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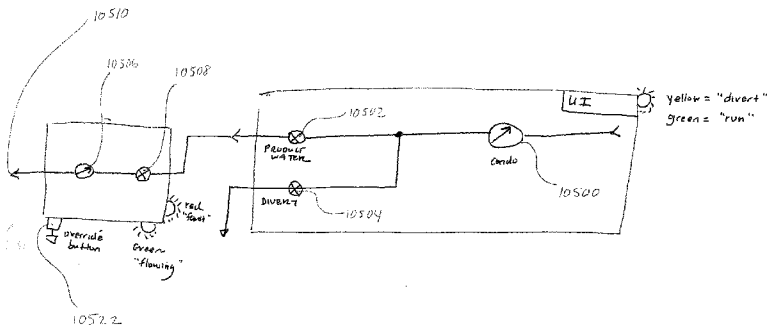


FIG. 130

(57) Abstract: A system for product water output. The system includes a controller, a first conductivity sensor (10500) in communication with the controller, a first product (10502) valve downstream from the first conductivity sensor and in communication with the controller, a second product valve (10508) downstream from the first product valve (10502) and in communication with the controller, a second conductivity sensor (10506) downstream from the second product valve (10508) and in communication with the controller, and a divert valve (10504) downstream from the first conductivity sensor (10500) and upstream from the first product valve (10502) and in communication with the controller.

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# CONTROL OF CONDUCTIVITY IN PRODUCT WATER OUTLET FOR EVAPORATION APPARATUS

## TECHNICAL FIELD

The present invention relates to water distillation and more particularly, to a water vapor distillation apparatus, method, and system.

## BACKGROUND INFORMATION

A dependable source of clean water eludes vast segments of humanity. For example, the Canadian International Development Agency reports that about 1.2 billion people lack access to safe drinking water. Published reports attribute millions and millions of deaths per year, mostly children, to water related diseases. Many water purification techniques are well known, including carbon filters, chlorination, pasteurization, and reverse osmosis. Many of these techniques are significantly affected by variations in the water quality and do not address a wide variety of common contaminants, such as bacteria, viruses, organics, arsenic, lead, mercury, and pesticides that may be found in water supplies in the developing world and elsewhere. Some of these systems require access to a supply of consumables, such as filters or chemicals. Moreover, some of these techniques are only well suited to centralized, large-scale water systems that require both a significant infrastructure and highly trained operators. The ability to produce reliable clean water without regard to the water source, on a smaller, decentralized scale, without the need for consumables and constant maintenance is very desirable, particularly in the developing world.

The use of vapor compression distillation to purify water is well known and may address many of these concerns. However, the poor financial resources, limited technical assets, and low population density that does not make it feasible to build centralized, large-scale water systems in much of the developing world, also limits the availability of adequate, affordable, and reliable power to operate vapor compression distillation systems, as well as hindering the ability to properly maintain such systems. In such circumstances, an improved vapor compression distillation system and associated components that increases efficiency and production capability, while decreasing the necessary power budget for system operation and the amount of system maintenance required may provide a solution.

## SUMMARY

In accordance with one aspect of the present invention, a system for product water output is disclosed. The system includes a controller, a first conductivity sensor in

communication with the controller, a first product valve downstream from the first conductivity sensor and in communication with the controller, a second product valve downstream from the first product valve and in communication with the controller, a second conductivity sensor downstream from the second product valve and in communication with the controller, and a divert valve downstream from the first conductivity sensor and upstream from the first product valve and in communication with the controller.

Some embodiments of this aspect of the present invention include one or more of the following: wherein the controller opens the divert valve and maintains the first product valve and second product valve in a closed position when the first conductivity sensor determines that the conductivity of product water is not within a first acceptable range; wherein the controller opens the first product valve and the second product valve when the first conductivity sensor determines that the conductivity of product water is within an acceptable range; wherein the second conductivity sensor determines the conductivity of the product water and the controller indicates a fault condition when the second conductivity sensor determines that the conductivity of product water is not within a second acceptable range; wherein the first acceptable range is lower than the second acceptable range; wherein the controller compares the conductivity from the first conductivity sensor and the second conductivity sensor and if the conductivity from the first conductivity sensor differs more than a threshold amount from the conductivity of the second conductivity sensor, a fault condition is indicated; wherein if it is determined that either the first conductivity sensor reading or the second conductivity sensor reading is not within the acceptable range, or threshold range for acceptability, then a fault condition is indicated; wherein the first conductivity sensor and the second conductivity sensor comprising: three probes connected by a cable, at least one of the three probes comprising a temperature sensor and wherein the resistance between each of the three probes is 500 k Ohms; wherein when the divert valve is open, if the controller receives a reading from the second conductivity sensor, a fault condition is indicated; wherein the system further includes a flow meter downstream from the first product valve and upstream from the second product valve.

In accordance with one aspect of the present invention, a method for determining the quality of product water output is disclosed. The method includes providing a controller, providing a first conductivity sensor in communication with the controller, providing a first product valve downstream from the first conductivity sensor and in communication with the controller, providing a second product valve downstream from the first product valve and in communication with the controller, providing a second conductivity sensor downstream from

the second product valve and in communication with the controller, and providing a divert valve downstream from the first conductivity sensor and upstream from the first product valve and in communication with the controller.

Some embodiments of this aspect of the present invention include one or more of the following: wherein the method further includes the first conductivity sensor determining that the conductivity of product water is not within a first acceptable range and opening the divert valve and maintaining the first product valve and second product valve in a closed position; wherein the method further includes the first conductivity sensor determining that the conductivity of product water is within an acceptable range and opening the first product valve and the second product valve; wherein the method further includes the second conductivity sensor determining the conductivity of the product water and the controller indicating a fault condition when the second conductivity sensor determining that the conductivity of product water is not within a second acceptable range; wherein the method further includes wherein the first acceptable range is lower than the second acceptable range; wherein the method further includes comparing the conductivity from the first conductivity sensor and the second conductivity sensor, and if the conductivity from the first conductivity sensor differs more than a threshold amount from the conductivity of the second conductivity sensor, indicating a fault condition; wherein the method further includes determining that either the first conductivity sensor reading or the second conductivity sensor reading is not within the acceptable range, or threshold range for acceptability, and indicating a fault condition; wherein the method further includes wherein the first conductivity sensor and the second conductivity sensor including three probes connected by a cable, at least one of the three probes comprising a temperature sensor and wherein the resistance between each of the three probes is 500 k Ohms; wherein the method further includes opening a divert valve, receiving a reading from the second conductivity sensor, and indicating a fault condition; wherein the method further includes providing a flow meter downstream from the first product valve and upstream from the second product valve.

In accordance with one aspect of the present invention, a fluid vapor distillation system is disclosed. The system includes a control system for controlling a fluid vapor distillation apparatus including a blow down controller for controlling a blow down valve, a source flow controller for controlling a source flow valve, and a blow down level sensor in communication with a blow down controller and a source flow controller, the blow down level sensor sends signals related to the blow down level to the blow down controller and the source flow controller indicative of the blow down level, wherein the source flow

controller actuates the source flow valve based at least on the blow down level sensor signals, and wherein the blow down controller actuates the blow down valve based at least on the blow down level sensor signals, whereby the blow down level and the source flow level are maintained using the blow down level sensor signals as input.

Some embodiments of this aspect of the present invention include one or more of the following: wherein the control system further includes at least one controller, an idle state wherein the at least one controllers are off, a fill state wherein the source valve is opened and source fluid enters a sump in the fluid vapor distillation apparatus, a heat state wherein a heater in the sump is maximized until fluid in the sump reaches a predetermined temperature, a heat exchanger prime state wherein the source valve is opened to a predetermined duty cycle, a start pump state wherein a bearing feed pump is run at a predetermined speed, and a blow motor is started, and a run state wherein the fluid vapor distillation apparatus produces product water. Also, wherein the system further includes a source fluid input, an evaporator condenser apparatus including a substantially cylindrical housing, and a plurality of tubes in the housing,
whereby the source fluid input is fluidly connected to the evaporator condenser and the evaporator condenser transforms source fluid into steam and transforms compressed steam into product fluid, a heat exchanger fluidly connected to the source fluid input and a product fluid output, the heat exchanger including an outer tube, and at least one inner tube, and a regenerative blower fluidly connected to the evaporator condenser, whereby the regenerative blower compresses steam, and whereby compressed steam flows to the evaporative condenser whereby compressed steam is transformed into product fluid. Wherein the heat exchanger is disposed about the housing of the evaporator condenser. Wherein the heat exchanger further includes wherein the outer tube is a source fluid flow path and the at least one inner tube is a product fluid flow path. Wherein the heat exchanger further includes at least three inner tubes. Wherein the at least three inner tubes are twined to form a substantially helical shape. Wherein the heat exchanger further includes two ends, and at each end a connector is attached, whereby the connectors form a connection to the evaporator condenser. Wherein the evaporator condenser tubes further includes packing inside the tubes. Wherein the packing is a rod. Wherein the evaporator condenser further including a steam chest fluidly connected to the plurality of tubes. Wherein the regenerative blower further includes an impeller assembly driven by a magnetic drive coupling. Wherein the control system includes at least two processors, a motor control engine processor and an ARM processor. Wherein the fluid vapor distillation apparatus further includes a

conductivity meter and a conductivity cell to determine the conductivity of the product fluid.

In accordance with another aspect of the present invention, a fluid vapor distillation apparatus is disclosed. The apparatus includes a source fluid input, an evaporator condenser apparatus including a substantially cylindrical housing, and a plurality of tubes in the housing, whereby the source fluid input is fluidly connected to the evaporator condenser and the evaporator condenser transforms source fluid into steam and transforms compressed steam into product fluid, a heat exchanger fluidly connected to the source fluid input and a product fluid output, the heat exchanger including an outer tube, and at least one inner tube, and a regenerative blower fluidly connected to the evaporator condenser, whereby the regenerative blower compresses steam, and whereby compressed steam flows to the evaporative condenser whereby compressed steam is transformed into product fluid, also, a control system for controlling the fluid vapor distillation apparatus including a blow down controller for controlling a blow down valve, a source flow controller for controlling a source flow valve, and a blow down level sensor in communication with a blow down controller and a source flow controller, the blow down level sensor sends signals related to the blow down level to the blow down controller and the source flow controller indicative of the blow down level, wherein the source flow controller actuates the source flow valve based at least on the blow down level sensor signals, and wherein the blow down controller actuates the blow down valve based at least on the blow down level sensor signals, whereby the blow down level and the source flow level are maintained using the blow down level sensor signals as input.

Some embodiments of this aspect of the present invention include one or more of the following: at least one controller, an idle state wherein the at least one controllers are off, a fill state wherein the source valve is opened and source fluid enters a sump in the fluid vapor distillation apparatus, a heat state wherein a heater in the sump is maximized until fluid in the sump reaches a predetermined temperature, a heat exchanger prime state wherein the source valve is opened to a predetermined duty cycle, a start pump state wherein a bearing feed pump is run at a predetermined speed, and a blow motor is started, and a run state wherein the fluid vapor distillation apparatus produces product water. Wherein the heat exchanger is disposed about the housing of the evaporator condenser. Wherein the heat exchanger further includes wherein the outer tube is a source fluid flow path and the at least one inner tube is a product fluid flow path. Wherein the heat exchanger further includes at least three inner tubes. Wherein the at least three inner tubes are twined

to form a substantially helical shape. Wherein the heat exchanger further includes two ends, and at each end a connector is attached, whereby the connectors form a connection to the evaporator condenser. Wherein the evaporator condenser tubes further includes packing inside the tubes. Wherein the packing is a rod. Wherein the evaporator condenser further including a steam chest fluidly connected to the plurality of tubes. Wherein the regenerative blower further includes an impeller assembly driven by a magnetic drive coupling. Wherein the control system includes at least two processors, a motor control engine processor and an ARM processor. Wherein the fluid vapor distillation apparatus further includes a conductivity meter and a conductivity cell to determine the conductivity of the product fluid.

In accordance with one aspect of the present invention, a fluid vapor distillation apparatus is disclosed. The apparatus includes a source fluid input, an evaporator condenser apparatus including a substantially cylindrical housing, and a plurality of tubes in the housing, whereby the source fluid input is fluidly connected to the evaporator condenser and the evaporator condenser transforms source fluid into steam and transforms compressed steam into product fluid, a heat exchanger fluidly connected to the source fluid input and a product fluid output, the heat exchanger including an outer tube, and at least one inner tube, and a regenerative blower fluidly connected to the evaporator condenser, whereby the regenerative blower compresses steam, and whereby compressed steam flows to the evaporative condenser whereby compressed steam is transformed into product fluid, also, a control system for controlling the fluid vapor distillation apparatus.

Some embodiments of this aspect of the present invention include one or more of the following: Wherein, the control system includes a blow down controller for controlling a blow down valve, a source flow controller for controlling a source flow valve, and a blow down level sensor in communication with a blow down controller and a source flow controller, the blow down level sensor sends signals related to the blow down level to the blow down controller and the source flow controller indicative of the blow down level, wherein the source flow controller actuates the source flow valve based at least on the blow down level sensor signals, and wherein the blow down controller actuates the blow down valve based at least on the blow down level sensor signals, whereby the blow down level and the source flow level are maintained using the blow down level sensor signals as input. Wherein the control system includes at least one controller, an idle state wherein the at least one controllers are off, a fill state wherein the source valve is opened and source fluid enters a sump in the fluid vapor distillation apparatus, a heat state wherein a heater in the sump is

maximized until fluid in the sump reaches a predetermined temperature, a heat exchanger prime state wherein the source valve is opened to a predetermined duty cycle, a start pump state wherein a bearing feed pump is run at a predetermined speed, and a blow motor is started, and a run state wherein the fluid vapor distillation apparatus produces product water. Wherein the heat exchanger is disposed about the housing of the evaporator condenser. Wherein the heat exchanger further includes wherein the outer tube is a source fluid flow path and the at least one inner tube is a product fluid flow path. Wherein the heat exchanger further includes at least three inner tubes. Wherein the at least three inner tubes are twined to form a substantially helical shape. Wherein the heat exchanger further includes two ends, and at each end a connector is attached, whereby the connectors form a connection to the evaporator condenser. Wherein the evaporator condenser tubes further includes packing inside the tubes. Wherein the packing is a rod. Wherein the evaporator condenser further including a steam chest fluidly connected to the plurality of tubes. Wherein the regenerative blower further includes an impeller assembly driven by a magnetic drive coupling. Wherein the control system includes at least two processors, a motor control engine processor and an ARM processor. Wherein the fluid vapor distillation apparatus further includes a conductivity meter and a conductivity cell to determine the conductivity of the product fluid.

In accordance with one aspect of the present invention, a water vapor distillation system is disclosed. The system includes a water vapor distillation apparatus including a source fluid input, an evaporator condenser apparatus including a substantially cylindrical housing, and a plurality of tubes in the housing, whereby the source fluid input is fluidly connected to the evaporator condenser and the evaporator condenser transforms source fluid into steam and transforms compressed steam into product fluid, a heat exchanger fluidly connected to the source fluid input and a product fluid output, the heat exchanger including an outer tube, and at least one inner tube, and a regenerative blower fluidly connected to the evaporator condenser, whereby the regenerative blower compresses steam, and whereby compressed steam flows to the evaporative condenser whereby compressed steam is transformed into product fluid, also, a control system for controlling the water vapor distillation apparatus, and, a Stirling engine electrically connected to the water vapor distillation apparatus, wherein the Stirling engine at least partially powers the water vapor distillation apparatus.

Some embodiments of this aspect of the present invention include one or more of the following: wherein the control system includes a blow down controller for controlling a

blow down valve, a source flow controller for controlling a source flow valve, and a blow down level sensor in communication with a blow down controller and a source flow controller, the blow down level sensor sends signals related to the blow down level to the blow down controller and the source flow controller indicative of the blow down level, wherein the source flow controller actuates the source flow valve based at least on the blow down level sensor signals, and wherein the blow down controller actuates the blow down valve based at least on the blow down level sensor signals, whereby the blow down level and the source flow level are maintained using the blow down level sensor signals as input. Wherein the system for controlling the apparatus further includes at least one controller, an idle state wherein the at least one controllers are off, a fill state wherein the source valve is opened and source fluid enters a sump in the fluid vapor distillation apparatus, a heat state wherein a heater in the sump is maximized until fluid in the sump reaches a predetermined temperature, a heat exchanger prime state wherein the source valve is opened to a predetermined duty cycle, a start pump state wherein a bearing feed pump is run at a predetermined speed, and a blow motor is started, and a run state wherein the fluid vapor distillation apparatus produces product water. Wherein the Stirling engine includes at least one rocking drive mechanism including a rocking beam having a rocker pivot, at least one cylinder, at least one piston, the piston housed within a respective cylinder whereby the piston is capable of substantially linearly reciprocating within the respective cylinder, and at least one coupling assembly having a proximal end and a distal end, the proximal end being connected to the piston and the distal end being connected to the rocking beam by an end pivot, whereby linear motion of the piston is converted to rotary motion of the rocking beam, a crankcase housing the rocking beam and housing a first portion of the coupling assembly, a crankshaft coupled to the rocking beam by way of a connecting rod, whereby the rotary motion of the rocking beam is transferred to the crankshaft, a working space housing the at least one cylinder, the at least one piston and a second portion of the coupling assembly, and a seal for sealing the workspace from the crankcase. Some embodiments of this embodiment of the system may include one or more of the following: Wherein the seal is a rolling diaphragm. Wherein the coupling assembly further includes a piston rod, and a link rod, the piston rod and link rod coupled together by a coupling means. Wherein the system further including a lubricating fluid pump in the crankcase. Various embodiments of the system may include one or more of the following: Wherein the heat exchanger is disposed about the housing of the evaporator condenser. Wherein the heat exchanger further includes where the outer tube is a source fluid flow path and the at least one inner

tube is a product fluid flow path. Wherein the heat exchanger further comprising at least three inner tubes.

