pressure signal of the pressure sensor during the initial part of the output stroke. This technique is only suited for air detection before the cassette is connected to a patient, since any air in the cassette will be pumped through the outlet port and into the infusion line during the air detection.

The prior art also comprises US2010/0090843, US5464392, US4936385 and WO2010/046728.

Summary

It is an object of the invention to at least partly overcome one or more limitations of the prior art. Specifically, it is an object to enable system tests during operation of an infusion system with a reciprocating pump while reducing the need to install specialized detectors in the fluid paths within the system. It is also an object to provide for automatic operation of the infusion system.

This and other objects, which may appear from the description below, are at least partly achieved by means of a method, a device, and a computer program product

according to the independent claims, embodiments thereof being defined by the dependent claims.

A first aspect of the invention is a method of operating an infusion system. The infusion system comprises a fluid chamber connected on a first fluid path to a source of infusion liquid and on a second fluid path to a connector, a valve arrangement for selectively opening and closing the first and second fluid paths, an actuator for driving a displacing element in the fluid chamber in alternate first and second directions to define a varying displacement volume, and a sensor for generating a measurement signal representative of the fluid pressure in the displacement volume. The method comprises the steps of: operating the actuator to drive the displacing element in fill and pump strokes by driving the displacing element in the fluid chamber in the first and second directions, respectively; operating the valve arrangement in synchronization with the actuator, so as to open the first fluid path and close the second fluid path during a fill stroke and to open the second fluid path and close the first fluid path during a pump stroke; and intermittently effecting a system test. The system test comprises: operating the valve arrangement to close the second fluid path; driving the displacing element a given distance in the first direction; obtaining the measurement signal from the sensor during at least part of the system test; and determining the integrity of the infusion system based on the thus-obtained measurement signal.

The method of the first aspect reduces the need to use specialized detectors in the fluid paths within the infusion system to assess the integrity of the infusion system during its operation, since one or more system tests may instead be effected based on the fluid pressure in the displacement volume. Furthermore, the system test is executed while the displacing element is driven in the first direction, i.e. in the direction of a fill stroke, while the second fluid path from the fluid chamber to the connector is closed. This allows the system test to be performed during operation of the infusion system, e.g. while the infusion system is in fluid communication with a patient via the second fluid path, since system faults such as air leakages and shortage of infusion liquid in the source may be detected without requiring the content of the fluid chamber to be pumped into the second fluid path.

In one embodiment, the given distance is less than the length of a fill stroke.

In one embodiment, the system test is effected during a fill stroke.

In one embodiment, the valve arrangement is actively controlled during the system test.

In one embodiment, the step of determining comprises identifying a decreasing flow of infusion liquid from the source based on a temporal change in the magnitude of the measurement signal. As used herein, "temporal" indicates the time domain, and the "temporal change" thus denotes a change in magnitude of signal values over time.

In such an embodiment, the system test may further comprise the step of deactivating the actuator and outputting an alarm signal, when the step of determining identifies said decreasing flow of infusion liquid.

In one embodiment, the step of determining is arranged to identify a leakage of air into the first fluid path. In such an embodiment, the step of determining may be arranged to discriminate between different locations and/or magnitudes of the leakage of air based on the temporal change in the magnitude of the measurement signal.

In one embodiment, the step of determining is arranged to identify a shortage of infusion liquid in the source.

In one embodiment, the step of determining comprises deriving a parameter value from the measurement signal and comparing the parameter value to a predetermined limit.

In one variant of such an embodiment, the system test may further comprise operating the valve arrangement such that the first fluid path is open during said driving. The parameter value may be selected from the group comprising: a change or rate of change in the measurement signal during at least part of said driving, a change in the measurement signal as a result of said driving, a difference between a profile of the measurement signal and a reference signal profile during at least part of said driving, and a difference between a profile of the measurement signal and a reference signal profile during a time period after completion of said driving.

In another variant of such an embodiment, the valve arrangement may be operated to open the first fluid path after initiation of said driving, and possibly after completion of said driving. The source may comprise a rigid container with a venting hole, and the method may further comprise the step of selectively operating a venting valve to close the venting hole before opening the first fluid path during the system test. Here, the parameter value may be indicative of an amount of air in the source, and the parameter value may be calculated as a function of a change in the measurement signal caused by the opening of the first fluid path. Generally, the parameter value may be selected from the group comprising: a change in the measurement signal as a result of opening the first fluid path, a change or rate of change in the measurement signal as a result of opening the first fluid path, and a difference between a profile of the measurement signal and a reference signal profile as a result of opening the first fluid path.

A second aspect of the invention is a computer program product comprising instructions for causing a computer to perform the method according to the first aspect of the second inventive concept.

A third aspect of the invention is a control device for operating an infusion system as described in relation to the first aspect. The control device comprises: means for causing the actuator to drive the displacing element in fill and pump strokes by driving the displacing element in the fluid chamber in the first and second directions, respectively; means for operating the valve arrangement in synchronization with the actuator, so as to

open the first fluid path and close the second fluid path during a fill stroke and to open the second fluid path and close the first fluid path during a pump stroke; and means for intermittently effecting a system test by: operating the valve arrangement to close the second fluid path; driving the displacing element a given distance in the first direction; obtaining the measurement signal from the sensor during at least part of the system test; and determining the integrity of the infusion system based on the thus-obtained measurement signal.

Embodiments of the third aspect may correspond to the above-identified embodiments of the first aspect.

Still other objectives, features, aspects and advantages of the present invention will appear from the following detailed description, from the attached claims as well as from the drawings.

Brief Description of the Drawings

Embodiments of the invention will now be described in more detail with reference to the accompanying schematic drawings.

Fig. 1 is an elevated section view of an exemplary infusion system.

Fig. 2 is a section view of an alternative arrangement of valves in the system of Fig. 1,

Fig. 3 is a flow chart of a source test procedure in an infusion system according to a first embodiment.

Figs 4A-4D are graphs of measurement signals obtained as a function of time in the infusion system of Fig. 1.

Fig. 5 is a flow chart of a source test procedure in an infusion system according to a second embodiment.

Detailed Description of Exemplary Embodiments

In the following, an exemplary infusion system is described for the purpose of illustrating embodiments of the invention, including processes for identifying leakage of air into the infusion system and/or for identifying an empty source container in the infusion system. Throughout the following description, like elements are designated by the same reference signs.

EXEMPLARY INFUSION SYSTEM

The following sections describe system tests that are carried out in an infusion system, by selectively operating a fluid displacing element and a valve arrangement in the infusion system, and by measuring and analysing a signal indicative of fluid pressure within the infusion system. These tests will be explained in relation to an exemplifying infusion system shown in Fig. 1.

The infusion system in Fig. 1 includes a positive displacement pump 1 which operates to pump a fluid through an infusion line 2, typically to a patient (not shown). The pump contains a fluid displacing element 3 that defines an internal displacement volume. The internal displacement volume is connected via a filling line 4 to a source container 5. Control valves 6, 7 are arranged in the infusion and filling lines 2, 4 such that the displacement volume may be repeatedly filled from the source container 5 and infused into the patient while the pump operates to move the fluid displacing element 3 back and forth in a fluid chamber 8 inside the pump. The source container 5 may contain any liquid that may be dispensed to a patient, such as medications, drugs, vitamins, vaccines, hormones, water, nutrition, etc, or combinations thereof. In the following, any such liquid is referred to as an "infusion liquid". As used herein, a liquid used for the sole purpose of priming the infusion system is also referred to as an infusion liquid.

In the example shown in Fig.1, the infusion pump is a so-called syringe pump which defines a cylindrical fluid chamber 8. The fluid displacing element 3 is implemented as a plunger or piston, which is slidably received and adapted to be reciprocated back and forth along the axis of the chamber 8. The front end of the chamber 8 has a port for connection to the infusion and filling lines 2, 4, via an appropriate connector 9. The plunger 3 is coupled to and driven by an actuator 10 of any suitable type. The actuator 10 may, e.g., include a DC or stepper motor, which is adapted to drive the plunger 3, via appropriate gearing (not shown). A control unit 11 is electrically connected to the actuator 10 to supply a control signal for controlling the movement of the plunger 3 in the chamber 8. The control unit 11 is also connected to obtain a measurement signal from a sensor 12 which is arranged to measure the axial force on the plunger 3. This measurement signal is representative of the fluid pressure in the displacement volume, which is the varying front-end space between the plunger 3 and the chamber 8. As will be further explained below, this measurement signal may be used by the control unit 11 to carry out system tests during operation of the infusion system.

In one embodiment, the fluid-containing part of the infusion pump 1 is designed as a disposable part or cartridge 13, e.g. of plastic material. The cartridge 13, typically formed as a syringe, includes a cylinder or barrel 14 that defines the chamber 8 in which the plunger 3 is mounted. The actuator 10 and gearing (not shown) is arranged in a pump housing 15a, which defines a mounting compartment 15b for the cartridge 13. When mounted in the mounting compartment 15b, the plunger 3 is engaged with a fixture/holder 16 which is driven by the actuator 10, such that the plunger 3 may be driven to reciprocate along the cylinder 14. The use of a disposable cartridge 13 may facilitate the task of keeping the infusion system clean and substantially sterile (such that the number of micro-organisms is reduced to such a low population that the likelihood of infection or contamination is substantially reduced or eliminated). Whenever the infusion system needs to be cleaned, the infusion and filling lines 2, 4 may be disconnected from the patient and

the source 5, respectively, and the pump 1 may be operated to drain any remaining liquid in the infusion system through the disconnected infusion line 2 and/or filling line 4. Then the cartridge 13 and filling and infusion lines 2, 4 may be detached and replaced by a new, suitably sterilized, set.

The sensor 12 may be placed anywhere in the drive train from the actuator 10 to the plunger 3 to measure variations in the force applied to one or more components within the drive train. If the fluid-containing part of the pump 1 is provided as a disposable cartridge 13, the sensor 12 is suitably arranged in the drive train within the pump housing 15a. In one embodiment, the sensor 12 is a force sensitive resistor, whose resistance changes as the force applied to the sensor changes. In alternative embodiments, the sensor is a capacitive sensor, piezoresistive sensor, piezoelectric sensor, vibrating wire sensor, magnetic sensor, optical sensor, potentiometer, micromachined sensor, linear transducer, encoder, strain gauge and the like.

In the example of Fig. 1, the infusion line 2 is formed by a first line section 17a that extends from the cartridge connector 9 attached to the port on the front end of the cartridge 13 to a first port of a 3-way connector 18, and by a second line section 17b that extends from a second port of the 3-way connector 18 to a system connector 19a. The filling line 4 is formed by the first line section 17a and a third line section 17c that extends from a third port of the 3-way connector 18 to a source connector 19b. The connectors 9, 18, 19a, 19b may be of any suitable type, e.g. Luer lock or slip connectors, threaded connectors, snap-fit connectors, etc. Suitably, at least the system connector 19a and the source connector 19b are releasable connectors, which may be attached and detached from the downstream system (e.g. a patient catheter or a downstream line set) and the source container 5, respectively. Depending on implementation, the infusion and filling lines 2, 4 may be made up of flexible tubing (e.g. plastic), rigid tubes, or pathways/channels of a solid block (e.g. a plastic cassette), or any combination thereof.

In the example of Fig. 1, the filling valve 7 is arranged to control the flow of fluid in the filling line 4, and the infusion valve 6 is arranged to control the flow of fluid in the infusion line 2. The valves 6, 7 are opened and closed in synchronization with the movement of the plunger 3 in the chamber 8. Specifically, the filling valve 7 is opened and the infusion valve 6 is closed during a “fill stroke”, in which the plunger is retracted within the fluid chamber 8, so as to generate a suction force that draws fluid into the fluid chamber 8 from the source container 5 via the filling line 4. Conversely, the infusion valve 6 is opened and the filling valve 7 is closed during a “pump stroke”, in which the plunger 3 is pushed into the fluid chamber 8, so as to generate a driving force that pushes fluid through the infusion line 2 and out of the system connector 19a.

It should be understood that the infusion system may be operated at low flow rates and that a pump stroke may last for several minutes, hours, or even days. When the plunger 3 reaches the end of the pump stroke, which may be indicated by a dedicated sensor (not

shown) in the pump, the control unit 11 initiates the fill stroke, which generally should be completed as fast as possible, whereupon the control unit 11 again initiates a pump stroke. In certain embodiments the displacement volume of the pump may be about 10-200 cm^3, and the infusion rate may be about 1-500 ml/h. These numbers are just examples and should not be interpreted in a limiting sense.

It should be realized that the above operation of repeatedly filling and emptying the fluid chamber 8 may be achieved without any active valve control, e.g. by using check valves, also known as non-return valves or one-way valves, as infusion and filling valves 6, 7. These check valves automatically open when subjected to a sufficient pressure differential in one direction, while otherwise being closed, also when subjected to a pressure differential in the opposite direction. However, for the purpose of enabling one or more of the different system tests that are described in the following, at least one of the infusion and filling valves 6, 7 may be a control valve, which is actively controlled to open and close by a control signal from the control unit 11. The other valve may also be actively controlled, as shown in Fig. 1, or be implemented as a check valve, depending on the system tests that are to be enabled. The control valve may, e.g., be implemented as a pinch valve, a revolution valve, a sliding valve, an integrated valve function of a cassette, etc, wherein the opening and closing of the valve may be controlled by an electro-magnet subject to the control signal from the control unit 11. Each control valve may be either normally closed or normally open.

The source 5 may be of any conventional type, e.g. a flexible container, such as a sealed plastic bag, a rigid container, such as a glass bottle, or a source that is capable of producing fluid on-line. The use of a rigid container may provide for additional variations of the system tests, as will be described in the following.