In accordance with another aspect of the present invention, a water vapor distillation apparatus is disclosed. The apparatus includes a blow down controller for controlling a blow down valve, a source flow controller for controlling a source flow valve, and a blow down level sensor in communication with a blow down controller and a source flow controller, the blow down level sensor sends signals related to the blow down level to the blow down controller and the source flow controller indicative of the blow down level, wherein the source flow controller actuates the source flow valve based at least on the blow down level sensor signals, and wherein the blow down controller actuates the blow down valve based at least on the blow down level sensor signals, whereby the blow down level and the source flow level are maintained using the blow down level sensor signals as input.

Some embodiments of this aspect of the present invention include one or more of the following: wherein the apparatus further includes at least one controller, an idle state wherein the at least one controllers are off, a fill state wherein the source valve is opened and source fluid enters a sump in the fluid vapor distillation apparatus, a heat state wherein a heater in the sump is maximized until fluid in the sump reaches a predetermined temperature, a heat exchanger prime state wherein the source valve is opened to a predetermined duty cycle, a start pump state wherein a bearing feed pump is run at a predetermined speed, and a blow motor is started, and a run state wherein the fluid vapor distillation apparatus produces product water. Wherein the apparatus further includes including a source fluid input, an evaporator condenser apparatus including a substantially cylindrical housing, and a plurality of tubes in the housing, whereby the source fluid input is fluidly connected to the evaporator condenser and the evaporator condenser transforms source fluid into steam and transforms compressed steam into product fluid, a heat exchanger fluidly connected to the source fluid input and a product fluid output, the heat exchanger including an outer tube, and at least one inner tube, and a regenerative blower fluidly connected to the evaporator condenser, whereby the regenerative blower compresses steam, and whereby compressed steam flows to the evaporative condenser whereby compressed steam is transformed into product fluid. Wherein the heat exchanger is disposed about the housing of the evaporator condenser. Wherein the heat exchanger further includes wherein the outer tube is a source fluid flow path and the at least one inner tube is a product fluid flow path. Wherein the heat exchanger further includes at least three inner tubes. Wherein the at least three inner tubes are twined to form a substantially helical

shape. Wherein the heat exchanger further includes two ends, and at each end a connector is attached, whereby the connectors form a connection to the evaporator condenser. Wherein the evaporator condenser tubes further includes packing inside the tubes. Wherein the packing is a rod. Wherein the evaporator condenser further including a steam chest fluidly connected to the plurality of tubes. Wherein the regenerative blower further includes an impeller assembly driven by a magnetic drive coupling. Wherein the control system includes at least two processors, a motor control engine processor and an ARM processor. Wherein the fluid vapor distillation apparatus further includes a conductivity meter and a conductivity cell to determine the conductivity of the product fluid.

In accordance with another aspect of the present invention, a water vapor distillation apparatus is disclosed. The apparatus includes a control system for controlling the water vapor distillation apparatus, the control system including at least one controller, an idle state wherein the at least one controllers are off, a fill state wherein the source valve is opened and source fluid enters a sump in the fluid vapor distillation apparatus, a heat state wherein a heater in the sump is maximized until fluid in the sump reaches a predetermined temperature, a heat exchanger prime state wherein the source valve is opened to a predetermined duty cycle, a start pump state wherein a bearing feed pump is run at a predetermined speed, and a blow motor is started, and a run state wherein the fluid vapor distillation apparatus produces product water.

Some embodiments of this aspect of the present invention include one or more of the following: Wherein the control system further includes a blow down controller for controlling a blow down valve, a source flow controller for controlling a source flow valve, and a blow down level sensor in communication with a blow down controller and a source flow controller, the blow down level sensor sends signals related to the blow down level to the blow down controller and the source flow controller indicative of the blow down level, wherein the source flow controller actuates the source flow valve based at least on the blow down level sensor signals, and wherein the blow down controller actuates the blow down valve based at least on the blow down level sensor signals, whereby the blow down level and the source flow level are maintained using the blow down level sensor signals as input. Wherein the apparatus further includes a source fluid input, an evaporator condenser apparatus including a substantially cylindrical housing, and a plurality of tubes in the housing, whereby the source fluid input is fluidly connected to the evaporator condenser and the evaporator condenser transforms source fluid into steam and transforms compressed steam into product fluid, a heat exchanger fluidly connected to the source fluid input and a

product fluid output, the heat exchanger including an outer tube, and at least one inner tube, and a regenerative blower fluidly connected to the evaporator condenser, whereby the regenerative blower compresses steam, and whereby compressed steam flows to the evaporative condenser whereby compressed steam is transformed into product fluid. Wherein the heat exchanger is disposed about the housing of the evaporator condenser. Wherein the heat exchanger further includes wherein the outer tube is a source fluid flow path and the at least one inner tube is a product fluid flow path. Wherein the heat exchanger further includes at least three inner tubes. Wherein the at least three inner tubes are twined to form a substantially helical shape. Wherein the heat exchanger further includes two ends, and at each end a connector is attached, whereby the connectors form a connection to the evaporator condenser. Wherein the evaporator condenser tubes further includes packing inside the tubes. Wherein the packing is a rod. Wherein the evaporator condenser further including a steam chest fluidly connected to the plurality of tubes. Wherein the regenerative blower further includes an impeller assembly driven by a magnetic drive coupling. Wherein the control system includes at least two processors, a motor control engine processor and an ARM processor. Wherein the fluid vapor distillation apparatus further includes a conductivity meter and a conductivity cell to determine the conductivity of the product fluid.

In accordance with one aspect of the present invention, a fluid vapor distillation apparatus is disclosed. The apparatus includes a source fluid input, and an evaporator condenser apparatus. The evaporator condenser apparatus includes a substantially cylindrical housing and a plurality of tubes in the housing. The source fluid input is fluidly connected to the evaporator condenser and the evaporator condenser transforms source fluid into steam and transforms compressed steam into product fluid. Also included in the fluid vapor distillation apparatus is a heat exchanger fluidly connected to the source fluid input and a product fluid output. The heat exchanger includes an outer tube and at least one inner tube. Also included in the fluid vapor distillation apparatus is a regenerative blower fluidly connected to the evaporator condenser. The regenerative blower compresses steam, and the compressed steam flows to the evaporative condenser where compressed steam is transformed into product fluid. The fluid vapor distillation apparatus also includes a control system.

Some embodiments of this aspect of the present invention include one or more of the following: where the heat exchanger is disposed about the housing of the evaporator condenser; where the heat exchanger further includes wherein the outer tube is a source

fluid flow path and the at least one inner tube is a product fluid flow path; where the heat exchanger further includes at least three inner tubes; where the at least three inner tubes are twined to form a substantially helical shape; where the heat exchanger further includes two ends, and at each end a connector is attached, whereby the connectors form a connection to the evaporator condenser; where the evaporator condenser tubes further include packing inside the tubes; where the packing is a rod; where the evaporator condenser further includes a steam chest fluidly connected to the plurality of tubes; and where the regenerative blower further comprising an impeller assembly driven by a magnetic drive coupling.

In accordance with another aspect of the present invention, a water vapor distillation system is disclosed. The water vapor distillation system includes a source fluid input, and an evaporator condenser apparatus. The evaporator condenser apparatus includes a substantially cylindrical housing and a plurality of tubes in the housing. The source fluid input is fluidly connected to the evaporator condenser and the evaporator condenser transforms source fluid into steam and transforms compressed steam into product fluid. Also included in the fluid vapor distillation apparatus is a heat exchanger fluidly connected to the source fluid input and a product fluid output. The heat exchanger includes an outer tube and at least one inner tube. Also included in the fluid vapor distillation apparatus is a regenerative blower fluidly connected to the evaporator condenser. The regenerative blower compresses steam, and the compressed steam flows to the evaporative condenser where compressed steam is transformed into product fluid.

The water vapor distillation system also includes a Stirling engine electrically connected to the water vapor distillation apparatus. The Stirling engine at least partially powers the water vapor distillation apparatus.

Some embodiments of this aspect of the present invention include where the Stirling engine includes at least one rocking drive mechanism where the rocking drive mechanism includes: a rocking beam having a rocker pivot, at least one cylinder and at least one piston. The piston is housed within a respective cylinder. The piston is capable of substantially linearly reciprocating within the respective cylinder. Also, the drive mechanism includes at least one coupling assembly having a proximal end and a distal end. The proximal end is connected to the piston and the distal end is connected to the rocking beam by an end pivot. The linear motion of the piston is converted to rotary motion of the rocking beam. Also, a crankcase housing the rocking beam and housing a first portion of the coupling assembly is included. A crankshaft coupled to the rocking beam by way of a connecting rod is also

included. The rotary motion of the rocking beam is transferred to the crankshaft. The machine also includes a working space housing the at least one cylinder, the at least one piston and a second portion of the coupling assembly. A seal is included for sealing the workspace from the crankcase.

Additionally, some embodiments of this aspect of the present invention include any one or more of the following: where the seal is a rolling diaphragm; also, where the coupling assembly further includes a piston rod and a link rod; where the piston rod and link rod are coupled together by a coupling means; where the heat exchanger is disposed about the housing of the evaporator condenser; where the heat exchanger further comprising wherein the outer tube is a source fluid flow path and the at least one inner tube is a product fluid flow path; where the heat exchanger further comprising at least three inner tubes; where the evaporator condenser further includes a steam chest fluidly connected to the plurality of tubes; and where the regenerative blower further includes an impeller assembly driven by a magnetic drive coupling.

These aspects of the invention are not meant to be exclusive and other features, aspects, and advantages of the present invention will be readily apparent to those of ordinary skill in the art when read in conjunction with the appended claims and accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages of the present invention will be better understood by reading the following detailed description, taken together with the drawings wherein:

FIG. 1 is an isometric view of the water vapor distillation apparatus;

FIG. 1A is an exploded view of the exemplary embodiment of the disclosure;

FIG. 1B is a cross-section view of the exemplary embodiment;

FIG. 1C is a cross-section view of the exemplary embodiment;

FIG. 1D is an assembly view of the exemplary embodiment;

FIG. 1E is a detail view of the exemplary embodiment of the frame;

FIG. 1F is an assembly view of an alternate embodiment;

FIG. 1G is an assembly view of an alternate embodiment;

FIG. 1H is an assembly view of an alternate embodiment;

FIG. 2 is an assembly view of the exemplary embodiment of the tube-in-tube heat exchanger assembly;

FIG. 2A is an exploded view one embodiment of the tube-in-tube heat exchanger;

FIG. 2B is an isometric view of the exemplary embodiment of the tube-in-tube heat exchanger from the back;

FIG. 2C is an isometric view of the exemplary embodiment of the tube-in-tube heat exchanger from the front;

FIG. 2D is a cross-section view of one embodiment of the tube-in-tube heat exchanger;

FIG. 2E is an exploded view of an alternate embodiment of a tube-in-tube heat exchanger;

FIG. 2F is a cut away view of one embodiment of the tube-in-tube heat exchanger illustrating the helical arrangement of the inner tubes;

FIG. 2G is an exploded view of an alternate embodiment of a tube-in-tube heat exchanger;

FIG. 2H is an isometric view of the exemplary embodiment of the tube-in-tube heat exchanger;

FIG. 2I is an isometric view of the exemplary embodiment of the tube-in-tube heat exchanger;

FIG. 2J is an exploded view of an alternate embodiment of the tube-in-tube heat exchanger configuration;

FIG. 2K is an assembly view of an alternate embodiment of the tube-in-tube heat exchanger configuration;

FIG. 2L is an assembly view of an alternate embodiment of the tube-in-tube heat exchanger configuration;

FIG. 2M is a detail view of an alternate embodiment of the tube-in-tube heat exchanger configuration;

FIG. 2N is a detail view of an alternate embodiment of the tube-in-tube heat exchanger configuration;

FIG. 2O is a schematic of an alternate embodiment of the tube-in-tube heat exchanger configuration;

FIG. 2P is an assembly view of an alternate embodiment of the heat exchanger;

FIG. 2Q is an exploded view of an alternate embodiment of the heat exchanger;

FIG. 2R is a section view of an alternate embodiment of the heat exchanger;

FIG. 3 is an exploded view of the connectors for the fitting assembly that attaches to the tube-in-tube heat exchanger;

FIG. 3A is a cross-section view of fitting assembly for the tube-in-tube heat exchanger;

FIG. 3B is a cross-section view of fitting assembly for the tube-in-tube heat exchanger;

FIG. 3C is an isometric view of the exemplary embodiment for the first connector;

FIG. 3D is a cross-section view of the exemplary embodiment for the first connector;

FIG. 3E is a cross-section view of the exemplary embodiment for the first connector;

FIG. 3F is a cross-section view of the exemplary embodiment for the first connector;

FIG. 3G is an isometric view of the exemplary embodiment for the second connector;

FIG. 3H is a cross-section view of fitting assembly for the tube-in-tube heat exchanger;

FIG. 3I is a cross-section view of the exemplary embodiment for the second connector;

FIG. 3J is a cross-section view of the exemplary embodiment for the second connector;

FIG. 4 is an isometric view of the exemplary embodiment of the evaporator/condenser assembly;

FIG. 4A is a cross-section view of the exemplary embodiment of the evaporator/condenser assembly;

FIG. 4B is an isometric cross-section view of the exemplary embodiment of the evaporator/condenser;

FIG. 4C is an isometric view of an alternate embodiment of the evaporator/condenser assembly;

FIG. 5 is an assembly view of the exemplary embodiment of the sump;

FIG. 5A is an exploded view of the exemplary embodiment of the sump;

FIG. 6 is an isometric detail view of the flange for the sump assembly;

FIG. 7 is an exploded view of the exemplary embodiment of the evaporator/condenser;

FIG. 7A is an top view of the exemplary embodiment of the evaporator/condenser assembly;

FIG. 7B shows the rate of distillate output for an evaporator as a function of pressure for several liquid boiling modes;

FIG. 8 is an isometric view of the exemplary embodiment of the tube for the evaporator/condenser;

FIG. 9 is an exploded view of the tube and rod configuration for the evaporator/condenser;

FIG. 9A is an isometric view of the exemplary embodiment of the rod for the evaporator/condenser;

FIG. 10 is an isometric view of the exemplary embodiment of the sump tube sheet;

FIG. 10A is an isometric view of the exemplary embodiment of the upper tube sheet;

FIG. 11 is a detail view of the top cap for the evaporator/condenser;

FIG. 12 is an isometric view of the exemplary embodiment of the steam chest;

FIG. 12A is an isometric view of the exemplary embodiment of the steam chest;

FIG. 12B is a cross-section view of the exemplary embodiment of the steam chest;

FIG. 12C is an exploded view of the exemplary embodiment of the steam chest;

FIG. 12D is an isometric view of an alternate embodiment;

FIG. 12E is a cross-section view of the exemplary embodiment of the steam chest;

FIG. 12F is a cross-section view of the exemplary embodiment of the steam chest;

FIG. 13 is an assembly view of an alternate embodiment of the evaporator/condenser;

FIG. 13A is a cross-section view of the alternate embodiment of the evaporator/condenser;

FIG. 13B is an assembly view of an alternate embodiment of the evaporator/condenser illustrating the arrangement of the tubes;

FIG. 13C is a cross-section view of the alternate embodiment of the evaporator/condenser illustrating the arrangement of the tubes;

FIG. 13D is an isometric view of the alternate embodiment of the evaporator/condenser without the sump installed;

FIG. 13E is an exploded view of the alternate embodiment of the evaporator/condenser;

FIG. 14 is an isometric view of the mist eliminator assembly;

FIG. 14A is an isometric view of the outside of the cap for the mist eliminator;

FIG. 14B is an isometric view of the inside of the cap for the mist eliminator;

FIG. 14C is a cross-section view of the mist eliminator assembly;

FIG. 14D is a cross-section view of the mist eliminator assembly;

FIG. 15 is assembly view of the exemplary embodiment of a regenerative blower;

FIG. 15A is bottom view of the exemplary embodiment of the regenerative blower assembly;

FIG. 15B is a top view of the exemplary embodiment of the regenerative blower assembly;

FIG. 15C is an exploded view of the exemplary embodiment of the regenerative blower;

FIG. 15D is a detailed view of the outer surface of the upper section of the housing for the exemplary embodiment of the regenerative blower;

FIG. 15E is a detailed view of the inner surface of the upper section of the housing for the exemplary embodiment of the regenerative blower;

FIG. 15F is a detailed view of the inner surface of the lower section of the housing for the exemplary embodiment of the regenerative blower;

FIG. 15G is a detailed view of the outer surface of the lower section of the housing for the exemplary embodiment of the regenerative blower;

FIG. 15H is a cross-section view of the exemplary embodiment of the regenerative blower;

FIG. 15I is a cross-section view of the exemplary embodiment of the regenerative blower;

FIG. 15J is a cross-section view of the exemplary embodiment of the regenerative blower;

FIG. 15K is a schematic of the exemplary embodiment of the regenerative blower assembly;

FIG. 15L is a cross-section view of the exemplary embodiment of the regenerative blower;

FIG. 16 is a detailed view of the impeller assembly for the exemplary embodiment of the regenerative blower;