Fig. 2 illustrates an alternative embodiment, in which the source container 5 is rigid and at least partially filled with liquid, and has a venting valve 5a controlling the open/closed state of a venting hole 5´ on the container 5, subject to a control signal from the control unit 11 (cf. Fig. 1). In Fig. 2, the venting valve 5a is arranged on a tube segment connected to the venting hole 5´. In a variant, the venting valve 5a may be directly attached to the venting hole 5´on the container 5. It should be understood that the set of components in Fig. 2 is intended to replace the corresponding set of components in Fig. 1, to form an infusion system.

The system tests are typically based on causing or using a certain combination of open/closed states among the valves 6, 7, 5a in the infusion system, and then activating the pump 1 to displace a test volume V_t. The test volume is typically displaced by controlling the pump 1 to displace the plunger 3 a certain distance to decrease (pump direction) or increase (fill direction) the displacement volume in the fluid chamber 8. Typically, the displacement is only a small part of a complete stroke, allowing for the system test to be carried out during a short time period. For example, the displacement may be less than

about 10%, and preferably less than about 1%, of a complete stroke. The system tests further involve measuring and evaluating the force response in the hydraulic system, i.e. the fluid displaced by the plunger 3, so as to determine the integrity of the hydraulic system. The force response may be measured by the aforesaid force sensor 12, either during and/or after the displacement of the test volume, or at a certain time point after initiation or completion of the displacement of the test volume. The evaluation may involve comparing the force response with a reference value, e.g. measured before the displacement of the test volume, or a reference response, e.g. obtained by theoretical modelling or from preceding calibration measurements. Generally, the system tests aim at determining the integrity of the infusion system based on a measurement signal from the sensor 12, typically by identifying presence/absence of a temporal change in the signal values of the measurement signal caused by the displacement of the test volume V_t. The temporal change may, e.g., occur in the signal values (signal profile) during and/or after the displacement, or in a difference between the signal values before and after the displacement.

Below follows a description of exemplifying system tests for empty source and/or air leakage detection.

TESTING FOR EMPTY SOURCE CONTAINER/AIR LEAKAGE

When operating an infusion system which is repeatedly filled by means of a reciprocating plunger, it may be important to properly identify if and when the source container 5 becomes empty, so as to avoid sucking air into the infusion system and thus pumping air into the patient. For the same reason, it may be equally important to identify other air leakages in the infusion system during the fill stroke, e.g. at the connector 9 on the front end of the syringe cartridge 13, or at the connector 19b between the filling line 4 and the source 5.

Thus, it may be desirable to be able to intermittently and preferably without manual intervention test the infusion system for air leakage/empty source container, denoted "source test" in the following. The source test may, e.g., be performed repetitively at well-defined time intervals, and/or each time the fluid chamber 8 has been refilled, e.g. after a fill stroke, and/or each time the pump has been manipulated manually, e.g. if a new cartridge 13 has been installed in the pump. The source test may be performed in conjunction with priming, a fill stroke, or at a predetermined time before a fill stroke is scheduled, e.g. in order to give an operator time to replace/refill the source 5 before the fluid chamber 8 is completely empty. Priming is a measure, well-known to those skilled in the art, for purging gas or undesired liquid substances from the infusion system, typically by causing infusion liquid to flow through the entire infusion system.

A first embodiment of a source test will now be described for the infusion system in Fig. 1, with reference to the flowchart in Fig. 3. The first embodiment is designed to test

the integrity of the hydraulic system extending from the fluid chamber 8 to the infusion valve 6 and to the source container 5.

First, if the plunger 3 is moving, the pump is controlled to stop the plunger (step 30). Then, the infusion valve 6 is closed and the filling valve 7 is opened (step 31). The initial force F_0 in the hydraulic system is then measured, using the force sensor (step 32). All subsequent force measurements may then be related to F_0 by e.g. subtracting F_0 from the actual reading (see below). Thereafter, the pump is operated to move the plunger 3 a predetermined distance in the fill direction, so as to suck the above-mentioned test volume V_t into the fluid chamber 8 (step 33). The distance may e.g. be represented as a preset number of steps of a stepper motor or as a preset plunger speed and displacement time. During displacement of the plunger 3, the force F(t) applied to the hydraulic system is monitored, e.g. by continuously sampling a measurement signal from the force sensor 12 (step 33). Then, in step 34, the measurement signal is evaluated to determine if the source is empty and/or if there is an air leakage in the hydraulic system. If step 34 indicates empty source container/air leakage, a high-importance alarm, e.g. in the form of an audible and/or visible signal, is issued and the infusion process is terminated, e.g. by the control unit 11 controlling the actuator 10 to immobilize the plunger 3, if needed (step 35). If step 34 is negative, and if the test is performed during a fill stroke, the filling valve 7 may be left open and the pump may be controlled to continue the fill stroke.

The evaluation in step 34 may test positive (e.g. the source container 5 is deemed empty, or an air leakage is identified) whenever a given condition is fulfilled. The condition is based on the force F, which may be either an absolute measure, e.g. given by the measured force value, or a relative measure, e.g. given by the difference between the measured force value and a reference force value, e.g. the above-mentioned initial force F_0 (cf. step 32). The use of a relative measure may improve the sensitivity of certain conditions, since changes in the measured force will be enhanced in the relative measure compared to the absolute measure.

Figs 4A-4D illustrate force responses, given by the measurement signal of the sensor 12 as a function of time, with different status of the hydraulic system. Figs 4A-4D also indicate the period (t_{disp}) of displacement of the plunger, also denoted "active period", which is followed by a period of no movement of the plunger, also denoted "idle period". The graph in Fig. 4A is obtained for an intact infusion system, i.e. without any leakage of air and with a non-empty source container. A proper choice of filling line (diameter and compliance) will, as shown in Fig. 4A, cause the force to rapidly decrease and reach an essentially constant force value (if the active period t_{disp} is long enough).

If there is a leakage of air into the hydraulic system, the force build-up during the active period will be less or even nearly non-existent. Fig. 4B illustrates the force response with an air leak close to the connector 9. Compared to the intact system, the force is significantly less negative during the active period. Fig. 4C illustrates the force response

with a large air leak close to the source 5. With such leakage, the force rapidly decreases to approximately the same negative value as for an intact system, but during the active period the force raises back to a value near the initial force value. Fig. 4D illustrates the force response with a small air leak close to the source 5. Compared to the intact system, the force is significantly less negative during the active period.

It is thus realized that the integrity of the infusion system may be determined based on the force response, and that it is also possible in step 34 to distinguish between different magnitudes and locations of air leakages.

It is of course possible to perform a similar test for air leakage in a subset of the hydraulic system, e.g. by displacing the test volume V_t into the fluid chamber 8 while both the infusion valve 6 and the filling valve 7 are closed. This test may be followed by the test illustrated in Fig. 3, e.g. by operating the pump 1 to displace another test volume V_t into the fluid chamber 8 and by opening the filling valve 7 just after or during this displacement. It is also conceivable to use only one test volume, e.g. to displace the test volume with valves 6, 7 closed, and open the filling valve 7 during or after the displacement. The evaluation (corresponding to step 34) would operate on the measured force before and after opening of the filling valve 7, with the aim to identify any air leakage in the filling line 4, on either side of the filling valve 7, and/or to identify an empty source.

In the following, examples of techniques for identifying an empty source in step 34 will be described and exemplified for different properties of the source container 5.

If the source container 5 is flexible and the infusion liquid in the source container is free of any internal pockets of air or other gases, an empty source may, e.g., be identified whenever one of the following conditions, or a combination thereof, is fulfilled:

(a) If the force becomes more negative than a predetermined limit F_{empty} after the test volume V_t has been sucked into the fluid chamber 8. The magnitude of the force may be taken some time after the displacement of the plunger 3 (i.e. in the idle period) to allow the hydraulic system to settle.

(b) If the change (ΔF) of the force or the rate of change (ROC) of the force during at least part of the active period is more negative than a predetermined limit R_{empty}. The ROC may be expressed as $\Delta F/\Delta V$, $\Delta F/\Delta x$, or $\Delta F/\Delta t$, with ΔF being the measured change of force, ΔV, Δx and Δt being the corresponding change of volume, plunger position and time, respectively.

(c) If the signal profile, i.e. F(t), deviates from the expected profile $F_{ne}(t)$ of a non-empty source during the active period, or part thereof. The deviation may e.g. be calculated by integration of the difference $F(t)-F_{ne}(t)$, and may be compared to a predetermined limit.

(d) If the signal profile, i.e. F(t), deviates from the expected profile $F_{ne}(t)$ of a non-empty source during a period after the displacement, i.e. in the idle period. The deviation may e.g. be calculated by integration of the difference $F(t)-F_{ne}(t)$, and may be compared to a predetermined limit.

If the source container 5 is flexible and the infusion liquid in the source container encloses one or more pockets of air, an empty source may, e.g., be identified whenever one of the following conditions, or a combination thereof, is fulfilled:

(e) If the change (ΔF) of the force or the rate of change (ROC) of the force during at least part of the active period is less negative than a predetermined limit $R_{air\_flexible}$. The ROC may be expressed as in b) above. The test relies on known characteristics of the filling line 4.

(f) If the signal profile, i.e. F(t), deviates from the expected profile $F_{ne\_flexible}(t)$ of a non-empty source during the active period, or part thereof. The deviation may e.g. be calculated by integration of the difference $F(t)- F_{ne\_flexible}(t)$, and may be compared to a predetermined limit.

The source container 5 in Fig. 2 enables an alternative way of detecting an empty source container (step 34), provided that the venting valve 5a is closed during the active period, or part thereof. Thus, an empty source may, e.g., be identified whenever one of the following conditions, or a combination thereof, is fulfilled:

(g) If the change (ΔF) of the force or the rate of change (ROC) of the force during at least part of the active period is less negative than a predetermined limit R_{air_tube}. The ROC may be expressed as in b) above. The test relies on known characteristics of the filling line 4.

(h) If the signal profile, i.e. F(t), deviates from the expected profile $F_{ne\_bottle}(t)$ of a non-empty source during the active period, or part thereof. The deviation may e.g. be calculated by integration of the difference $F(t)-F_{ne\_bottle}(t)$, and may be compared to a predetermined limit.

The expected profiles $F_{ne}(t)$, $F_{ne\_flexible}(t)$ and $F_{ne\_bottle}(t)$ may be obtained by modelling, or through a preceding calibration procedure of the hydraulic system, e.g. by displacing the test volume in the system and measuring the force response (signal profile) via the sensor 12, and possibly by averaging several measured force responses.

A second embodiment of a source test will now be described with reference to the flowchart in Fig. 5. The second embodiment is useful whenever the source container 5 is rigid and has a venting valve 5a (cf. Fig. 2).

First, if the plunger 3 is moving, the pump is controlled to stop the plunger 3 (step 50). Then, both the infusion valve 6 and the filling valve 7 are closed (step 51). Similarly to the first embodiment, the pump is then operated to displace the plunger 3 a predetermined distance in the fill direction, so as to suck the test volume V_t into the fluid chamber 8 (step 52). After completion of the displacement, and suitably after a time delay to allow the hydraulic system to settle, a value F_1 representative of the force applied to the hydraulic system is obtained from the force sensor 12 (step 53). Then, the venting valve 5a is closed, if not already closed (step 54), and the filling valve 7 is opened (step 55). When the pressure in the hydraulic system has equilibrated, a value F_2 representative of the force applied to the hydraulic system is obtained from the force sensor 12 (step 56). Then, in step 57, the integrity of the hydraulic system is evaluated, e.g. by comparing the (absolute) difference between F_1 and F_2 to a predetermined limit F_{empty}. The difference is representative of the volume of gas in the rigid container 5. Thus, if the absolute difference exceeds F_{empty}, the source container 5 is either empty or there may be an air leak in the hydraulic system between the filling valve 7 and the venting valve 5a. It is to be understood that other types of measures may be evaluated in step 57 to identify an empty source/air leakage, e.g. either of the ratios F1/F2 and F2/F1, or the normalized difference (F1-F2)/F1. Further suitable conditions may be identified by routine testing.

The invention has mainly been described above with reference to a few embodiments. However, as is readily appreciated by a person skilled in the art, other embodiments than the ones disclosed above are equally possible within the scope and spirit of the invention, which is defined and limited only by the appended patent claims.

For example, the system tests are applicable for any conceivable type of positive displacement pump, in which a fluid displacing element defines a displacement volume which is connected to an infusion line and a filling line. Such positive displacement pumps include diaphragm and membrane pumps, in which the fluid displacing element is a membrane which may be driven to flex in alternate directions.

Furthermore, even though the foregoing description refers to operations of "opening" and "closing" of valves, it is evident that such an operation will be redundant if the valve already is in an appropriately closed or opened state at the relevant time point. Still further, certain valves need not be actively controlled by the control unit, but may be implemented as appropriately arranged check valves. For example, to enable the source test in Fig. 5, the filling and venting valves 7, 5a should be actively controlled, whereas the infusion valve 6 may be a check valve. Thus, "operation" of a valve may be caused either by active control or by an appropriate pressure differential being applied over the valve as a result of the movement of the fluid displacing element 3. It should be emphasized, though, that even if a check valve may be used instead, it may be desirable to use an actively controlled valve, e.g. to increase precision, obtain lower response times for opening/closing valves, to

achieve a certain timing for the opening/closing of a valve in relation to the movement of the fluid displacing element 3, etc.

In the illustrated embodiments, the filling and infusion lines 4, 2 share a common fluid path in the first line segment 17a. In an alternative, the filling and infusion lines are fully separated, by extending from different ports on the pump.