FIG. 16A is a cross-section view of the impeller assembly;

FIG. 17 is an assembly view of the alternate embodiment of a regenerative blower;

FIG. 17A is an assembly view of the alternate embodiment of a regenerative blower;

FIG. 17B is a cross-section view of the alternate embodiment of the regenerative blower assembly;

FIG. 17C is a cross-section view of the alternate embodiment of the regenerative blower assembly;

FIG. 17D is a cross-section view of the alternate embodiment of the regenerative blower assembly;

FIG. 17E is an exploded view of the alternate embodiment of the regenerative blower;

FIG. 17F is an assembly view of the impeller housing;

FIG. 17G is an exploded view of the impeller housing;

FIG. 17H is a cross-section view of the alternate embodiment for the impeller housing assembly;

FIG. 17I is a cross-section view of the alternate embodiment for the impeller housing assembly;

FIG. 17J is a bottom view of the lower section of the impeller housing;

FIG. 17K is a detail view of the inner surface of the lower section of the impeller housing;

FIG. 17L is a top view of the upper section of the impeller housing assembly;

FIG. 17M is a top view of the upper section of the housing for the impeller assembly without the cover installed;

FIG. 17N is a detailed view of the inner surface of the upper section of the housing for the impeller assembly;

FIG. 18 is a detailed view of the impeller assembly for the alternate embodiment of the regenerative blower;

FIG. 18A is a cross-section view of the impeller assembly;

FIG. 19 is an assembly view of the level sensor assembly;

FIG. 19A is an exploded view of the exemplary embodiment of the level sensor assembly;

FIG. 19B is cross-section view of the settling tank within the level sensor housing;

FIG. 19C is cross-section view of the blowdown sensor and product level sensor reservoirs within the level sensor housing;

FIG. 19D is an assembly view of an alternate embodiment of the level sensor assembly;

FIG. 19E is an exploded view of an alternate embodiment of the level sensor assembly;

FIG. 19F is a cross-section view of an alternate embodiment of the level sensor assembly;

FIG. 19G is a schematic of the operation of the level sensor assembly;

FIG. 19H is an alternate embodiment of the level sensor assembly;

FIG. 20 is an isometric view of level sensor assembly;

FIG. 20A is cross-section view of the level sensor assembly;

FIG. 21 is an isometric view of the front side of the bearing feed-water pump;

FIG. 21A is an isometric view of the back side of the bearing feed-water pump;

FIG. 22 is a schematic of the flow path of the source water for the exemplary embodiment of the water vapor distillation apparatus;

FIG. 22A is a schematic of the source water entering the heat exchanger;

FIG. 22B is a schematic of the source water passing through the heat exchanger;

FIG. 22C is a schematic of the source water exiting the heat exchanger;

FIG. 22D is a schematic of the source water passing through the regenerative blower;

FIG. 22E is a schematic of the source water exiting the regenerative blower and entering

FIG. 23 is a schematic of the flow paths of the blowdown water for the exemplary embodiment of the water vapor distillation apparatus;

FIG. 23A is a schematic of the blowdown water exiting evaporator/condenser assembly and entering the level sensor housing;

FIG. 23B is a schematic of the blowdown water filling the settling tank within the level sensor housing;

FIG. 23C is a schematic of the blowdown water filling the blowdown level sensor reservoir within the level sensor housing;

FIG. 23D is a schematic of the blowdown water exiting the level sensor housing and entering the strainer;

FIG. 23E is a schematic of the blowdown water exiting the strainer and entering the heat exchanger;

FIG. 23F is a schematic of the blowdown water passing through the heat exchanger;

FIG. 23G is a schematic of the blowdown water exiting the heat exchanger;

FIG. 24 is a schematic of the flow paths of the product water for the exemplary embodiment the water vapor distillation apparatus;

FIG. 24A is a schematic of the product water exiting the evaporator/condenser assembly and entering the level sensor housing;

FIG. 24B is a schematic of the product water entering the product level sensor reservoir within the level sensor housing;

FIG. 24C is a schematic of the product water exiting the product level sensor reservoir and entering the heat exchanger;

FIG. 24D is a schematic of the product water passing through the heat exchanger;

FIG. 24E is a schematic of the product water exiting the heat exchanger;

FIG. 24F is a schematic of the product water entering the bearing-feed water reservoir within the level sensor housing;

FIG. 24G is a schematic of the product water exiting the level sensor housing and entering the bearing feed-water pump;

FIG. 24H is a schematic of the product water exiting the bearing feed-water pump and entering the regenerative blower;

FIG. 24I is a schematic of the product water exiting the regenerative blower and entering the level sensor housing;

FIG. 25 is a schematic of the vent paths for the exemplary embodiment the water vapor distillation apparatus;

FIG. 25A is a schematic of the vent path allowing air to exit the blowdown sensor reservoir and enter the evaporative/condenser;

FIG. 25B is a schematic of the vent path allowing air to exit the product sensor reservoir and enter the evaporative/condenser;

FIG. 25C is a schematic of the vent path allowing air to exit the evaporator/condenser assembly;

FIG. 26 is a schematic of the low-pressure steam entering the tubes of the evaporator/condenser assembly from the sump;

FIG. 26A is a schematic of the low-pressure steam passing through the tubes of the evaporator/condenser assembly;

FIG. 26B is a schematic of the wet-low-pressure steam exiting the tubes of the evaporator/condenser assembly and entering the steam chest;

FIG 26C is a schematic of the wet-low-pressure steam flowing through the steam chest of the evaporator/condenser assembly;

FIG. 26D is a schematic of the creation of blowdown water as the low-pressure steam passing through the steam chest;

FIG 26E is a schematic of the dry-low-pressure steam exiting the steam chest and entering the regenerative blower;

FIG. 26F is a schematic of the dry-low-pressure steam passing through the regenerative blower;

FIG. 26G is a schematic of the high-pressure steam exiting the regenerative blower;

FIG. 26H is a schematic of the high-pressure steam entering the steam tube;

FIG. 26I is a schematic of the high-pressure steam exiting the steam tube and entering the evaporator/condenser chamber;

FIG. 26J is a schematic of the creation of product water from the high-pressure steam condensing within the evaporator/condenser chamber;

FIG. 27 is a chart illustrating the relationship between the differential pressure across the regenerative blower and the amount of energy required to produce one liter of product;

FIG. 28 is a chart illustrating the relationship between the production rate of product and the number of heat transfer tubes within the evaporator/condenser assembly;

FIG. 29 is a chart illustrating the production rate of product water of the evaporator/condenser assembly as a function of the amount of heat transfer surface area with the evaporator/condenser chamber;

FIG. 30 is a chart illustrating the efficiency of heat transfer surfaces for a varying amount of heat transfer tubes within the evaporator/condenser chamber as related to the change in pressure across the regenerative blower;

FIG. 31 is a chart illustrating the production rate and the amount of energy consumed by the evaporator/condenser assembly at different pressure differentials across the regenerative blower;

FIG. 32 is a cross-sectional and top view of a rotor and stator in accordance with a particular embodiment showing the support structure for the input, the vanes and chambers between the vanes, and the rotating drive shaft;

FIG. 32A is a side top view of a rotor and stator corresponding to the embodiment shown in FIG. 32, showing the support structures for the input and output, the vanes, the eccentric configuration within the housing unit, and the drive shaft;

FIG. 32B is a top view of a rotor and stator corresponding to the embodiment shown in FIGS. 32 and 32A, showing support structures for input and output, the vanes, the eccentric configuration within the housing unit, and the drive shaft;

FIG. 32C is a cross-sectional view of a rotor and stator corresponding to the embodiment shown in FIGS. 32, 32A, and 32B showing vanes, drive shaft, and bearings;

FIG. 32D is a cross-sectional view of a liquid ring pump according to one embodiment showing a capacitive sensor;

FIG. 32E is a cross-sectional view of a liquid ring pump according to one embodiment showing the eccentric rotor, rotor vanes, drive shaft with bearings, the rotating housing unit for the liquid ring pump, the still housing, and the cyclone effect and resulting mist and water droplet elimination from the steam;

FIG. 32F is a schematic diagram of An alternate embodiment for the liquid ring pump;

FIG. 32G is a top view of an alternate embodiment for a rotor showing multiple vanes and chambers between the vanes, and intake and exit holes in each individual chamber;

FIG. 32H is further detail of a liquid ring pump showing the stationary intake port and the rotating drive shaft, rotor and housing unit;

FIG. 32I is a view of a seal which may be present between the stationary and rotor sections of a liquid ring pump separating the intake orifice from the exit orifice;

FIG. 33 is side view of a backpressure regulator in accordance with one embodiment;

FIG. 33A is a diagonal view of the backpressure regulator shown in FIG. 33;

FIG. 33B is a side view of an alternate embodiment of the backpressure regulator having a vertically positioned port;

FIG. 33C is a diagonal view of the backpressure regulator shown in FIG. 33B;

FIG. 33D is a diagonal view of an alternate embodiment of the backpressure regulator;

FIG. 33E is a close-up view of section C of FIG. 33D, depicting a notch in the port of the backpressure regulator;

FIG. 33F is a cutaway side view of one embodiment of the backpressure regulator;

FIG. 33G is a close up view of section E of FIG. 33F, depicting a small opening in an orifice of the backpressure regulator;

FIG. 34 is a schematic of a backpressure regulator implemented within a apparatus;

FIG. 35 is a schematic of an alternate embodiment for a water vapor distillation apparatus;

FIG. 35A is a detailed schematic of an alternate embodiment for the level sensor housing illustrating an external connecting valve between source and blowdown fluid lines;

FIG. 36 is a view of one face of the pump side of a fluid distribution manifold;

FIG. 36A is a view of a second face of the pump side of a fluid distribution manifold;

FIG. 36B is a view of one face of the evaporator/condenser side of a fluid distribution manifold;

FIG. 36C is a view of a second face of the evaporator/condenser side of a fluid distribution manifold;

FIG. 37 is a top view of a coupler of an alternate embodiment of a fitting assembly;

FIG. 37A is a side view of an alternate embodiment of a fitting assembly in FIG. 37;

FIG. 38 is a cross-sectional view of alternate embodiment of the evaporator/condenser having individual heating layers and ribs;

FIG. 38A is a detail of a cross-section of an alternate embodiment of the evaporator/condenser showing how the ribs effectively partition the steam/evaporation from the liquid/condensation layers;

FIG. 39 is a schematic diagram of an alternate embodiment for the heat exchanger;

FIG. 39A is schematic diagram of an alternative embodiment for the heat exchanger;

FIG. 40 is a schematic overview of the an alternate embodiment of the water vapor distillation apparatus including a pressure measurement of the system using a cold sensor;

FIG. 41 is shows a view of a flip-filter with the intake stream and blowdown stream flowing through filter units, each filter unit rotating around a pivot joint about a center axis;

FIG. 41A shows flip filter housing;

FIG. 41B is detail view of the flip-filter in FIG. 41;

FIG. 41C is an alternative embodiment of a multi-unit flip filter;

FIG. 41D is a schematic of an alternate embodiment of a flip-filter;

FIG. 41E is a schematic of the flow path of one embodiment of the flip-filter;

FIG. 41F is a schematic illustrating a manual switch for changing water flow through individual units of a flip-filter in FIG. 41E;

FIG. 42 is a depiction of a monitoring system for distributed utilities;

FIG. 43 is a depiction of a distribution system for utilities;

FIG. 44 is a conceptual flow diagram of a possible embodiment of a system incorporating an alternate embodiment of the water vapor distillation apparatus;

FIG. 44A is a schematic block diagram of a power source for use with the system shown in FIG. 44;

FIGS. 45A-45E depict the principle of operation of a Stirling cycle machine;

FIG. 46 shows a view of a rocking beam drive in accordance with one embodiment;

FIG. 47 shows a view of a rocking beam drive in accordance with one embodiment;

FIG. 48 shows a view of an engine in accordance with one embodiment;

FIGS. 49A-49D depicts various views of a rocking beam drive in accordance with one embodiment;

FIG. 50 shows a bearing style rod connector in accordance with one embodiment;

FIGS. 51A-51B show a flexure in accordance with one embodiment;

FIG. 52 shows a four cylinder double rocking beam drive arrangement in accordance with one embodiment;

FIG. 53 shows a cross section of a crankshaft in accordance with one embodiment;

FIG. 54A shows a view of an engine in accordance with one embodiment;

FIG. 54B shows a crankshaft coupling in accordance with one embodiment;

FIG. 54C shows a view of a sleeve rotor in accordance with one embodiment;

FIG. 54D shows a view of a crankshaft in accordance with one embodiment;

FIG. 54E is a cross section of the sleeve rotor and spline shaft in accordance with one embodiment;

FIG. 54F is a cross section of the crankshaft and the spline shaft in accordance with one embodiment;

FIG. 54G are various views a sleeve rotor, crankshaft and spline shaft in accordance with one embodiment;

FIG. 55 shows the operation of pistons of an engine in accordance with one embodiment;

FIG. 56A shows an unwrapped schematic view of a working space and cylinders in accordance with one embodiment;

FIG. 56B shows a schematic view of a cylinder, heater head, and regenerator in accordance with one embodiment;

FIG. 56C shows a view of a cylinder head in accordance with one embodiment;

FIG. 57A shows a view of a rolling diaphragm, along with supporting top seal piston and bottom seal piston, in accordance with one embodiment;

FIG. 57B shows an exploded view of a rocking beam driven engine in accordance with one embodiment;

FIG. 57C shows a view of a cylinder, heater head, regenerator, and rolling diaphragm, in accordance with one embodiment;

FIGS. 57D-57E show various views of a rolling diaphragm during operation, in accordance with one embodiment;

FIG. 57F shows an unwrapped schematic view of a working space and cylinders in accordance with one embodiment;

FIG. 57G shows a view of an external combustion engine in accordance with one;

FIGS. 58A-58E show views of various embodiments of a rolling diaphragm;

FIG. 59A shows a view of a metal bellows and accompanying piston rod and pistons in accordance with one embodiment;

FIGS. 59B-59D show views of metal bellows diaphragms, in accordance with one embodiment;

FIGS. 59E-59G show a view of metal bellows in accordance with various embodiments;

FIG. 59H shows a schematic of a rolling diaphragm identifying various load regions;

FIG. 59I shows a schematic of the rolling diaphragm identifying the convolution region;

FIG. 60 shows a view of a piston and piston seal in accordance with one embodiment;

FIG. 61 shows a view of a piston rod and piston rod seal in accordance with one embodiment;

FIG. 62A shows a view of a piston seal backing ring in accordance with one embodiment;

FIG. 62B shows a pressure diagram for a backing ring in accordance with one embodiment;

FIGS. 62C and 62D show a piston seal in accordance with one embodiment;

FIGS. 62E and 62F show a piston rod seal in accordance with one embodiment;

FIG. 63A shows a view of a piston seal backing ring in accordance with one embodiment;

FIG. 63B shows a pressure diagram for a piston seal backing ring in accordance with one embodiment;

FIG. 64A shows a view of a piston rod seal backing ring in accordance with one embodiment;

FIG. 64B shows a pressure diagram for a piston rod seal backing ring in accordance with one embodiment;

FIG. 65 shows views of a piston guide ring in accordance with one embodiment;

FIG. 66 shows an unwrapped schematic illustration of a working space and cylinders in accordance with one embodiment;

FIG. 67A shows a view of an engine in accordance with one embodiment;

FIG. 67B shows a view of an engine in accordance with one embodiment;

FIG. 68 shows a view of a crankshaft in accordance with one embodiment;

FIGS. 69A-69C show various configurations of pump drives in accordance with various embodiments;

FIGS. 70A shows a view of an oil pump in accordance with one embodiment;

FIG. 70B shows a view of an engine in accordance with one embodiment;

FIG. 70C shows another view of the engine depicted in FIG. 70B;

FIGS. 71A and 71B show views of an engine in accordance with one embodiment;

FIG. 71C shows a view of a coupling joint in accordance with one embodiment;

FIG. 71D shows a view of a crankshaft and spline shaft of an engine in accordance with one embodiment;

FIG. 72A shows an illustrative view of a generator connected to one embodiment of the apparatus;

FIG. 72B shows a schematic representation of an auxiliary power unit for providing electrical power and heat to a water vapor distillation apparatus;

FIG. 72C shows a schematic view of a system according to one embodiment;

FIG. 73 is a schematic of the flow paths for an embodiment of the water vapor distillation apparatus;

FIG. 74 is an isometric view of the of an embodiment of the tube-in-tube heat exchanger from the front with one embodiment of a connector;

FIGS. 74A-74C are isometric, cross sectional and end views, respectively, of one embodiment of the connector shown in FIG. 74;

FIG. 75 is a flow chart of the water task states;

FIG. 76 is a schematic of a communications system for the at least one water vapor distillation apparatus, according to one embodiment;

FIG. 77 is an isometric view of one embodiment of a case/shell for various embodiments of a water vapor distillation apparatus;

FIG. 78 is an isometric view of one embodiment of a case/shell for various embodiments of a water vapor distillation apparatus;

FIGS. 79A-79E are various views of one embodiment of a case/shell for various embodiments of a water vapor distillation apparatus;

FIG. 80 is an isometric view of one embodiment of a case/shell for various embodiments of a water vapor distillation apparatus;

FIG. 81 is an isometric view of one embodiment of a case/shell for various embodiments of a water vapor distillation apparatus;

FIG. 82 is an isometric view of one embodiment of a case/shell for various embodiments of a water vapor distillation apparatus;