Furthermore, the force sensor 12 may be replaced or supplemented by a sensor that is arranged to directly measure the fluid pressure in the displacement volume, or in the filling and infusion lines 4, 2 between the fluid chamber 8 and the filling and infusion valves 7, 6. Thus, there is at least one sensor that, irrespective of its type and placement, generates a measurement signal representing fluid pressure in the displacement volume.

Still further, the skilled person realizes that the system tests may be adapted to an infusion system in which the pump is arranged to draw liquid from more than one source, via a respective combination of filling line and filling valve, and/or in which the pump is arranged to infuse the liquid to more than one patient, via a respective combination of infusion line and infusion valve.

Furthermore, in all of the above embodiments, it may be convenient to implement an overall security check, which compares the measurement signal of the force sensor 12 to maximum and minimum safety limits F_{max} and F_{min}. If one force reading, or a predetermined number of consecutive force readings, fall outside the range F_{max}-F_{min}, the actuator 10 is suitably controlled to stop the plunger 3 and an alarm signal is issued.

The control unit 11 may be configured to collect sensor data at specific time points before and/or during and/or after a plunger displacement, as required by the respective system test, and to carry out the system test(s) based on the thus-collected measurement values. Alternatively, the control unit 11 may collect sensor data on a continuous basis at a particular sampling rate, and then carry out the system test(s) by evaluating the resulting sequence of measurement values.

In all of the above embodiments, the control unit 11 may be implemented by one or more separate devices containing analog or digital circuitry for generating control signals for the actuator 10 and the valve(s), for obtaining the measurement signal from the sensor 12, and for executing any one of the above-described tests. The control unit 11 may be implemented by special-purpose software (or firmware) run on one or more general-purpose or special-purpose computing devices. In this context, it is to be understood that each "element" or "means" of such a computing device refers to a conceptual equivalent of a method step; there is not always a one-to-one correspondence between elements/means and particular pieces of hardware or software routines. One piece of hardware sometimes comprises different means/elements. For example, a processing unit serves as one element/means when executing one instruction, but serves as another element/means when executing another instruction. In addition, one element/means may be implemented by one instruction in some cases, but by a plurality of instructions in some other cases. Such a

software-controlled computing device may include one or more processing units, e.g. a CPU ("Central Processing Unit"), a DSP ("Digital Signal Processor"), an ASIC ("Application-Specific Integrated Circuit"), discrete analog and/or digital components, or some other programmable logical device, such as an FPGA ("Field Programmable Gate Array"). The computing device may further include a system memory and a system bus that couples various system components including the system memory to the processing unit. The system bus may be any of several types of bus structures including a memory bus or memory controller, a peripheral bus, and a local bus using any of a variety of bus architectures. The system memory may include computer storage media in the form of volatile and/or non-volatile memory such as read only memory (ROM), random access memory (RAM) and flash memory. The special-purpose software may be stored in the system memory, or on other removable/non-removable volatile/non-volatile computer storage media which is included in or accessible to the computing device, such as magnetic media, optical media, flash memory cards, digital tape, solid state RAM, solid state ROM, etc. The computing device may include one or more communication interfaces, such as a serial interface, a parallel interface, a USB interface, a wireless interface, a network adapter, etc. One or more I/O devices may be connected to the computing device, via a communication interface, including e.g. a keyboard, a mouse, a touch screen, a display, a printer, a disk drive, etc. The special-purpose software may be provided to the computing device on any suitable computer-readable medium, including a record medium and a read-only memory.

CLAIMS

1. A method of operating an infusion system, said infusion system comprising a fluid chamber (8) connected on a first fluid path (4) to a source (5) of infusion liquid and on a second fluid path (2) to a connector (19a), a valve arrangement (6, 7) for selectively opening and closing the first and second fluid paths (4, 2), an actuator (10) for driving a displacing element (3) in the fluid chamber (8) in alternate first and second directions to define a varying displacement volume, and a sensor (12) for generating a measurement signal representative of the fluid pressure in the displacement volume, said method comprising the steps of:

operating the actuator (10) to drive the displacing element (3) in fill and pump strokes by driving the displacing element (3) in the fluid chamber (8) in the first and second directions, respectively,

operating the valve arrangement (6, 7) in synchronization with the actuator (10), so as to open the first fluid path (4) and close the second fluid path (2) during a fill stroke and to open the second fluid path (2) and close the first fluid path (4) during a pump stroke, and

intermittently effecting a system test by:

operating the valve arrangement (6, 7) to close the second fluid path (2);

driving the displacing element (3) a given distance in the first direction;

obtaining the measurement signal from the sensor (12) during at least part of the system test; and

determining the integrity of the infusion system based on the thus-obtained measurement signal.

2. The method of claim 1, wherein said given distance is less than the length of a fill stroke.

3. The method of claim 1 or 2, wherein the system test is effected during a fill stroke.

4. The method of any preceding claim, wherein the step of determining comprises identifying a decreasing flow of infusion liquid from the source (5) based on a temporal change in the magnitude of the measurement signal.

5. The method of claim 4, wherein the system test further comprises the step of deactivating the actuator (10) and outputting an alarm signal, when the step of determining identifies said decreasing flow of infusion liquid.

6. The method of claim 4 or 5, wherein the step of determining is arranged to identify a leakage of air into the first fluid path (4).

7. The method of claim 6, wherein the step of determining is arranged to discriminate between different locations and/or magnitudes of the leakage of air based on the temporal change in the magnitude of the measurement signal.

8. The method of any one of claims 4-7, wherein the step of determining is arranged to identify a shortage of infusion liquid in the source (5).

9. The method of any preceding claim, wherein the step of determining comprises deriving a parameter value from the measurement signal and comparing the parameter value to a predetermined limit.

10. The method of claim 9, wherein the system test further comprises operating the valve arrangement (6, 7) such that the first fluid path (4) is open during said driving.

11. The method of claim 10, wherein the parameter value is selected from the group comprising: a change or rate of change in the measurement signal during at least part of said driving, a change in the measurement signal as a result of said driving, a difference between a profile of the measurement signal and a reference signal profile during at least part of said driving, and a difference between a profile of the measurement signal and a reference signal profile during a time period after completion of said driving.

12. The method of claim 9, wherein the valve arrangement (6, 7) is operated to open the first fluid path (4) after initiation of said driving.

13. The method of claim 12, wherein the valve arrangement (6, 7) is operated to open the first fluid path (4) after completion of said driving.

14. The method of claim 13, wherein the source (5) comprises a rigid container with a venting hole, said method further comprising the step of selectively operating a venting valve (5a) to close the venting hole before opening the first fluid path (4) during the system test.

15. The method of claim 14, wherein the parameter value is indicative of an amount of air in the source (5), and the parameter value is calculated as a function of a change in the measurement signal caused by the opening of the first fluid path (4).

16. The method of any one of claims 12-14, wherein the parameter value is selected from the group comprising: a change in the measurement signal as a result of opening the first fluid path (4), a change or rate of change in the measurement signal as a result of opening the first fluid path (4), and a difference between a profile of the measurement signal and a reference signal profile as a result of opening the first fluid path (4).

17. A computer program product comprising computer code which, when executed on a data-processing system, is adapted to carry out the method of any one of claims 1-16.

18. A control device for operating an infusion system, said infusion system comprising a fluid chamber (8) connected on a first fluid path (4) to a source (5) of infusion liquid and on a second fluid path (2) to a connector (19a), a valve arrangement (6, 7) for selectively opening and closing the first and second fluid paths (4, 2), an actuator (10) for driving a displacing element (3) in the fluid chamber (8) in alternate first and second directions to define a varying displacement volume, and a sensor (12) for generating a measurement signal representative of the fluid pressure in the displacement volume, said control device comprising:

means for causing the actuator (10) to drive the displacing element (3) in fill and pump strokes by driving the displacing element (3) in the fluid chamber (8) in the first and second directions, respectively,

means for operating the valve arrangement (6, 7) in synchronization with the actuator (10), so as to open the first fluid path (4) and close the second fluid path (2) during a fill stroke and to open the second fluid path (2) and close the first fluid path (4) during a pump stroke, and

means for intermittently effecting a system test by:

operating the valve arrangement (6, 7) to close the second fluid path (2);

driving the displacing element (3) a given distance in the first direction;

obtaining the measurement signal from the sensor (12) during at least part of the system test; and

determining the integrity of the infusion system based on the thus-obtained measurement signal.

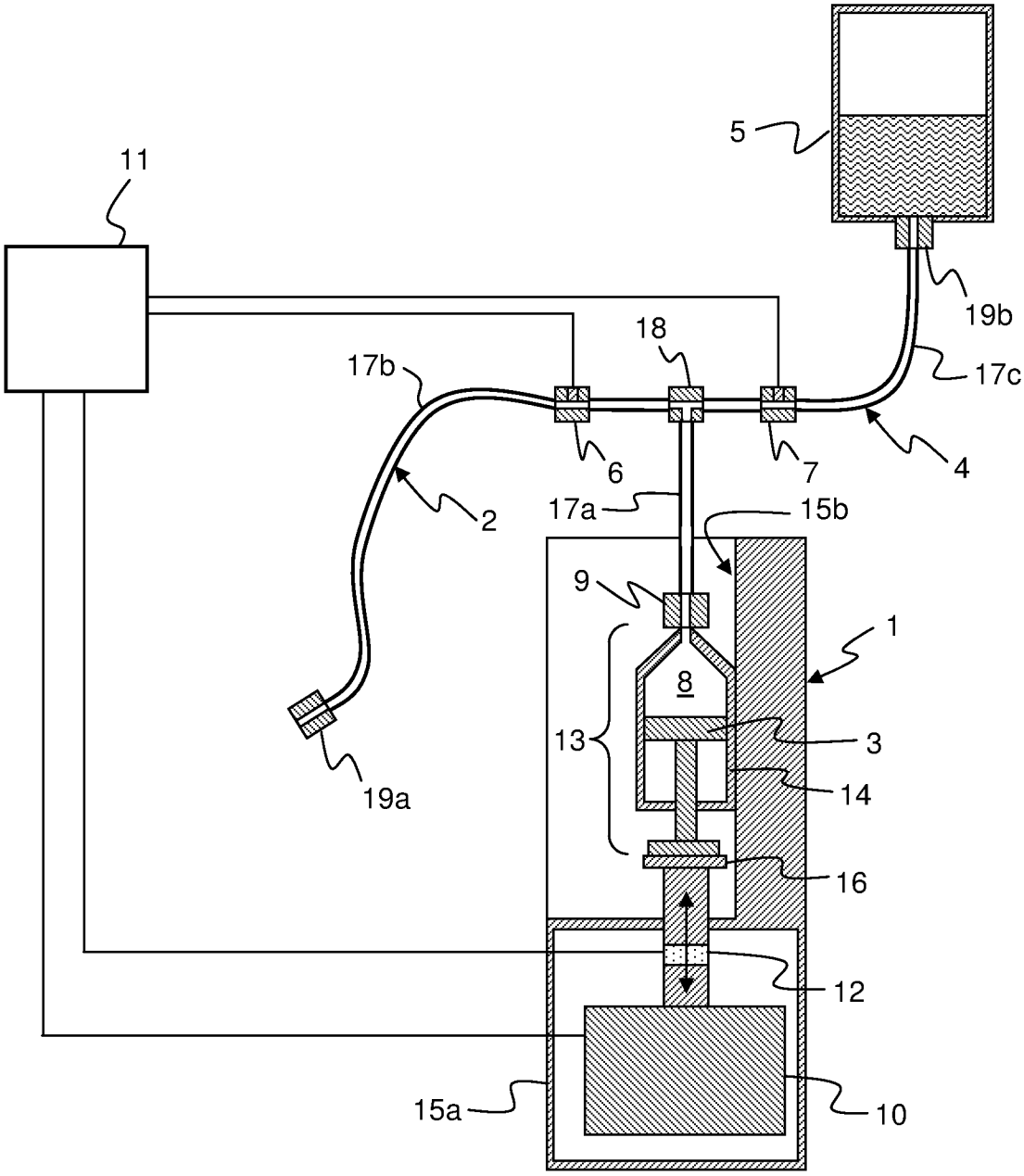
5
11
19b
18
17b
17c
6
7
4
2
17a
15b
9
1
8
13
3
14
19a
16
12
15a
10