FIG. 83 is a partial view of a water vapor distillation apparatus according to one embodiment;

FIG. 84A-84F are various views of a partial water vapor distillation apparatus and system according to one embodiment;

FIG. 85A is an exploded view of a partial water vapor distillation apparatus and system according to one embodiment;

FIG. 85B is a detailed view of "A" shown in FIG. 85B;

FIG. 86 is an exploded view of one embodiment of the water vapor distillation apparatus and system;

FIG. 87A is an isometric view of one embodiment of the water vapor distillation apparatus;

FIG. 87B is an isometric view of one embodiment of the water vapor distillation apparatus;

FIG. 87C is a partial isometric view of one embodiment of the water vapor distillation apparatus;

FIG. 87D is a bottom isometric view of one embodiment of the water vapor distillation apparatus and system;

FIG. 88 is an exploded view of one embodiment of the hydraulic manifold;

FIG. 90A is a front view of one embodiment of a mist eliminator;

FIG. 90B is a sectional view of the mist eliminator shown in FIG. 90A;

FIG. 90C is bottom isometric view of the mist eliminator shown in FIG. 90A;

FIG. 90D is a bottom view of the mist eliminator shown in FIG. 90A;

FIG. 90E is an exploded view of the mist eliminator shown in FIG. 90A;

FIG. 91A is a bottom isometric view of one embodiment of a mist eliminator;

FIG. 91B is a front view of the embodiment of the mist eliminator shown in FIG. 91A;

FIG. 92A is a front view of one embodiment of a mist eliminator;

FIG. 92B is a bottom view of the embodiment of the mist eliminator shown in FIG. 92A;

FIG. 93A is a front view of an embodiment of a mist eliminator;

FIG. 93B is a side view of the embodiment of the mist eliminator shown in FIG. 93A;

FIG. 94 is an isometric view of one embodiment of a mist eliminator;

FIGS. 95A - 95B are view of a baffle port;

FIG. 96 is a cross sectional view of the embodiment of a mist eliminator shown in FIG. 94 and a baffle port inside a steam chest with a partial view of the evaporator condenser;

FIG. 97 is a cross sectional view of an embodiment of a mist eliminator shown in FIG. 92A and a baffle port inside a steam chest with a partial view of the evaporator condenser;

FIG. 98A is a top view of one embodiment of a mist eliminator;

FIG. 98B is a side view of the embodiment of the mist eliminator shown in FIG. 98A;

FIG. 99A is an isometric view of one embodiment of the mist eliminator;

FIG. 99B is a cross sectional view of the embodiment of the mist eliminator shown in FIG. 99A;

FIG. 99C is an exploded view of the embodiment of the mist eliminator shown in FIG. 99A;

FIGS. 100A – 100C are various view of the one embodiment of the case/shell of the system;

FIG. 101 is a partially exploded view of one embodiment of the system;

FIG. 102 is an exploded view of some components of the system, according to one embodiment;

FIG. 103 is an exploded view of some components of the system, according to one embodiment;

FIG. 104 is a back view of one embodiment of portions of the system;

FIG. 105 is an isometric, exploded and partial cross sectional view of one embodiment of the drain valves;

FIG. 106 is a side view of one embodiment of portions of the system;

FIG. 107 is one embodiment of a fluid schematic of the water vapor distillation apparatus;

FIG.108 is an exploded view of one embodiment of the valve manifold;

FIG. 109 is an exploded view of one embodiment of the conductivity manifold;

FIG. 110 is an isometric view of one embodiment of a level sensor assembly;

FIG. 111 is an exploded view of one embodiment of a level sensor assembly;

FIG. 112 is a view of one embodiment of a level sensor assembly with portions in ghost lines;

FIG. 113 is an exploded view of one embodiment of a level sensor;

FIG. 114 is an isometric partially exploded view of one embodiment of the heat exchanger;

FIG. 115A is an exploded view of one embodiment of the source water termination and a tube termination;

FIG. 115B is an isometric view of one embodiment of the source water termination and a tube termination;

FIG. 116 is an exploded view of the compressor assembly according to one embodiment;

FIG. 117 is a cross sectional view of one embodiment of the compressor assembly;

FIG. 118A is a view of one embodiment of the shaft;

FIG. 118B is a sectional view of one embodiment of the shaft;

FIG. 119 is an exploded view one embodiment of the shaft;

FIG. 120 is an exploded view of portions of the compressor assembly according to one embodiment;

FIG. 121 is a cross sectional view of the stator assembly according to one embodiment;

FIG. 122 is an exploded view of the evaporator/condenser assembly according to one embodiment;

FIG. 123 is an exploded view of the sump assembly;

FIG. 124 is an exploded view of the bottom tubesheet assembly according to one embodiment;

FIG. 125A is an exploded view of the top tubesheet assembly according to one embodiment;

FIG. 125B is a cross sectional view of the top tubesheet assembly according to one embodiment;

FIG. 126 is a cross sectional view of the evaporator/compressor according to one embodiment;

FIG. 127A is a top view of one embodiment of a filler rod;

FIG. 127B is a cross sectional view of the embodiment of the filler rod shown in FIG. 127A;

FIG. 128A is a detail view of "Detail A" from FIG. 127A;

FIG. 128B is a detail view of "Detail B" from FIG. 127B;

FIG. 129 is one embodiment of a conductivity fluid schematic;

FIG. 130 is one embodiment of a conductivity fluid schematic;

FIG. 131 is one embodiment of a conductivity fluid schematic;

FIG. 132 is one embodiment of a conductivity sensor;

FIG. 133 is a flow diagram of one method of determining the quality of product water output, according to one embodiment;

FIG. 134 is one embodiment of a motor temperature controller;

FIG. 135 is one embodiment of a heater and vent controller;

FIG. 136 is one embodiment of a product level controller;

FIG. 137 is a diagrammatic representation of one embodiment of a network;

FIG. 138 is a diagrammatic representation of one embodiment of communication between one system/device and one external manager;

FIG. 139 is a diagrammatic representation of one embodiment of a network; and

FIG. 140 is a diagrammatic representation of one embodiment of logging data in one embodiment of a network.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Definitions. As used in this description and the accompanying claims, the following terms shall have the meanings indicated, unless the context otherwise requires.

The term "fluid" is used herein to include any type of fluid including water. Thus, although the exemplary embodiment and various other embodiments are described herein with reference to water, the scope of the apparatus, system and methods includes any type of fluid. Also, herein, the term "liquid" may be used to indicate the exemplary embodiment, where the fluid is a liquid.

The term "evaporator condenser" is used herein to refer to an apparatus that is a combination evaporator and condenser. Thus, a structure is referred to as an evaporator condenser where the structure itself serves as both. The evaporator condenser structure is referred to herein as an evaporator/condenser, evaporator condenser or evaporator and condenser. Further, in some instances, where either the evaporator or the condenser is being referred to individually, it should be understood that the term is not limiting and refers to the evaporator condenser structure.

The term "unclean water" is used herein to refer to any water wherein it is desired to make cleaner prior to consuming the water.

The term "cleaner water" is used herein to refer to water that is cleaner as product water than as source water.

The term "source water" refers to any water that enters the apparatus.

The term "product water" refers to the cleaner water that exits the apparatus.

The term "purifying" as used herein, and in any appended claims, refers to reducing the concentration of one or more contaminants or otherwise altering the concentration of one or more contaminants.

The term "specified levels" as used herein refers to some desired level of concentration, as established by a user for a particular application. One instance of a specified level may be limiting a contaminant level in a fluid to carry out an industrial or commercial process. An example is eliminating contaminant levels in solvents or reactants to a level acceptable to enable an industrially significant yield in a chemical reaction (e.g., polymerization). Another instance of a specified level may be a certain contaminant level in a fluid as set forth by a governmental or intergovernmental agency for safety or health reasons. Examples might include the concentration of one or more contaminants in water to be used for drinking or particular health or medical applications, the concentration levels being set forth by organizations such as the World Health Organization or the U.S. Environmental Protection Agency.

The term "system" as used herein may refer to any combination of elements, including but not limited to, a water vapor distillation apparatus (which may be referred to as a water system or a water vapor distillation system) and a water vapor distillation apparatus together with a power source, such as a Stirling engine.

Herein is disclosed an apparatus for distilling unclean water known as source water into cleaner water known as product water. The apparatus cleanses the source water by evaporating the water to separate the particulate from the source water. The term "purifying" as used herein, and in any appended claims, refers to substantially reducing the concentration of one or more contaminants to less than or equal to specified levels or otherwise substantially altering the concentration of one or more contaminants to within a specified range.

The source water may first pass through a counter flow tube-in-tube heat exchanger to increase the temperature of the water. Increasing the temperature of the source water reduces the amount of thermal energy required to evaporate the water within the evaporator/condenser. The source water may receive thermal energy from the other fluid streams present in the heat exchanger. Typically, these other streams have a higher temperature than the source water motivating thermal energy to flow from the higher temperature streams to the lower temperature source water.

Receiving the heated source water is the evaporator area of the evaporator/condenser assembly. This assembly evaporates the source water to separate the contaminants from the

water. Thermal energy may be supplied using a heating element and high-pressure steam. Typically, the heating element will be used during initial start-up, thus under normal operating conditions the thermal energy will be provided by the high-pressure steam. The source water fills the inner tubes of the evaporator area of the evaporator/condenser. When the high-pressure steam condenses on the outer surfaces of these tubes thermal energy is conducted to the source water. This thermal energy causes some of the source water to evaporate into low-pressure steam. After the source water transforms into a low-pressure steam, the steam may exit the outlet of the tubes and pass through a separator. The separator removes any remaining water droplets within the steam ensuring that the low-pressure steam is dry before entering the compressor.

Upon exiting the evaporator area of the evaporator/condenser the low-pressure steam enters a compressor. The compressor creates high-pressure steam by compressing the low-pressure steam. As the steam is compressed the temperature of the steam increases. With the steam at an elevated temperature and pressure the steam exits the compressor.

The high-pressure steam enters the condenser area of the evaporator/condenser. As the steam fills the internal cavity the steam condenses on the tubes contained within the cavity. The high-pressure steam transfers thermal energy to the source water within the tubes. This heat transfer causes the steam to condense upon the outer surface of the tubes creating product water. The product water is collected in the base of the condenser area of the evaporator/condenser. The product water leaves the evaporator area of the evaporator/condenser and enters the level sensor housing.

The level sensor housing contains level sensors for determining the amount of product and blowdown water within the apparatus. These sensors allow an operator to adjust the amount of product water being produced or the amount of incoming source water depending on the water levels within the apparatus.

The water vapor distillation apparatus as described herein with respect to various embodiments may further be used in conjunction with a Stirling engine to form a water vapor distillation system. The power needed by the water vapor distillation apparatus may be provided by a Stirling engine electrically connected to the water vapor distillation apparatus.

Referring to FIG. 1, one embodiment of the water vapor distillation apparatus **100** is shown. For the purposes of this description, the embodiment shown in FIG.1 will be referred to as the exemplary embodiment. Other embodiments are contemplated some of which will be discussed herein. The apparatus **100** may include a heat exchanger **102**,

evaporator/condenser assembly **104**, regenerative blower **106**, level sensor assembly **108**, a bearing feed-water pump **110**, and a frame **112**. See also FIGS. 1A-E for additional views and cross sections of the water vapor distillation apparatus **100**.

Referring to FIGS. 1F-H, these figures illustrate alternate embodiments of the water vapor distillation apparatus **100**. FIG. 1F depicts an apparatus **120** having an alternate configuration of the evaporator/condenser assembly **122**. Similarly, FIG. 1G discloses an apparatus having another configuration of the evaporator/condenser assembly **132**. Similarly, FIG. 1H illustrates another embodiment of the apparatus not including the level sensor assembly **108** and bearing feed-water pump **110** from FIGS. 1-1E.

## HEAT EXCHANGER

Referring now to FIGS. 2-2A, in the exemplary embodiment of the water vapor distillation apparatus, the heat exchanger may be a counter flow tube-in-tube heat exchanger assembly **200**. In this embodiment, heat exchanger assembly **200** may include an outer tube **202**, a plurality of inner tubes **204** and a pair of connectors **206** illustrated in FIG. 2A. Alternate embodiments of the heat exchanger assembly **200** may not include connectors **206**.

Still referring to FIGS. 2-2A, the heat exchanger assembly **200** may contain several independent fluid paths. In the exemplary embodiment, the outer tube **202** contains source water and four inner tubes **204**. Three of these inner tubes **204** may contain product water created by the apparatus. The fourth inner tube may contain blowdown water.

Still referring to FIGS. 2-2A, the heat exchanger assembly **200** increases the temperature of the incoming source water and reduces the temperature of the outgoing product water. As the source water contacts the outer surface of the inner tubes **204**, thermal energy is conducted from the higher temperature blowdown and product water to the lower temperature source water through the wall of the inner tubes **204**. Increasing the temperature of the source water improves the efficiency of the water vapor distillation apparatus **100** because source water having a higher temperature requires less energy to evaporate the water. Moreover, reducing the temperature of the product water prepares the water for use by the consumer.

Still referring to FIGS. 2-2A, in the exemplary embodiment the heat exchanger **200** is a tube-in-tube heat exchanger having an outer tube **202** having several functions. First, the outer tube **202** protects and contains the inner tubes **204**. The outer tube **202** protects the inner tubes **204** from corrosion by acting as a barrier between the inner tubes **204** and

the surrounding environment. In addition, the outer tube **202** also improves the efficiency of the heat exchanger **200** by preventing the exchange of thermal energy to the surrounding environment. The outer tube **202** insulates the inner tubes **204** reducing any heat transfer to or from the surrounding environment. Similarly, the outer tube **202** may resist heat transfer from the inner tubes **204** focusing the heat transfer towards the source water and improving the efficiency of the heat exchanger **200**.

Still referring to FIGS. 2-2A, the outer tube **202** may be manufactured from any material, but low thermal conductivity is desirable. The low thermal conductivity is important, because the outer tube **202** insulates the inner tubes **204** from the surrounding environment. The low thermal conductivity of the outer tube improves the efficiency of the heat exchanger, because a low thermal conductive material reduces thermal energy losses or gains to the surrounding environment. In addition, low thermal conductive material lowers the amount of thermal energy that may be transferred from the inner tubes **204** to the outer tube **202**. This resistance to heat transfer allows more thermal energy to be transferred to the source water rather than escaping from the apparatus through the outer tube **202**. Thus an outer tube **202** manufactured from a material having a low thermal conductivity allows more thermal energy to be transferred to the source water rather than lost or gained to the surrounding environment.

Still referring to FIGS. 2-2A, in the exemplary embodiment the outer tube **202** is manufactured from a clear silicone. In addition to having a low thermal conductivity, silicone material is also corrosion resistant. This is an important characteristic to prevent corrosion of the heat exchanger **200**. The source water within the outer tube **202** may contain chemicals and/or other highly reactive materials. These materials may cause outer tubing **202** made from other materials to breakdown reducing the service life of the heat exchanger **200**. In alternate embodiments, the outer tube **202** may be manufactured from other materials, such as plastic or rubber having high temperatures resistance. Also, in one embodiment the outer tube **202** is made from convoluted tubing to enhance mixing, which increases heat transfer efficiency.

Referring now to FIGS. 2B-C, another desirable characteristic is for the outer tubing **202** to be sufficiently elastic to support installation of the heat exchanger **200** within the water vapor distillation apparatus **100**. In some applications space for the distillation apparatus may be limited by other environmental or situational constraints. For example, in the exemplary embodiment the heat exchanger **200** is wrapped around the evaporator/condenser. In other embodiments, the heat exchanger may also be integrated

into the insulated cover of the water vapor distillation apparatus to minimize heat lost or gained from the environment. In the exemplary embodiment the heat exchanger **200** is configured in a coil as shown in FIGS. 2B-C. To achieve this configuration the inner tubes **204** are slid into the outer tube **202** and then wound around a mandrel. An elastic outer tube **202** assists with positioning the ends of the heat exchanger **200** at particular locations within the apparatus. Thus, having an elastic outer tube **202** may facilitate in the installation of the heat exchanger **200** within the water vapor distillation apparatus **100**.

Still referring to FIGS. 2B-C, the elasticity of the outer tubing **202** material may also be affected by the wall thickness. Tubing having a thick wall thickness has less flexibility. The thicker wall thickness, however, may improve the thermal characteristics of the tubing, because the thicker wall has greater resistance heat transfer. In addition, the wall thickness of the tubing must be sufficient to withstand the internal pressures generated by the source water within the tubing. Tubing having an increased wall thickness, however, has decreased elasticity and increases the size of the heat exchanger assembly. Thicker walled tubing requires a larger bend radius affecting the installation the heat exchanger **200**. Conversely, tubing having too little wall thickness tends to kink during installation. This distortion of the tubing may restrict the flow of source water through the outer tube **202** causing a reduction in the efficiency of the heat exchanger **200**.

The diameter of the outer tube **202** may be any diameter capable of containing a plurality of inner tubes **204**. The larger the diameter, however, lowers the flexibility of the tubing. Any reduction in flexibility may adversely affect the installation of the heat exchanger into the water vapor distillation apparatus **100**. In the exemplary embodiment, the diameter of the outer tube **202** is one inch. This diameter allows the tube-in-tube heat exchanger **200** to be wrapped around the evaporator/condenser **104** upon final installation and contains four inner tubes **204** for transporting product and blowdown water. In alternate embodiments the heat exchanger may have as few as two inner tubes **204**. Similarly, in other embodiments the heat exchanger may have more than four inner tubes **204**.

Now referring to FIGS. 2A and 2D, the inner tubes **204** may provide separate flow paths for the source, product, and blowdown water. In the exemplary embodiment, these tubes contain product and blowdown water. However, in other embodiments, the inner tubes may contain additional fluid streams. The inner tubes **204** separate the clean and safe product water from the contaminated and unhealthy source and blowdown water. In the exemplary embodiment, there are three inner tubes **204** for product water and one inner tube

**204** for blowdown. The source water travels within the outer tube **202** of the heat exchanger **200**. In various other embodiments, the number of inner tubes may vary, i.e., greater number of inner tubes may be included or a lesser number of inner tubes may be included.

Still referring to FIGS. 2A and 2D, the inner tubes **204** conduct thermal energy through the tube walls. Thermal energy flows from the high temperature product and blowdown water within the inner tubes **204** through the tube walls to the low temperature source water. Thus, the inner tubes **204** are preferably made from a material having a high thermal conductivity, and additionally, preferably from a material that is corrosion resistant. In the exemplary embodiment, the inner tubes **204** are manufactured from copper. The inner tubes **204** may be manufactured from other materials such as brass or titanium with preference that these other materials have the properties of high thermal conductivity and corrosion resistance. For applications where the source and blowdown water may be highly concentrated, such as sea water, the inner tubes **204** may be manufactured from but not limited to copper-nickel, titanium or thermally conductive plastics.

In addition to the tubing material, the diameter and thickness of the tubing may also affect the rate of thermal energy transfer. Inner tubing **204** having a greater wall thickness may have less thermal efficiency because increasing the wall thickness of the tubing mat also increase the resistance to heat transfer. In the exemplary embodiment, the inner tubes **204** have .25 inch outside diameter. Although a thinner wall thickness increases the rate of heat transfer, the wall thickness must be sufficient to be shaped or formed without distorting. Thinner walled tubing is more likely to kink, pinch or collapse during formation. In addition, the wall thickness of the inner tubes **204** must be sufficient to withstand the internal pressure created by the water passing through the tubes.

Still referring to FIGS. 2A and 2D, additional methods for improving the rate of heat transfer of the inner tubes **204** may include unequal inner tube diameters and extended surfaces on the inner tubes to enhance heat transfer (fins, pins, ribs …). In addition, the outer tube **202** may have a textured interior surface causing turbulence in the flow of the source water to enhance heat transfer. The rate of heat transfer is increased because the texture surface produces a turbulent flow within the tube **202**. The turbulence increases the amount of water that contacts the outer surfaces of the inner tubes **204** where the heat transfer occurs. In contrast, without a texture surface the water may flow in a more laminar manner. This laminar flow will allow only a limited amount of water to contact the outer surfaces of the inner tubes **204**. The remaining water not in contact with the inner tubes **204**

receives less thermal energy because the convective thermal transfer between the water near the inner tubes and the remaining water is not as efficient as the heat transfer near the outer surface of the inner tubes **204**. Some examples of textured surfaces may include but are not limited to dimples, fins, bumps or grooves. In another embodiment may shrink to fit outer tube to increase shell side flow velocity and therefore enhance heat transfer.

Referring now to FIGS. 2E, typically, the inner tubes **204** are positioned parallel to one another. In some embodiments, however, the inner tubes **204** are braided or twined together to form a helix or a substantially helical shape as illustrated in FIGS. 2F-G. The helix shape increases the amount of surface area for heat transfer, because the length of the inner tubes **204** is longer than inner tubes **204** of the parallel arrangement. The increased surface area provides more area for heat transfer, thus increasing the efficiency of the heat exchanger **200**. In addition, the helical shape may cause a turbulent flow of source water within the outer tubing **202** improving the heat transfer efficiency as previously described. In the exemplary embodiment, the heat exchanger **200** has four inner tubes **204** arranged in a helical shape illustrated on FIGS. 2H-I.

The total length of the tubes-in-tube heat exchanger **200** is governed by the desired efficiency of the apparatus. A heat exchanger **200** having a longer length yields better efficiency. In the exemplary embodiment, the heat exchanger **200** is approximately 50 feet long. This yields approximately 90% efficiency. Alternatively, a length of 25 feet yields an efficiency of approximately 84%.

Referring now to FIGS. 2, 2J, and 2K the heat exchanger assembly **200** may also include a connector **206** at either end of the heat exchanger **200**. In the exemplary embodiment, the heat exchanger **200** has two connectors located at either end of the assembly. These connectors **206** along with the outer tube **202** define an inner cavity for containing the source water. In addition, the connectors attach to the ends of the inner tubes **204** and provide separate fluid paths for the product and blowdown water to enter and/or exit the heat exchanger **200**. The connectors **206** allow the heat exchanger assembly to be mechanically connected to the evaporator/condenser and other apparatus components. In some embodiments an extension **207** may be included within the heat exchanger **200** to provide an additional port to remove or supply water to the heat exchanger **200**.

Referring now to FIGS. 2L-O, these figures illustrate an alternate embodiment of the heat exchanger **200** having three inner tubes **204** passing through connectors **208**. The connectors **208** are sealed and attached to the inner tubes **204** and the outer tube **202** at either end of the heat exchanger **200** to contain the source water inside the outer tube **202**.

An o-ring may be installed within the connectors **208** to seal the interface between the connector **208** and the inner tubes **204**. This type seal may allow the inner tubes **204** to move freely and independently of the connector **208**. Furthermore, the inner tubes **204** may be arranged in a helical shape as shown in FIG. 2N. Referring also to FIGS. 74-74C, another embodiment of the connector 7400 is shown, which may be used in any of the embodiments described herein.

Referring to FIGS. 2P-R, these figures illustrate an alternate embodiment for the heat exchanger **210**. In this embodiment, the heat exchanger **210** is a plate heat exchanger having metal plates **212** and plastic plates **214**. The metal plates **212** may be manufacture from any metallic materials, such as stainless steel. Other embodiments may include but are not limited to plates manufactured from titanium or metal alloy. The plastic plates **214** are made from any type of plastic capable of performing. In one embodiment, the plate heat exchanger **210** is made from alternately metal and plastic plates. In other embodiments metal plates **212** may be followed by two or more plastic plates **214** as illustrated in FIG. 2R. The plate heat exchanger **210** may begin and/or end with a plate **216** manufacture from the same or different material as the previous plate. In alternate embodiments, plate **216** may be manufactured from a metallic or plastic material. The metal plates **212** consist of two metal plates stacked onto one another creating channels for fluid flow as shown in FIG. 2R.

Referring now to FIG. 3, the exemplary embodiment of the counter flow tube-in-tube heat exchanger **200** may include a fitting assembly **300**. The fitting assembly supports installation of the heat exchanger **200** within the water vapor distillation apparatus **100**. In addition, the fitting assembly **300** allows the heat exchanger **200** to be easily disconnected from the apparatus for maintenance. The assembly may consist of a first connector **302** (Also identified as connector **206** of FIG. 2) and a second connector **310** shown on FIG. 3. See also, FIGS. 3A-B for cross-section views of the fitting assembly **300**.

Still referring to FIG. 3, in the exemplary embodiment of the fitting assembly **300** is manufactured from brass. Other materials may be used to manufacture the fitting assembly **300** including, but are not limited to stainless steel, plastic, copper, copper nickel or titanium. For installation purposes, having the fitting assembly manufactured from similar material as the tubing that attaches to the assembly is preferred. Similar materials allow for the assembly to be installed within the water vapor distillation apparatus using a soldering or welding technique. The fitting assembly **300** is preferably manufactured from materials that are corrosion resistant and heat resistant (250°F). In addition, the materials preferably

allows for a fluid tight connection when the assembly is installed. For applications where the source and blowdown water may be highly concentrated, such as sea water, the fitting assembly **300** may be manufactured from but not limited to copper-nickel or titanium.

Still referring to FIG. 3, the first connector **302** includes a first end **304** and a second end **306**. The first end **304** attaches to the heat exchanger **200** as shown in FIGS. 2-2A. The connector may be attached to the heat exchanger **200** by clamping the outer tube **202** using a hose clamp against the outer surface of the first end **304** of the connector **302**. The inner tubes **204** of the heat exchanger **200** may also connect to the connector **302** at the first end **304**. These tubes may be soldered to the heat exchanger side of the connector **302**. Other methods of attachment may include, but are not limited to welding, press fitting, mechanical clamping or insert molding. See also FIGS. 3A-3B for cross-section views of fitting assembly **300**.

Now referring to FIG. 3C, in this embodiment the first end **304** of the connector **302** may have five ports. Three ports may be in fluid connection with one another as shown on FIGS. 3D-E. This configuration may combine multiple streams of product water into one stream. Multiple streams of product water increases the amount of heat transfer from the product water to the source water, because there is more product water within the heat exchanger to provide thermal energy to the source water. The remaining ports are separate and provide fluid pathways for blowdown and source water illustrated in FIGS. 3E-F. Alternate embodiments may not have any ports in fluid connection with one another.

Still referring to FIG. 3C, connector **302** has a second end **306** for mating with the second connector **310**. This second end **306** may have three ports providing flow paths for product, source and blowdown water. The product flow path may include an extension **308**. The extension **308** supports assembling connectors **302** and **310** together because the extension **308** allows for the o-ring groove within the body of the second connector **310** rather than on the mating surface **310**. Having the o-ring groove within the body of the second connector **310** allows the flow paths through the connector assembly to be positioned near one another without having overlapping sealing areas.

Now referring to FIGS. 3G-H, the second connector **310** includes a first end **312** and a second end **314**. The first end **312** mates with the first connector **302** as shown on FIG. 3. This end may also include an extension **316** as shown in FIG. 3G. The extension **316** allows for the o-ring groove to be located within the body of the first connector **302** rather than within the surface of end **306** of the first connector **302**. In addition, this connector may have a leak path **318** on the first end **312**. This path is located around the port for the

product water to prevent source or blowdown water from entering the product stream. Blowdown and source water may contain contaminants that affect the quality and safety of the product water. The leak path allows the blowdown and source water to leave the fitting rather than entering the product stream through a drain **320** illustrated on FIGS. 3G-I. In addition to the drain **320**, the exemplary embodiment may include three independent fluid paths within the connector **310** illustrated on FIGS. 3I-J.

The first connector **302** may be assembled to the second connector **310** using a Marmon clamp to allow for serviceability of the apparatus. This type of clamp provides an even clamping force and ease of disassembly/reassembly of the connection. Other methods of assembling the connectors together include, but are not limited using a C-clamp or fasteners (i.e. bolts and nuts). In addition, the circumference of the connectors **302** and **310** may be tapered, as shown on FIGS. 3E-F and 3I-J, to receive the clamp during installation of the fitting assembly **300**. In other embodiments, the fitting assembly **300** may be permanently joined by welding or soldering the connectors together.

## EVAPORATOR CONDENSER

Now referring to FIGS. 4-4B, the exemplary embodiment of the evaporator condenser (also herein referred to as an "evaporator/condenser") assembly **400** may consist of an evaporator/condenser chamber **402** having a top and bottom. The chamber **402** may include a shell **410**, an upper tube sheet **414** and a lower tube sheet **412**. Attached to the lower tube sheet **412** is a sump assembly **404** for holding incoming source water. Similarly, attached to the upper tube sheet **414** is an upper flange **406**. This flange connects the steam chest **408** to the evaporator/condenser chamber **402**. Within the evaporator/condenser chamber **402** are a plurality of rods **416** where each rod is surrounded by a tube **418** as illustrated in FIG. 4A and 4B. The tubes **418** are in fluid connection with the sump **404** and upper flange **406**. See also FIG. 4C illustrating an alternate embodiment of the evaporator/condenser assembly **420**.

Now referring to FIG. 5, the sump assembly **500** (also identified as **404** on FIG. 4) may include an upper housing **502**, a lower housing **504**, a drain fitting **506**, drain pipe **508**, and heating element **510**. See also FIG. 5A for an exploded view of the sump assembly **500** and FIG. 6 for detailed view of the upper housing **502**. The sump assembly **500** contains and heats source water, as well as collects particulate carried by the source water. When the source water changes state from a fluid to a vapor particulate is left behind and is collected in the sump assembly **500**.

Still referring to FIGS. 5-5A, the sump assembly **500** may be made from material that is corrosion and high-temperature resistant. A corrosion resistant material is preferred because the sump is exposed to high temperatures, moisture, and corrosive source water. In the exemplary embodiment the sump is manufactured from stainless steel. In an alternate embodiment the sump may be manufactured from RADEL® or other high-temperature plastic in conjunction with an alternate configuration for attaching the heating element **510**. For applications where the source water may be highly concentrated, such as sea water, the sump assembly **500** may be manufactured from but not limited to titanium, copper-nickel, naval bronze, or high-temperature plastic.

Still referring to FIGS. 5-5A, the source water may be heated using a heating element **510** of the sump assembly **500**. The heat element **510** increases the temperature of the source water during initial start up of the water vapor distillation apparatus **100**. This element provides additional thermal energy causing the source water to change from a fluid to a vapor. In the exemplary embodiment, the heat element **510** may be a 120 Volt/1200 Watt resistive element electric heater.

Still referring to FIGS. 5-5A, the sump assembly **500** may include a bottom housing **504** having an angled lower surface in order to assist with the collection of particulate. The bottom housing **504** may have any angle sufficient to collect the particulate in one area of the housing. In the exemplary embodiment the bottom housing **504** has a 17 degree angled-lower surface. In other embodiments, the bottom housing **504** may have a flat bottom.

Still referring to FIGS. 5-5A, the exemplary embodiment may include a drain assembly consisting of a drain fitting **506** and a drain pipe **508**. The drain assembly provides access to inside of the evaporator area of the evaporator/condenser to remove particulate buildup without having to disassemble the apparatus. The drain assembly may be located near the bottom of the sump to reduce scaling (buildup of particulates) on the tubes inside the evaporator/condenser. Scaling is prevented by allowing periodic removal of the scale in the sump assembly **500**. Having less particulate in the sump assembly **500** reduces the likelihood that particulate will flow into the tubes of the evaporator/condenser. In the exemplary embodiment the drain assembly is positioned to receive particulate from the angled-lower surface of the bottom housing **504**. The drain assembly may be made of any material that may be attached to the bottom housing **504** and is corrosion and heat resistant. In the exemplary embodiment, the drain fitting **506** is a flanged sanitary fitting manufactured from stainless steel. Referring now also to FIG. 73, a sump drain **7302** fluid pathway is shown. In some embodiments, sump drain **7302** fluid pathway may be used to

facilitate the cleaning or flushing of the apparatus **100**. In some embodiments, the sump drain **7302** fluid pathway may be sealed to the outside environment by a valve, for example, but not limited to, a manual ball valve. In some embodiments, the valve may be a non-manual valve, for example, an actuated valve controlled by the control system, and in some of these embodiments, the cleaning and flushing may be at least partially automated.

Still referring to FIGS. 5-5A, attached to the drain fitting **506** may be a drain pipe **508**. The drain pipe **508** provides a fluid path way for particulate to travel from the drain fitting **506** out of the evaporator/condenser assembly **400**. The drain pipe **508** may be manufactured from any material, with preference that the material is corrosion and heat resistant and is capable of being attached to the drain fitting **506**. In the exemplary embodiment, the drain pipe **508** is manufactured from stainless steel. The diameter of the drain pipe **508** is preferably sufficient to allow for removal of particulate from the sump assembly **500**. A larger diameter pipe is desirable because there is a less likelihood of the drain pipe **508** becoming clogged with particulate while draining the sump assembly **500**.

Now referring to FIG. 7, the exemplary embodiment of the evaporator/condenser chamber **700** (also identified as **402** of FIG. 4) may include a shell **702** (also identified as **410** of FIGS. 4A-B, a lower flange **704** (also identified as **502** of FIG. 5 and **600** of FIG. 6), a lower-tube sheet **706** (also identified as **412** of FIGS. 4A-B), a plurality of tie rods **708**, a plurality of tubes **710** (also identified as **418** of FIGS. 4A-B), an upper flange **712** (also identified as **406** of FIG. 4) and an upper-tube sheet **714** (also identified as **414** of FIGS. 4A-B). See also FIG. 7A for an assembly view evaporator/condenser chamber **700**.

Still referring to FIG. 7, the shell **702** defines an internal cavity where thermal energy is transferred from the high-pressure steam to the source water. This heat transfer supports the phase change of the source water from a fluid to a vapor. In addition, the heat transfer also causes the incoming steam to condense into product water. The shell **702** may be manufactured from any material that has sufficient corrosion resistant and strength characteristics. In the exemplary embodiment, the shell **702** is manufactured from fiberglass. It is preferable that the shell has an inner diameter sufficient to contain the desired number of tubes **710**. Within the internal cavity of the shell is a plurality of tubes **710** having surface area for transferring thermal energy from the high-pressure steam entering the chamber to source water within the tubes **710**.

Still referring to FIG. 7, the evaporator/condenser chamber **700** defines an inner cavity for the condensation of high-pressure steam. Within this cavity is a plurality of tubes **710** that transfer thermal energy from high-pressure steam to source water within the tubes

as the steam condensing upon outer surfaces of the tubes. The heat transfer through the tube walls causes the source water to undergo a phase change through a process called thin film evaporation as described in U.S. Patent Application Pub. No. US 2005/0183832 A1 published on Aug. 25, 2005 entitled "Method and Apparatus for Phase Change Enhancement," the contents of which are hereby incorporated by reference herein.