FIG. 1

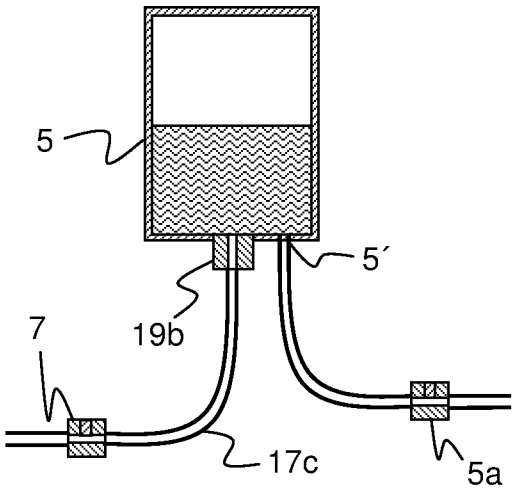
5
5´
19b
7
17c
5a

FIG. 2

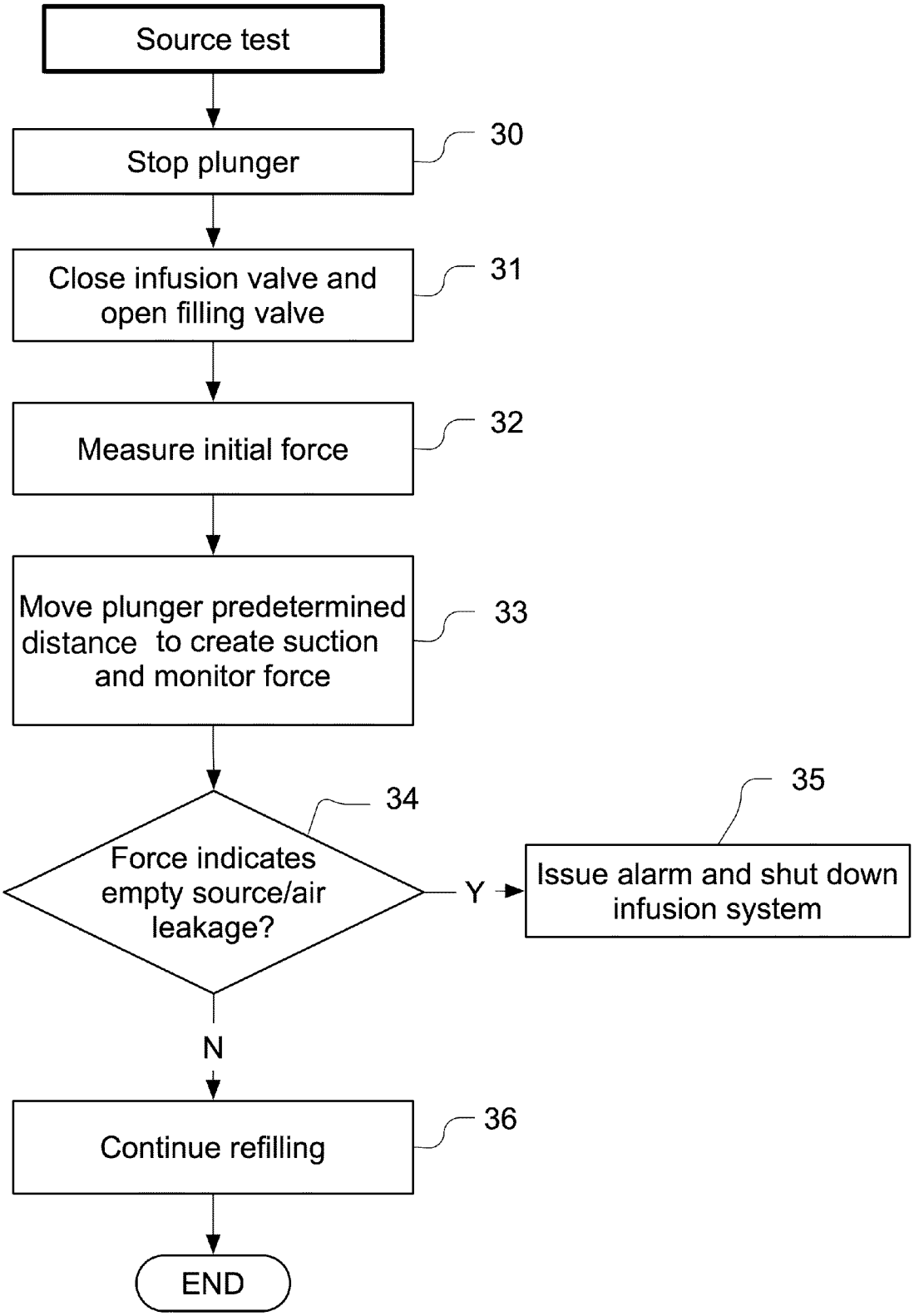
Source test
Stop plunger
30
Close infusion valve and open filling valve
31
Measure initial force
32
Move plunger predetermined distance to create suction and monitor force
33
Force indicates empty source/air leakage?
34
Y
Issue alarm and shut down infusion system
35
N
Continue refilling
36
END