Still referring to FIG. 7, in the tubes **710** of the evaporator/condenser, a Taylor bubble may be developed which has an outer surface including a thin film in contact with an inner surface of the tubes **710**. The Taylor bubble is heated as it rises within the tube so that fluid in the thin film transitions into vapor within the bubble.

Now referring to FIG. 7B, typically an evaporator may operate in either of two modes: pool boiling mode or thin film mode. In thin film boiling, a thin film of fluid is created on the inner wall of the tubes facilitating heat transfer from the tube wall to the free surface of the fluid. The efficiency of phase change typically increases for thin film mode as compared to pool boiling mode. FIG. 7B shows the difference in the rate of distillate production as a function of condenser pressure for pool boiling and thin film boiling under similar conditions for a representative evaporator. The bottom curve **70** corresponds to pool boiling while the middle curve **75** corresponds to thin film boiling. As will be noted from these two curves, thin film boiling mode offers significantly higher efficiency than pool boiling mode. Thin film boiling is more difficult to maintain than pool boiling, however. Thin film evaporation is typically achieved using apparatus that includes very small openings. This apparatus may easily clog, particularly when the source fluid contains contaminants. Additionally, in thin film mode the water level is typically held just marginally above the tops of the tubes in a vertical tube-type evaporator. For reasons such as this, the apparatus may also be sensitive to movement and positioning of the apparatus.

Referring back to FIG. 7, in the exemplary embodiment the tubes **710** have an outer diameter of .75 inches and may be manufactured from copper. In alternate embodiments, the tubes **710** may be manufactured from other materials including but not limited to nickel copper or other composite materials. In various other embodiments, the diameter of the tubes may different, i.e., may be smaller or larger. For possible applications where the source water may be seawater, the tubes **710** may be manufactured from copper-nickel or titanium material. These materials have high corrosion resistant properties to maintain the heat transfer characteristics of the tubes when exposed to highly concentrated source water, such as, salt water. The diameter of the tubes **710** may also vary depending on many variables. The diameter of the tubes **710** may be limited by the inner diameter of the shell

**702** and the desired amount of heat transfer efficiency. Another constraint may be serviceability. A smaller diameter is more difficult to remove scale from because the reduced diameter restricts access to the inner surfaces of the tube walls. The length of the tubes **710** may be determined by the length of the inner cavity defined by the shell **702** and the thickness of the tube sheets **706** and **714**. In the exemplary embodiment the tubes **710** extend beyond the ends of the tube sheets into the lower flange **704** and upper flange **712**.

Referring now to FIG. 8, in the exemplary embodiment the tubes **800** (also identified as **710** of FIG. 7A-B) have a bead **802** near each end. The bead **802** prevents the tubes **800** from sliding through the apertures in the lower tube sheet **706** and the upper tube sheet **714**.

Referring now to FIG. 9, improved efficiency of a phase change operation may be achieved by providing packing within the evaporator/condenser tubes **904**. The introduction of such packing may allow the evaporator to take on some of the characteristics of thin film mode, due to the interaction between the fluid, the packing and the tube **904**. The packing may be any material shaped such that the material preferentially fills the volume of a tube **904** near the tube's longitudinal axis versus the volume near the tube's interior wall. Such packing material serves to concentrate the vapor near the walls of the tube for efficient heat exchange. For example, in the exemplary embodiment the packing may comprise a rod **902**. Each rod **902** may be of any cross-sectional shape including a cylindrical or rectangular shape. The cross-sectional area of each packing rod **902** may be any area that will fit within the cross-section of the tube. The cross-sectional area of each rod **902** may vary along the rod's length. A given rod **902** may extend the length of a given evaporator tube **904** or any subset thereof. It is preferable that the rod material be hydrophobic and capable of repeated thermal cycling. In the exemplary embodiment the rods **902** are manufactured from glass fiber filled RYTON® or glass fiber filled polypropylene.

Still referring to FIG. 9, each rod **902** may be positioned anywhere within the tube **904** including preferentially in the upper portion of the tube. In one specific embodiment, each rod is approximately half the length of the associated tube and is positioned approximately in the top half of the tube. The top curve **80** in FIG. 7B shows the increase in boiling efficiency for thin film boiling for a representative evaporator where the evaporator tubes include packing material in approximately the top half of the tubes. With such packing, the phase change efficiency is also, advantageously, much less sensitive to changes in the fluid level above the tubes, the orientation of the tubes with respect to the vertical, the feed pressure for the tubes and other operating parameters for the evaporator. In the exemplary embodiment the rods **902** have approximately the same length as the tubes **904**.

Referring now to FIG. 9A, in the exemplary embodiment, the rods **902** may have a plurality of members **906** extending out from the center and along the longitudinal axis of the rod **902**. These members **906** maintain the rod **902** within the center of the tube **904** to produce the most efficient flow path for the source water. Any number of members may be used, however, it is preferential that there is a sufficient number to maintain the rod **902** in the center of the tube **904**. In alternate embodiments, the rods **902** may not have members **906**. In alternate embodiments the rod **902** may be held in place within the tube **904** by wrapping the rod **902** in a wire or cross drilling holes within the rod **902** to support installation of pins to position the rod **902** within the tube **904**.

Referring back to FIG. 7, the tubes **710** (Also identified as **800** of FIG. 8 and **904** of FIG. 9) are secured in place by the pair of tube sheets **706** and **714**. These sheets are secured to each end of the shell **702** using the tie rods **708**. The tube sheets **706** and **714** have a plurality of apertures that provide a pathway for the source water to enter and exit the tubes **710**. When the tubes **710** are installed within the chamber **700**, the apertures within the tube sheets **706** and **714** receive the ends of the tubes **710**. The lower tube sheet **706** (also identified as **1002** on FIG. 10) is attached to the bottom of the shell **702**. See FIG. 10 for a detail view of the lower tube sheet. The upper tube sheet **714** (also identified as **1004** on FIG. 10A) is attached to the top of the shell **702**. See FIG. 10 A for a detail view of the upper tube sheet. Both tube sheets have similar dimensions except that the upper tube sheet **714** has an additional aperture located in the center of the sheet. This aperture provides an opening for the high-pressure steam to enter the evaporator/condenser chamber **700**.

Still referring to FIG. 7, in the exemplary embodiments the upper-tube sheet **714** and the lower-tube sheet **706** may be manufactured from RADEL®. This material has low creep, hydrolytic stability, thermal stability and low thermal conductivity. Furthermore, tube sheets manufactured from RADEL® may be formed by machining or injection molding. In alternate embodiments, the tube sheets may be manufactured from other materials including but are not limited to G10.

Still referring to FIG. 7, the size of the plurality of apertures within the tube sheets **706** and **714** for receiving the tubes **710** is governed by the outside diameter of the tubes **710**. These apertures must be sufficient to receive the end of the tubes **710** and also include a seal. Typically, an o-ring groove is provided within the tube sheets to receive an o-ring. This o-ring provides a water-tight seal between the inner tubes **710**

and the tube sheets **706** and **714**. In addition, this type of seal simplifies construction, facilitates the use of dissimilar materials within the evaporator/condenser, and allows the tubes **710** to move during repeated thermal cycles. This seal prevents the product water from entering into the sump **500** of FIG. 5 or source water entering the chamber **700**. In alternate embodiments, the tubes **710** may be installed within the apertures of the tube sheets **706** and **714** by the using the methods of, but not limited to soldering, welding, press fitting, bonding (i.e. silicone, RTV, epoxy ...), brazing or swaging depending on the tube sheet material.

Now referring to FIG. 10, in the exemplary embodiment the o-ring grooves are located at various depths in the tube sheets **1002** and **1004**. The different depths of the o-ring grooves allows the tubes **710** to be positioned more closely together, because the o-ring grooves from adjacent tubes do not overlap one another. Overlapping o-ring grooves do not provide a sufficient seal, thus each o-ring groove must be independent of the other o-ring grooves within the tube sheet. As a result of varying the location of the o-ring grooves at different depths within the tube sheet, adjacent o-ring grooves do not overlap one another allowing the tubes to be positioned closer together. Thus having the tubes **710** located closer to one another allows more tubes to be positioned within the evaporator/condenser chamber **700**.

Referring back to FIG. 7, the tube sheets **706** and **714** are also secured to the lower flange **704** and the upper flange **712** using the tie rods **708**. The lower flange **704** (also identified as **502** of FIG. 5 and **600** of FIG. 6) connects the sump **500** of FIG. 5 to the evaporator/condenser chamber **700** of FIG. 7. In addition, the lower flange **704** provides a fluid connection for the source water within the sump to the inlet of tubes **710** positioned on the lower tube sheet **706**. The lower flange **704** may have any height with preference that the height is sufficient to allow for an even distribution of the source water entering the tubes **710**. Typically a flange having a height of one to two inches provides for an even distribution of source water into the tubes **710**. In alternate embodiments the height of the flange may be larger to increase the capacity of the sump to collect particulate.

Still referring to FIG. 7, the upper flange **712** (also identified as **1100** of FIG. 11) provides a fluid connection between the outlet of the tubes **710** and the steam chest **408** of FIG. 4. In addition, the upper flange **712** collects the source water removed from the low-pressure steam as the steam passes through the steam chest **408**. This water is then

transferred out of the apparatus through the blowdown port **1102** located within the side of the upper flange **1100** of FIG. 11.

Still referring to FIG. 7, the lower flange **704** and upper flange **712** may be manufactured out of any material having sufficient structural strength and corrosion and temperature resistant properties. In one embodiment, the flanges may be manufactured from RADEL®. In the exemplary embodiment the flanges may be manufactured from nickel-plated aluminum. In other embodiments the lower flange may be manufacture from material including but not limited to stainless steel, titanium and copper-nickel.

Referring to FIG. 7-7A, located near the outer edge of the lower flange **704** and the upper flange **712** is a plurality of apertures to receive the tie rods **708**. These rods are axially positioned on a bolt circle concentric to and along the outside perimeter of the shell **702**. The length of the tie rods **708** is governed by the length of the shell **702** and the thickness of the lower-tube sheet **706**, lower flange **704**, upper flange **712** and upper-tube sheet **714**. The tie rods **708** may have threaded ends for attaching a threaded fastener onto each end of the rod securing the components of the evaporator/condenser together. In addition, the tie rods **708** may be manufactured from any material that is of sufficient strength for the purpose, such as, stainless steel. Tie rods **708** may be manufactured from other materials including, but not limited to bronze, titanium, fiberglass composite materials, and carbon steel. In the exemplary embodiment, the tie rods **708** may have flats machined near each end to provide a flat surface for receiving a device to hold the rods in place during installation.

Referring now to FIGS. 12-12C, connected to the upper flange **1100** (also identified as **712** of FIG. 7) may be a steam chest **1200** (also identified as **408** in FIG. 4). In the exemplary embodiment, the steam chest **1200** may include a base **1202**, a steam separator assembly **1204**, a cap **1206** and a steam tube **1208**. The base **1202** defines an internal cavity for receiving the low-pressure steam created within the tubes **710** of the evaporator area of the evaporator/condenser chamber **700**. The base **1202** may have any height such that there is sufficient space to allow water droplets contained within the vapor to be separated. The height of the steam chest allows the water droplets carried by the steam and forcibly ejected from outlets of the tubes **710** from the rapid release of steam bubbles to decelerate and fall back towards the upper flange **712** (also identified as **1100** on FIG. 11). .

Still referring to FIGS 12-12C, within the base **1202** may be a steam separator assembly **1204**. This assembly consists of a basket and mesh (not shown in FIGS. 12-

12C). The basket contains a quantity of wire mesh. In the exemplary embodiment, the steam separator assembly **1204** removes water droplets from the incoming low-pressure steam by manipulating the steam through a layer of wire mesh. As the steam passes through the mesh the water droplets start to collect on the surfaces of the mesh. These droplets may contain contaminants or particulate. As the droplets increase in size, the water falls onto the bottom of the basket. A plurality of apertures may be located in the bottom of the basket to allow water to collect within the upper flange **712**. In addition, these apertures provide a fluid path way for low-pressure steam to enter the steam separator assembly **1204**. In addition, the wire mesh provides a barrier from the splashing blowdown water located within the upper flange **712** of the evaporator/condenser.

Still referring to FIGS. 12-12C, in alternate embodiments the steam separator assembly **1204** may contain a series of plates for collecting the water droplets from the low-pressure water vapor as the vapor passes through or around each plate. The plates manipulate the steam to cause water droplets to collect onto the plates. The water is collected in the assembly because the plates are arranged creating sharp bends in the flow path of the steam. These bends reduce the velocity of and change the direction of the steam. The water droplet may continue along their initial trajectory due to momentum. The droplets may then impact the walls or plates of the assembly where the droplets are collected. When enough droplets have collected on the walls or plates of the assembly, the water droplets may fall down towards the upper flange **406** of the evaporator/condenser.

Still referring to FIGS. 12-12C, the base **1202** may also have an observation window **1210**. This window allows people operating the apparatus to visually observe the internals of the steam chest to determine if the apparatus is functioning properly. In other embodiments, the steam chest **1200** may not include an observation window **1210**. This alternate embodiment is illustrated in FIG. 12D. In still other embodiments, the size and shape of the window may vary. In some embodiments, the steam chest may include multiple windows.

In the exemplary embodiment, the steam separator assembly may be manufactured from stainless steel. Other materials may be used, however, with preference that those materials have corrosion and high temperature resistant properties. Other types of materials may include, but are not limited to RADEL®, titanium, copper-nickel, plated aluminum, fiber composites, and high temperature plastics.

Still referring to FIGS. 12-12C, attached to the base **1202** is the cap **1206**. The cap and base define the internal cavity for separating the water from the low-pressure steam. In addition, the cap **1206** may have two ports, an outlet port **1211** and inlet port **1212** shown on FIGS. 12B, 12E and 12F. The outlet port provides a fluid path way for the dry low-pressure steam to exit the steam chest **1200**. In the exemplary embodiment, the outlet port **1211** is located near the top surface of the cap **1206** because the locating the port away from the outlets of the tubes **710** of the evaporator/condenser promotes dryer steam. In alternate embodiments, however, the outlet port **1211** may have a different location within the cap **1206**. Similarly, the inlet port **1212** provides a fluid path way for high-pressure steam to enter the high-pressure steam tube **1208** within the steam chest **1200**. In the exemplary embodiment, the inlet port **1212** is located near the top surface of the cap **1206**. In alternate embodiments, the inlet port **1212** may have a different location within the cap **1206**. In the exemplary embodiment, the cap **1206** is manufactured from plated aluminum. Other types of materials may include, but are not limited to stainless steel, plastics, titanium and copper-nickel. The size of these ports may affect the pressure drop across the compressor.

Still referring to FIGS. 12-12C, connected to the inlet port **1212** within the steam chest **1200** is a steam tube **1208**. This tube provides a fluid path way for the high-pressure steam to pass through the steam chest and enter the condenser area of the evaporator/condenser chamber. The inner diameter of the steam tube **1208** may be any size, such that the tube does not adversely affect the flow of high-pressure steam from the regenerative blower to the evaporator/condenser chamber. In the exemplary embodiment the steam tube **1208** may be manufactured from stainless steel. Other materials may be used to manufacture the steam tube **1208**, but these materials must have sufficient corrosion resistant and high temperature resistant properties. Such materials may include, but are not limited to plated aluminum, plastics, titanium and copper-nickel. For applications where the source water may be highly concentrated, such as sea water, the steam chest **1200** may be manufactured from but not limited to titanium, nickel, bronze, nickel-copper and copper-nickel.

Referring now to FIGS. 13-13C, an alternate embodiment of the evaporator/condenser assembly **1300** is shown. In this embodiment, the evaporator/condenser assembly **1300** includes a sump **1302**, an evaporator/condenser chamber **1304**, a mist eliminator assembly **1306**, a plurality of tie rids **1308**, a lower

flange **1310** and an upper flange **1312**. See FIG. 13D for a detail view of the evaporator/condenser assembly without the sump **1302**.

Now referring to FIG. 13E, the evaporator/condenser chamber may include a shell **1314**, a plurality of tubes **1316**, a lower flange **1310** and an upper flange **1312**. The evaporator/condenser chamber **1304** defines an inner cavity for the condensation of high-pressure steam. Tubes **1316** transfer thermal energy from the high-pressure steam to source water within the tubes when the steam condenses upon the outer surface of the tubes **1316**. In this embodiment the tubes **1316** may have an outer diameter of .75 inches and manufactured from copper. In alternate embodiments, the tubes **1316** may be manufactured from other materials including but not limited to nickel copper or other composite materials. The diameter of the tubes **1316** may also vary depending on many variables. See previous discussion in the exemplary embodiment concerning the diameter of the tubes. The length of the tubes **1316** may be determined by the length of the inner cavity defined by the shell **1314** and the thickness of the lower flange **1310** and upper flange **1312**.

Still referring to FIG. 13E, the tubes **1316** are supported within the inner cavity defined by the shell **1314** by the lower flange **1310** and upper flange **1312**, as shown on FIGS. 13B, 13C and 13E. Each flange has a plurality of apertures located axially around the center of the flange. These apertures may contain the ends of the tubes **1316**. In addition, the lower flange **1310** and upper flange **1312** also secure the shell **1314** in place and provide pathways to the sump **1302** and the mist eliminator assembly **1306**. As the source water fills the sump **1302**, some water begins to fill the tubes **1316** located in the inner cavity of the shell **1314**. As thermal energy is transferred to the source water in the tubes **1316**, the water begins to evaporate. The source water vapor travels through the tubes **1316** and into the mist eliminator assembly **1306**. The vapor enters the mist eliminator through the apertures located in the upper flange **1312**.

Still referring to FIG. 13E, the shell **1314** is secured to the lower flange **1310** and upper flange **1312** using a plurality of tie rods **1308**. These tie rods are positioned outside axially around the perimeter of the shell **1314**. In addition, the tie rods **1308** also secure the mist eliminator **1306** to the upper flange **1312** and the sump **1302** to the lower flange **1310**. The length of the tie rods is governed by the length of the shell **1314** and the thickness of the lower flange **1310**, upper flange **1312**, sump **1302** and mist eliminator **1306**. The tie rods **1308** may have threaded ends for attaching a threaded fastener onto each end of the rod securing the components of the evaporator/condenser

together. In addition, the tie rods **1308** may be manufactured from any material that is of sufficient strength, such as, stainless steel. Tie rods **1308** may be manufactured from other materials including, but not limited to bronze, titanium, fiberglass composite materials, and carbon steel.

Still referring to FIG. 13E, in the exemplary embodiment the shell **1314** is manufactured from fiberglass. Other materials may be used with preference that those materials are corrosion resistant, have low thermal conductivity, and sufficient structural strength to withstand the internal pressures developed during the operation of the evaporator/condenser assembly **1300**. See discussion for the exemplary embodiment relating to the size of the inner diameter of the shell.

Still referring to FIG. 13E, the sump **1302** is connected to the lower flange **1310** and is in fluid connection with the tubes **1316** of the evaporator/condenser assembly chamber **1304**. The sump **1302** collects the incoming source water from the heat exchanger. The source water enters the sump **1302** through an inlet port locate within the side wall of the sump. In other embodiments the inlet port may be located at a different location (i.e. on the bottom). In this embodiment the sump **1302** is made from a composite material, G10 plastic. In other embodiments the sump **1302** may be manufactured from any other material having sufficient corrosion and high-temperatures resistant properties. Other materials include but are not limited to aluminum RADEL® and stainless steel. The sump **1302** may also include a heating element to provide thermal energy to the source water. This thermal energy assists the source water in changing from a fluid to a vapor.

Referring now to FIGS. 14-14C, attached to the upper flange **1312** is the mist eliminator assembly **1400** (also identified as **1306** of FIG. 13). This assembly may consist of a cap **1402**, steam pipe **1404**, and mist separator **1406** illustrated on FIG. 14. The cap **1402** contains the low-pressure steam that is created from the evaporator side of the evaporator/condenser. The cap **1402** may have three ports **1408**, **1410**, and **1412** as shown FIGS. 14A-C. See discussion for the steam chest of the exemplary embodiment relating to the height of the volume for removing the water droplets. In addition, the cap **1402** defines a cavity that contains the mist separator **1406** shown on FIGS. 14, 14C and 14D.

Still referring to FIGS. 14-14C, the first port **1408** may be located in the center of the top surface of the cap **1402** and is for receiving the first end of the steam pipe **1404**. This port allows the high-pressure steam created by the compressor to re-enter

the evaporator/condenser through first end of the steam pipe **1404**. The steam pipe **1404** provides a fluid path way for high-pressure steam to enter the evaporator/condenser through the mist eliminator assembly **1400** without mixing with the low-pressure steam entering the mist eliminator assembly **1400**. In this embodiment, the steam pipe **1404** is manufactured from stainless steel. In other embodiments the steam pipe may be manufactured from materials including, but not limited to plated aluminum, RADEL®, copper-nickel and titanium. The length of the steam pipe **1404** must be sufficient to allow for connecting with the compressor and passing through the entire mist eliminator assembly **1400**. The second end of the steam pipe is received within a port located at the center of the upper flange **1312**. The inner diameter of the steam pipe **1404** may affect the pressure drop across the compressor. Another effect on the system is that the steam pipe **1404** reduces the effective volume within the mist eliminator to remove water droplets from the low-pressure steam.

Still referring to FIGS. 14-14C, the steam pipe **1404** also may have a plurality of exterior grooves for receiving the mist separator **1406**. The mist separator **1406** is circular plate having an aperture. This aperture allows the low-pressure steam to pass through the plate. In one embodiment a plurality of mist separators are installed within the grooves of the steam pipe **1404**. These plates would be oriented such that the aperture is located 180° from the preceding plate. In addition, the plate nearest to the outlet port **1410** would be orientated such that the aperture was 180° from the port. In alternate embodiments the plates may include grooves on the top surface of the plates to collect water droplets. These grooves may be tapered to allow the collected water to flow off the plate and fall down towards the base of the mist eliminator assembly **1400**. The mist separator **1406** may be secured to the steam pipe **1404** using a pair of snap rings and a wave washer.

Still referring to FIGS. 14-14C, the second port **1410** may be located also in the top surface of the cap **1402** and allows the dry low-pressure steam to exit the mist eliminator assembly **1400**. See previous discussion for the exemplary embodiment concerning the size and location of the outlet port.

Still referring to FIGS. 14-14C, the third port **1412** may be located within the side wall of the cap **1402**. This port allows water removed from the low-pressure steam to exit the apparatus. The location of the port is preferably at a height where the blowdown water may exit the mist eliminator assembly **1400** without an excessive buildup of blowdown water within the assembly. In addition, the height of the port

preferably is not too low, but rather preferably is sufficient to maintain a level of blowdown water covering the outlets of the tubes. In the exemplary embodiment, a tube may be connected to port **1412** and the blowdown water may pass through a level sensor housing **108** and heat exchanger **102** before exiting the apparatus **100**.

Still referring to FIGS. 14-14C, the mist eliminator assembly **1400** may be manufactured from any material having sufficient corrosion and high temperature resistant properties. In this embodiment, the mist eliminator assembly is manufactured from stainless steel. The assembly may be manufactured from other materials including but not limited to RADEL®, stainless steel, titanium, and copper-nickel.

## COMPRESSOR

The water vapor distillation apparatus **100** may include a compressor **106**. In the exemplary embodiment the compressor is a regenerative blower. Other types of compressors may be implemented, but for purposes of this application a regenerative blower is depicted and is described with reference to the exemplary embodiment. The purpose of the regenerative blower is to compress the low-pressure steam exiting the evaporator area of the evaporator/condenser to create high-pressure steam. Increasing the pressure of the steam raises the temperature of the steam. This increase in temperature is desirable because when the high-pressure steam condenses on the tubes of the condenser area of the evaporator/condenser the thermal energy is transferred to the incoming source water. This heat transfer is important because the thermal energy transferred from the high-pressure steam supplies low-pressure steam to the regenerative blower.

The change in pressure between the low-pressure steam and the high-pressure steam is governed by the desired output of product water. The output of the product water is related to the flow rate of the high-pressure steam. If the flow rate of steam for the high-pressure steam from the compressor to the condenser area of the evaporator/condenser is greater than the ability of the condenser to receive the steam then the steam may become superheated. Conversely, if the evaporator side of the evaporator/condenser produces more steam than the compressor is capable of compressing then the condenser side of the evaporator/condenser may not be operating at full capacity because of the limited flow-rate of high-pressure steam from the compressor.

Referring now to FIGS. 15-15G, the exemplary embodiment may include a regenerative blower assembly **1500** for compressing the low-pressure steam from the

evaporator area of the evaporator/condenser. The regenerative blower assembly **1500** includes an upper housing **1502** and a lower housing **1504** defining an internal cavity as illustrated in FIG. 15C. See FIGS. 15D-G for detail views of the upper housing **1502** and lower housing **1504**. Located in the internal cavity defined by the upper housing **1502** and lower housing **1504** is an impeller assembly **1506**. The housings may be manufactured from a variety of plastics including but not limited to RYTON®, ULTEM®, or Polysulfone. Alternatively, the housings may be manufactured from materials including but not limited to titanium, copper-nickel, and aluminum-nickel bronze. In the exemplary embodiment the upper housing **1502** and the lower housing **1504** are manufactured from aluminum. In alternate embodiments, other materials may be used with preference that those materials have the properties of high-temperature resistance, corrosion resistance, do not absorb water and have sufficient structural strength. The housings preferably is of sufficient size to accommodate the impeller assembly and the associated internal passageways. Furthermore, the housings preferably provide adequate clearance between the stationary housing and the rotating impeller to avoid sliding contact and prevent leakage from occurring between the two stages of the blower. In addition to the clearances, the upper housing **1502** and the lower **1504** may be mirror images of one another.

Referring now to FIGS.15D-F, the upper housing **1502** and lower housing **1504** may have an inlet port **1510** and an outlet port **1512**. The low-pressure steam from the evaporator/condenser enters the blower assembly **1500** through the inlet port **1510**. In the exemplary embodiment, the inlet port is shaped to create a spiral flow around the annular flow channel in the upper housing **1502** and lower housing **1504**. After compressing the low-pressure steam, the higher-pressure steam is discharged from the outlet port **1512**. Between the inlet ports **1510** and the outlet ports **1512** of the upper housing **1502** and lower housing **1504** the clearances are reduced to prevent the mixing of the high-pressure steam exiting the blower assembly and the low-pressure steam entering the assembly. The exemplary embodiment may include a stripper plate **1516**. At this plate the open flow channels provided in the upper housing 1502 and lower housing **1504** allow only the high-pressure steam that is within the impeller blades to pass through to an area near the inlet port **1510**, called the inlet region.

Still referring to FIGS.15D-F, the carryover of the high-pressure steam through the stripper plate **1516** into the inlet region may irreversibly mix with the incoming low-pressure steam entering the blower assembly **1500** from the inlet port **1510**. The mixing

of the steam may cause an increase in the temperature of the incoming low-pressure steam. The high-pressure steam carryover may also block the incoming flow of low-pressure steam because of the expansion of the high-pressure steam in the inlet region. The decompression duct **1514** in the upper housing **1502** and lower housing **1504** extracts the compressed steam entrapped in the impeller blades and ejects the steam into the inlet region blocking the incoming low-pressure steam.

Still referring to FIGS.15D-F, the distance between the inlet ports **1510** and outlet ports **1512** is controlled by the size of the stripper plate **1516**. In the exemplary embodiment the stripper plate area is optimized for reducing the amount of high-pressure steam carryover into the inlet region and maximizing the working flow channels within the upper housing **1502** and lower housing **1504**.

Referring now to FIGS. 15H-K, in the exemplary embodiment the shaft **1514** is supported by pressurized water fed bearings **1516** that are pressed into the impeller assembly **1506** and are supported by the shaft **1514**. In this embodiment, the bearings may be manufactured from graphite. In alternate embodiments, the bearings may be manufactured from materials including but not limited to Teflon composites and bronze alloys.

Still referring to FIGS. 15H-K, the water supplied to the pressurized water fed bearings **1516** is preferably clean water as the water may enter the compression chamber of the blower assembly **1500**. If the water enters the compression chamber, the water will likely mix with the pure steam. Contaminated water mixing with the pure steam will result in contaminated high-pressure steam. In the exemplary embodiment product water is supplied to the bearings.

Hydrodynamic lubrication is desired for the high-speed blower bearings **1516** of the exemplary embodiment. In hydrodynamic operation, the rotating bearing rides on a film of lubricant, and does not contact the stationary shaft. This mode of lubrication offers the lowest coefficients of friction and wear is essentially non-existent since there is no physical contact of components.

Operating in the other lubrication regimes like Mixed Film Lubrication and Boundary Lubrication results in higher power loss and higher wear rates than hydrodynamic operation. In the exemplary embodiment the blower may operate having hydrodynamic lubrication, film lubrication or a combination of both. The running clearance between the rotating bearing and the stationary shaft; rotating speed of the

bearing; and lubricating fluid pressure and flow may affect the bearing lubrication mode.

Referring to FIGS. 15H-K, in a hydrodynamic bearing the limiting load factor may be affected by the thermal dissipation capabilities. When compared to an un-lubricated (or a boundary-lubricated) bearing, a hydrodynamic bearing has an additional mechanism for dissipating heat. The hydrodynamic bearing's most effective way to reject heat is to allow the lubricating fluid to carry away thermal energy. In the exemplary embodiment the bearing-feed water removes thermal energy from the bearings **1516**. In this embodiment, the volume of water flowing through the bearing are preferably sufficient to maintain the bearing's temperature within operational limits. In addition, diametrical clearances may be varied to control bearing feed-water flow rate, however, these clearances preferably are not large enough to create a loss of hydrodynamic pressure.

Still referring to FIGS. 15H-K, the amount of bearing-feed water supplied to the bearings **1516** is preferably sufficient to maintain hydrodynamic lubrication. Any excess of bearing-feed water may adversely affect the blower assembly **1500**. For example, excess water may quench the high-pressure steam unnecessarily reducing the thermal efficiency of the apparatus. Another adverse affect of excess bearing-feed water may be power loss due to shearing of the fluid water when the excess bearing-feed water is ejected outward from the impeller assembly and forced between the housing wall and the passing impeller blades.

Referring to FIG. 15L, in the exemplary embodiment, a return path **1526** for the bearing-feed water is provided within the blower to prevent excess bearing-feed water from entering the impeller buckets.

Referring back to FIGS. 15H-K, in the exemplary embodiment the bearing feed-water pump maintains a pressure of two to five psi on the input to the pressurized water fed bearings **1516**. The bearing-feed-water flow rate may be maintained by having a constant bearing-feed-water pressure. In the exemplary embodiment, the pressure of the bearing-feed water may be controlled to ensure the flow rate of bearing-feed water to bearings **1516**.

Still referring to FIGS. 15H-K, in the exemplary embodiment the impeller assembly may be driven by the motor using a magnetic drive coupling rather than a mechanical seal. The lack of mechanical seal results in no frictional losses associated with moving parts contacting one-another. In this embodiment the magnetic drive

coupling may include an inner rotor magnet **1518**, a containment shell **1520**, an outer magnet **1522**, and drive motor **1508**.

Still referring to FIGS. 15H-K, the inner magnet rotor **1518** may be embedded within a cup. In the exemplary embodiment the magnets are axially positioned. In other embodiments the magnets may be positioned radially. This cup may be manufactured from plastic or metallic materials. In some embodiments the cup material may be but is not limited to RYTON®, ULTEM®, or polysulfone. Similarly, the magnets may be manufactured from materials including but not limited to Ferrite, aluminum-nickel-cobalt, samarium cobalt and neodymium iron boron. In the exemplary embodiment the cup is attached to the impeller assembly **1500**. In the exemplary embodiment the cup is press fit onto the shaft **1514**. Other methods of attaching the cup may include but are not limited to keyseat and setscrews.

Still referring to FIGS. 15H-K, the magnetic coupling shell **1520** is positioned between inner rotor magnet **1518** and the outer rotor magnet **1522**. The magnetic coupling shell **1520** is the pressure vessel or the containment shell for the blower assembly **1500**. This shell seals the steam that is being compressed within the blower assembly **1500** preventing the steam from escaping into the surrounding environment.

Still referring to FIGS. 15H-K, Eddy current losses may occur because the shell **1520** is located between the inner rotor magnet **1518** and the outer rotor magnet **1522**. If the shell **1520** is electrically conductive then the rotating magnetic field may cause electrical currents to flow through the shell we may cause a loss of power. Conversely, a shell **1520** manufactured from a highly electrically-resistive material is preferred to reduce the amount of Eddy current loss. In the exemplary embodiment titanium may be used for manufacturing the magnetic coupling shell **1520**. This material provides a combination of high-electrical resistivity and corrosion resistance. Corrosion resistance is preferred because of the likelihood of contact between the bearing-feed water and the shell **1520**. In other embodiments the shell **1520** may be manufactured from plastic materials having a higher electrical resistivity and corrosion resistance properties. In these alternate embodiments the shell **1520** may be manufactured from material including but not limited to RYTON®, ULTEM®, polysulfone, and PEEK.

Still referring to FIGS. 15H-K, the outer rotor magnet **1522** may be connected to a drive motor **1508**. This motor rotates the outer rotor magnet **1522** causing the inner rotor magnet to rotate allowing the impeller assembly **1506** to compress the low-pressure steam within the cavity defined by the upper housing **1502** and the lower

housing **1504**. In the exemplary embodiment the drive motor may be an electric motor. In alternate embodiments the drive may be but is not limited to internal combustion or Stirling engine.

Still referring to FIGS. 15H-K, the blower assembly **1500** may be configured as a two single-stage blower or a two-stage blower. In the operation of a two single-stage blower the incoming low-pressure steam from the evaporator side of the evaporator/condenser is supplied to both the inlet ports of the two separate stages of the blower simultaneously. The first stage may be at the bottom between the lower housing **1504** and the impeller assembly **1506** and the second stage may be at the top between the upper housing **1502** and the impeller assembly **1506**. As the impeller assembly **1506** rotates, the incoming low-pressure steam from the inlet port **1510** of both stages is compressed simultaneously and the high-pressure steam exits from the outlet port **1512** of the upper housing **1502** and the outlet port **1512** of the lower housing **1504**.

Still referring to FIGS. 15H-K, in contrast the two-stage blower has two distinct compression cycles. During the first compression cycle the low-pressure steam from the evaporator of the evaporator/condenser is supplied to the inlet **1514** of the lower housing. The compressed steam from the first stage exits through the outlet port **1516** in the lower housing and is supplied to the inlet port **1510** of the upper housing **1502**. This steam compressed in the first stage is compressed again during the second stage. After the second compression cycle the steam may exit the blower assembly **1500** through the outlet port **1512** of the upper housing **1502** at an increased pressure.