FIG. 3

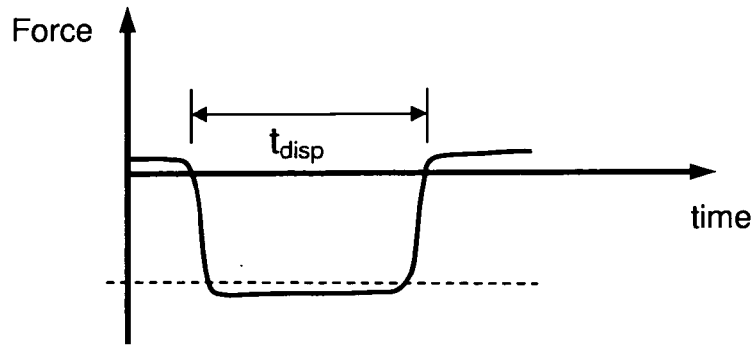

FIG. 4A

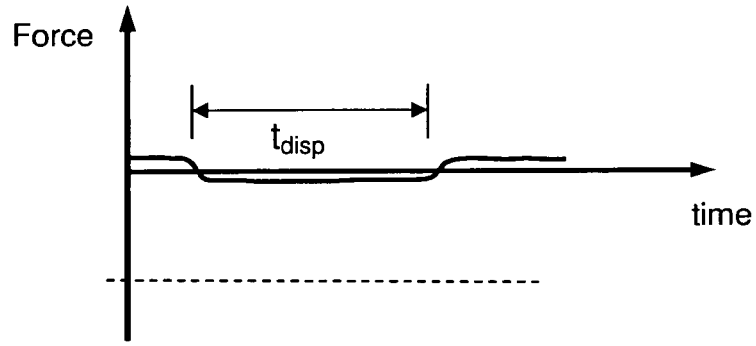

FIG. 4B

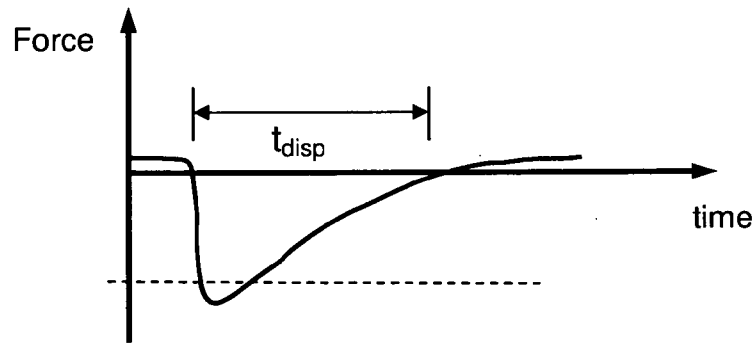

FIG. 4C

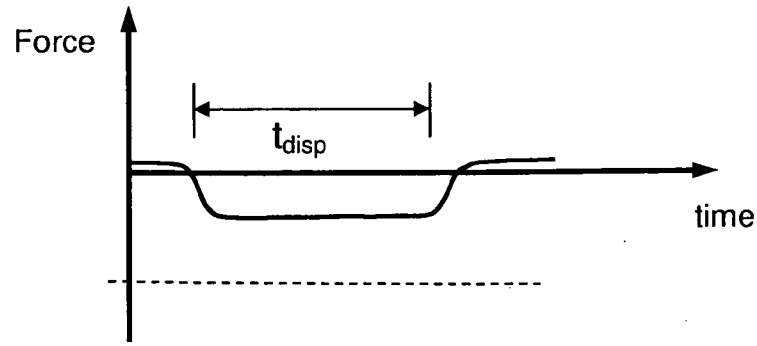

FIG. 4D

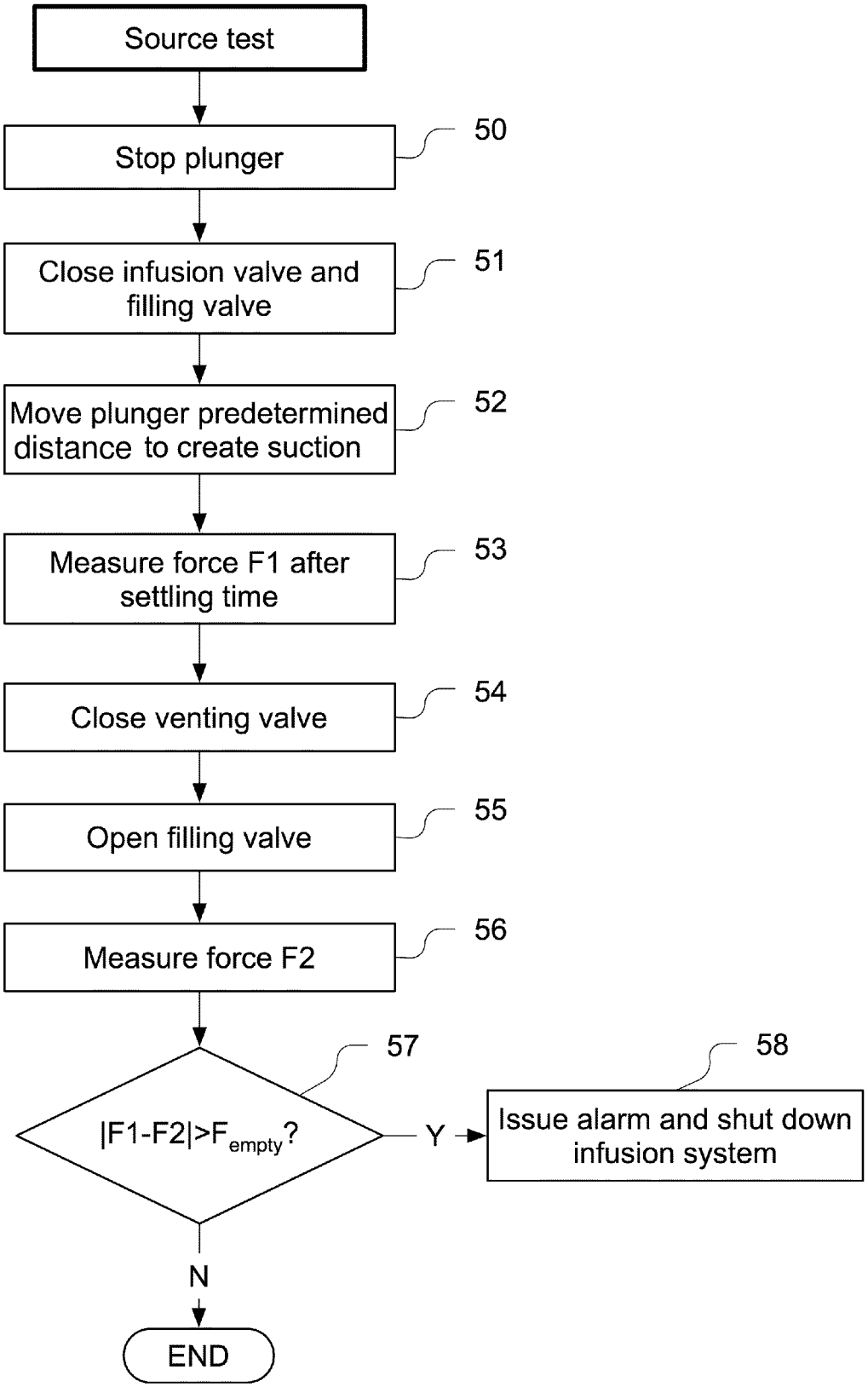
Source test
Stop plunger
50
Close infusion valve and filling valve
51
Move plunger predetermined distance to create suction
52
Measure force F1 after settling time
53
Close venting valve
54
Open filling valve
55
Measure force F2
56
|F1-F2|>F empty ?
57
Y
Issue alarm and shut down infusion system
58
N
END

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2012/054073

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 1-16
because they relate to subject matter not required to be searched by this Authority, namely:

see FURTHER INFORMATION sheet PCT/ISA/210

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/054073

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61M5/142 A61M5/168 A61M5/36 A61M1/36
ADD. A61M5/14

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)
A61M

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 practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/145009 A1 (VANDERVEEN TIMOTHY W [US] ET AL) 7 July 2005 (2005-07-07) the whole document	17,18
X	WO 2004/035116 A1 (ABBOTT LAB [US]) 29 April 2004 (2004-04-29) the whole document	17,18
X	WO 2010/046728 A1 (DEBIOTECH SA [CH]; CHAPPEL ERIC [FR]; SCHNEEBERGER NIKLAUS [CH]; NEFTE) 29 April 2010 (2010-04-29) the whole document	17,18
X	US 2003/214412 A1 (HO CHEN [US] ET AL) 20 November 2003 (2003-11-20) the whole document	17,18

-/--

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

[X] See patent family 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 application or patent 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
1 June 2012	12/06/2012

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, Fax: (+31-70) 340-3016	Petersch, Bernhard

3

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/054073

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2009/044221 A1 (GAMBRO LUNDIA AB [SE]; CALEFFI LUCA [IT]; SAKOTA RANKO [IT]; FRANZONI) 9 April 2009 (2009-04-09) the whole document -----	17,18

3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2012/054073

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		ES 2376666 T3	15-03-2012
		US 2010280430 A1	04-11-2010
		WO 2009044221 A1	09-04-2009

Continuation of Box II.1

Claims Nos.: 1-16

Claims 1-16 refer to methods "of operating an infusion system" and hence methods treatment of the human/animal body by surgery and therapy practised on the human/animal body in the sense of Rule 39.1(iv) and Rule 67.1(iv) PCT, in particular in the light of the description description page 2, line 33 to page 3, line 29, and since claim 1 explicitly includes the step of "operating the actuator (10) [...] in fill and pump strokes" and "operating the valve arrangement (6,7) [...] to open the second fluid path (2) [...] during a pump stroke" which is synonymous to performing drug infusion into a patient (see also page 3, lines 25-27), which is why these claims have not been searched (Rule 39.1 PCT). In addition, no examination according to Article 33(1) PCT is carried out for these claims (Rule 67.1 PCT).