For a given blower design, both the two single-stage blower and the two-stage blower configurations have a unique pressure flow curves. These curves indicate that the two single-stage blower produces a higher flow rate of steam compared to the two-stage blower that produces higher pressure differential. Based on the system operating differential pressure the flow rate and the efficiency of the blower is dependant on the flow characteristics of the blower. Depending on the differential pressure across the blower assembly **1500**, one configuration may be preferred over the other. In the exemplary embodiment, the blower assembly **1500** has a two Single-stage blower configuration.

Now referring to FIGS. 16-16A, within the internal cavity defined by the upper housing **1502** and lower housing **1504** is the impeller assembly **1600** (also identified as **1506** of FIG. 15). The impeller assembly **1600** includes a plurality of impeller blades on each side of the impeller **1602** and a spindle **1604**. In the exemplary embodiment the

impeller **1602** may be manufactured from Radel® and the impeller spindle **1604** may be manufactured from aluminum. In alternate embodiments these parts may be manufactured from materials including but not limited to titanium, PPS, ULTEM®. Other materials may be used to manufacture these parts with preference that these materials have high-temperature resistant properties and do not absorb water. In addition, impeller spindle **1604** may have passages for the return of the bearing-feed water back to the sump. These passages prevent the bearing-feed water from entering the impeller buckets.

Still referring to FIGS. 16-16A, the blades are designed on each side of the impeller **1602** periphery to produce a series of helical flows as the impeller is rotating. This flow causes the steam to repeatedly pass through the blades for additional energy as the steam flows through the open annular channel. The number of blades and the bucket volume may be designed to optimize the desired flow rate and the pressure differential. The number of blades and bucket volume is inversely proportional to each other, thus increasing the number of blades creates higher pressure differential but lower flow rate. The labyrinth grooves on the outer periphery of the impeller **1602** prevents steam leakage across the stages of the blower assembly **1500** thereby increasing the blower efficiency.

Referring back to FIGS 15H-K, the shaft **1514** is attached to the upper housing **1502** and lower housing **1504** and is stationary. In the exemplary embodiment the shaft **1514** may be manufactured from titanium. In other embodiments the shaft **1514** may be manufactured from materials including but not limited to aluminum oxide, silicon nitride or titanium, and stainless steel having coatings for increasing wear resistance and corrosion resistance properties. In addition the shaft **1514** may have passages channeling the bearing-feed water to the bearings **1516**.

Still referring to FIGS. 15H-K, the blower assembly **1500** in a two-stage blower configuration may create a downward axial thrust force. This force is generated because the second stage at the top of the impeller assembly **1506** is at a higher pressure compared to the first stage that is at the bottom of the impeller assembly **1506**. In an alternate embodiment, this thrust force may be balanced by an equal and opposite magnetic force created by offsetting the inner rotor magnet **1518** and the outer rotor magnet **1522**. This configuration prevents excessive wear of the thrust face of the lower pressurized water fed bearing **1516**.

Referring now to FIGS. 17-17E, an alternate regenerative blower embodiment **1700** is shown. This embodiment may include an impeller housing assembly **1702**, a mounting plate **1704**, and a mounting flange **1706**. See FIGS. 17B-D for cross-section views of regenerative blower assembly **1700**. See also FIG. 17E for an exploded view of the regenerative blower assembly **1700**.

Referring now to FIGS. 17-17E, the mounting plate **1704** connects the mounting flange **1706** to the impeller housing assembly **1702**. The mounting plate also provides ports that provide fluid pathways into the lower housing **1708** of the impeller housing assembly **1702** as shown on FIG. 17E. In addition, the mounting plate provides passages for the bearing-feed water to exit the blower assembly **1700**.

Now referring to FIGS. 17F-I, the impeller housing assembly **1702** may include a lower housing **1708**, an impeller assembly **1710**, and an upper housing **1712**. Also see FIGS. 17H-I for cross-section views of the impeller housing assembly **1702**.

Referring now to FIGS. 17F-I, the lower housing **1708** and upper housing **1712** define an interior cavity containing the impeller assembly **1710**. This cavity provides a volume for the impeller to compress the incoming low-pressure steam. Steam may enter the impeller housing assembly through inlet ports located within the lower housing **1708** and the upper housing **1712**. After the low-pressure steam is compressed by the impeller assembly **1710**, the high-pressure steam may exit through outlet ports located in the lower housing **1708** and the upper housing **1712**. See FIGS. 17J-K for a detail view of the lower housing **1708**. In addition the lower housing **1708** and the upper housing **1712** may be manufactured from but not limited to aluminum, titanium, PPS, and ULTEM®.

Still referring to FIGS. 17F-I, the upper housing **1712** may include an access cover **1714** attached to the top surface of the housing. See FIG. 17L showing a top view of the upper housing **1712** with the access cover **1714** installed. This cover allows for access to the ports located within the upper housing cover. See FIG. 17M providing a top view of the upper housing **1712** without the access cover **1714** installed. This view illustrates the inlet and outlet ports located within the upper housing **1712**.

Referring now to FIG. 17N, the lower housing **1708** and the upper housing **1712** may include a decompression duct **1716** and a strip plate **1718** on the inner surface of the housings. These features perform similar functions as those described in the exemplary embodiment of the blower assembly **1500**.

Referring now to FIGS. 18-18A, the inner cavity defined by the lower housing **1708** and upper housing **1712** contains the impeller assembly **1800** (also identified as **1710** of FIG. 17). This assembly may include a spindle **1802** and impeller having blades **1804** as shown on FIGS. 18-18A. As the low-pressure steam enters the inner cavity of the impeller housing **1702**, the impeller assembly **1800** compresses the steam as the assembly is rotated.

Still referring to FIGS. 18-18A, the drive motor provides the rotational energy to rotate the impeller **1804** and blades. Located between the inner surface of the spindle and the shaft may be bearings **1716**. These bearings support the shaft and allow the impeller **1804** to rotate freely. The bearings **1716** may be located near the ends of the spindle **1802**.

In alternate embodiments of the apparatus, low-pressure steam may be compressed using a liquid ring pump as described in U.S. Patent Application Publication No. US 2005/0016828 A1 published on January 27, 2005 and entitled "Pressurized Vapor Cycle Liquid Distillation," the contents of which are hereby incorporated by reference herein.

## LEVEL SENSOR ASSEMBLY

Referring now to FIG. 19, the exemplary embodiment of the water vapor distillation apparatus **100** may also include a level sensor assembly **1900** (also identified as **108** in FIG. 1). This assembly measures the amount of product and/or blowdown water produced by the apparatus **100**.

Referring now to FIGS. 19-19A, the exemplary embodiment of the level sensor assembly **1900** may include a settling tank **1902** and level sensor housing **1904**. The settling tank **1902** collects particulate carried within the blowdown water prior to the water entering into the blowdown level sensor tank **1912**. The tank removes particulate from the blowdown water by reducing the velocity of the water as it flows through the tank. The settling tank **1902** defines an internal volume. The volume may be divided nearly in half by using a fin **1905** extending from the side wall opposite the drain port **1908** to close proximity of the drain port **1908**. This fin **1905** may extend from the bottom to the top of the volume. Blowdown enters through the inlet port **1906** and must flow around the fin **1905** before the water may exit through the level sensing port **1910**. As the blowdown enters into the body of the vessel the velocity decreases due to the increase in area. Any particles in the blowdown may fall out of suspension due to the reduction in velocity. The settling tank **1902** may be manufactured out any material

having corrosion and heat resistant properties. In the exemplary embodiment the housing is manufactured from RADEL®. In alternate embodiments the settling tank **1902** may be manufactured from other materials including but note limited to titanium, copper-nickel and stainless steel.

Still referring to FIGS. 19-19A, the settling tank **1902** may have three ports an inlet **1906**, a drain **1908** and a level sensor port **1910**. The inlet port **1906** may be located within the top surface of the settling tank **1902** as shown on FIGS. 19A-B and may be adjacent to the separating fin **1905** and opposite the drain port **1908**. This port allows blowdown water to enter the tank. The drain port **1908** may be located in the bottom of the settling tank **1902** as shown on FIGS. 19A-B. The drain port **1908** provides access to the reservoir to facilitate removal of particulate from the tank. In the exemplary embodiment, the bottom of the tank may be sloped towards the drain as illustrated in FIG. 19B. The level sensor port **1910** may be located within the top surface of the tank as illustrated in FIG. 19A and also adjacent to the separating fin **1905** but on the opposite side as the inlet port **1906**. This port provides a fluid pathway to the blowdown level sensor reservoir **1912**. A fourth port is not shown in FIG. 19A. This port allows blowdown water to exit the level sensor assembly **1900** and enter the heat exchanger. This port may be located within one of the side walls of the upper half of the settling tank **1902** and away from the inlet port **1906**.

Still referring to FIGS. 19-19A, in the exemplary embodiment a strainer may be installed within the flow path after the blowdown water exits the blowdown level sensor reservoir **1912** and settling tank **1902**. The strainer may collect large particulate while allowing blowdown water to flow to other apparatus components. The strainer may be manufactured from material having corrosion resistant properties. In the exemplary embodiment the strainer is manufactured from stainless steel. In addition, the filter element may be removable to support cleaning of the element. The strainer removes particulate from the blowdown water to limit the amount of particulate that enters the heat exchanger. Excess particulate in the blowdown water may cause the inner tubes of the heat exchanger to clog with scale and sediment reducing the efficiency of the heat exchanger. In addition, particulate may produce blockage preventing the flow of blowdown water through the heat exchanger.

Still referring to FIGS. 19-19A, the settling tank **1902** is in fluid connection with the level sensor housing **1904**. This housing may have three interior reservoirs including but not limited to a blowdown level sensor reservoir **1912**, a product level

sensor reservoir **1914**, and a bearing feed-water reservoir **1916**. The blowdown level sensor reservoir **1912** is independent of the other reservoirs to prevent contamination from mixing the product water with the blowdown water. The level sensor housing **1904** may be manufactured out any material having corrosion and heat resistant properties. In the exemplary embodiment the housing is manufactured from RADEL®. In other embodiments the housing may be manufactured from other materials including but not limited to titanium, copper-nickel and stainless steel. In other embodiments the housing may be shaped differently with preference that the ball float may have a range of movement of 45 degrees and during this movement there is a constant change in volume of the fluid level.

Still referring to FIGS. 19-19A, within the level sensor housing **1904** there is a blowdown level sensor reservoir **1912**. This reservoir is in fluid connection with the settling tank **1902** through measuring port **1910** located within the top surface of the tank **1902**. The reservoir provides a location where the rate of blowdown water generated by the apparatus may be measured using a level sensor **1918**. As the blowdown water fills the settling tank, some of that water flows through the measuring port **1910** into the blowdown level sensor reservoir **1912**. In addition, a vent port **1923** may be located within the top of the reservoir. This port allows air to escape the reservoir allowing blowdown water to fill the cavity. The volume of the reservoir must be sufficient to maintain a level of water. Housings having too small volume may quickly fill and drain adversely affecting the function of the level sensors. In contrast, reservoirs having a large volume may have slower level sensor response times due to the small fluid level height changes for a given increase or decrease in volume. A larger volume may also dampen out the any fluctuations in the water level produced by the operation of the apparatus. Referring now also to FIG. 73, in some embodiments, a blowdown drain **7300** fluid pathway may be included and in fluid connection with the level sensor assembly. In some embodiments, the blowdown drain **7300** fluid pathway may be used to facilitate the cleaning or flushing of the apparatus **100**. In some embodiments, the blowdown drain **7300** fluid pathway may be sealed to the outside environment by a valve, for example, but not limited to, a manual ball valve. In some embodiments, the valve may be a non-manual valve, for example, an actuated valve controlled by the control system, and in some of these embodiments, the cleaning and flushing may be at least partially automated.

Still referring to FIGS. 19-19A, the product level sensor reservoir **1914** may be located next to the blowdown level sensor reservoir **1912**. The product level reservoir **1914** has an inlet port **1920** and an outlet port **1922**. Product water enters the reservoir through the inlet port **1920** and exits the reservoir through the outlet port **1922**. The outlet port **1922** may be located below the low end measurement point of the level sensor to improve flow of water out of the reservoir. Similarly, the inlet port 1920 may be located below the low end measurement point of the level sensor to minimize disruption caused by the incoming water. In the exemplary embodiment the inlet port **1920** and outlet port **1922** are located on the side of the level sensor housing **1904** as shown in FIG. 19A. This reservoir provides a space for measuring the rate of product being generated by the apparatus. In addition, a vent port **1923** may be located within the top of the reservoir. This port allows air to escape the reservoir allowing product water to fill the cavity.

Still referring to FIGS. 19-19A, the product level sensor reservoir **1914** is in fluid connection with the bearing feed-water reservoir **1916**. An external port **1924** provides a fluid pathway for the product water to flow between the product level sensor reservoir **1914** and the bearing feed-water reservoir **1916** shown on FIG. 19C. Product water enters the bearing feed-water reservoir **1916** through the external port **1924**. In addition, the bearing feed-water reservoir **1916** has a supply port **1926** and a return port **1928** shown on FIG. 19C. The supply port **1926** provides a fluid pathway to lubricate the bearings within the regenerative blower assembly. Similarly, a return port **1928** provides a fluid pathway for the product water to return from lubricating the bearings of the regenerative blower assembly. The supply and return ports may be located on the side of the level sensor housing **1904** as shown in FIG. 19C.

Still referring to FIGS. 19-19A, to monitor the amount of product water within the bearing feed-water reservoir **1916** an optical level sensor may be installed. In the exemplary embodiment, the optical level sensor may be located at approximately 2/3 height in the bearing feed-water reservoir **1916**. This sensor senses when water is present within the reservoir indicating that there is sufficient water to lubricate the bearings. The sensor may be installed by threading the sensor into the level sensor housing **1904**. The sensor may include an o-ring to provide a water-tight seal. In other embodiments the sensor may be but is not limited to conductance sensor, float switches, capacitance sensors, or an ultrasonic sensor.

Referring now to FIGS. 19D-F, an alternate level sensor housing **1930** having two reservoirs is shown. Within the level sensor housing **1930** there is a blowdown level sensor reservoir **1932**. This reservoir is similar to and performs the same function as the previously described blowdown reservoir **1912** within the level sensor housing **1904**. In contrast, the product level sensor reservoir **1934** now contains product water to feed the bearings of the regenerative blower. The bearing feed-water reservoir **1916** of level sensor housing **1904** is eliminated from this configuration. Instead, product water is withdrawn from the product level sensor reservoir to supply water for the regenerative blower.

Still referring to FIGS. 19D-F, the product level sensor reservoir **1934** may have an inlet port **1935**, an outlet port **1936**, a return port **1938** and a supply port **1940**. The inlet port **1935** allows product water to enter the reservoir. Similarly, the outlet port **1936** provides a fluid pathway for product water to leave the housing. Furthermore, the supply port **1940** allows product water to leave the reservoir to lubricate the bearings of the regenerative blower. After passing through the bearings of the regenerative blower, product water may re-enter the product level sensor housing through the return port **1938**. These ports may be located any where in the housing, but locating the supply port **1940** and the return port **1938** near the bottom of the housing may limit any adverse effect on the function of the level sensor.

Referring now to FIGS. 19G-H, a sensor **1942** may be positioned on the outside of the level sensor housing **1904** to receive input from the level sensor assembly **1918**. Upon receiving input from the level sensor assembly **1918** the sensor **1942** may signal that the water level in the tank is within a particular range or at a particular level. In the exemplary embodiment the sensor may be a continuous analogue sensor. This type of sensor provides continuous feedback as to the position of the level sensor assembly **1918**. When the magnets within the level sensors change their position, a change in voltage occurs that is measured and used to determine the location of the sensor. Other embodiments may include but are not limited to a hall sensor or reed switch. FIG. 19H illustrates one possible alternate embodiment for a level sensor assembly including a set of float magnets **1944** and position magnets **1946**. The position magnets **1946** are attached to the side of the level sensor housing **1904**.

Now referring to FIGS. 20-20A, within the blowdown level sensor reservoir **1912** and the product level sensor reservoir **1914** are level sensors **2000** (also identified

as **1918** of FIGS. 19A and 19E). These sensors may include a base **2002**, an arm **2004**, and a float ball **2006**.

Referring still to FIGS. 20-20A, the exemplary embodiment of the level sensors **2000** may include a base **2002** supporting the arm **2004** and the float ball **2006**. The assembly also includes two magnets (not shown). The base is connected to the arm and float ball assembly and the assembly pivots on a small diameter axial (not shown). In addition the base **2002** holds two magnets. These magnets are located 180 degrees from one another and are located on face of the base **2002** and parallel to the pivot. In addition, there magnets may be positioned coaxially to the pivot point within the base **2002**. In the exemplary embodiment the magnets may be cylinder magnets having an axial magnetization direction.

Referring still to FIGS. 20-20A, the level sensors **2000** measure the rotation of the arm and ball assembly with respect to the pivot. In the exemplary embodiment, the maximum angle of displacement is 45 degrees. In this embodiment the level sensors are installed to prevent the float ball **2006** from being positioned directly below the pivot. In other embodiments the maximum angle of displacement may be as large as 80 degrees. The sensor may monitor the magnets through the wall of the housing. This configuration allows the sensors not to be exposed to corrosive blowdown water and to seal the level sensor housing. The base may be manufactured from any material having corrosion resistant, heat resistant and non-magnetic properties. In the exemplary embodiment the base **2002** is manufactured from G10 plastic. In alternate embodiments the base **2002** may be manufactured from other materials including but not limited to RADEL®, titanium, copper-nickel and fiberglass laminate.

Still referring to FIGS. 20-20A, attached to the base **2002** is an arm **2004**. The arm **2004** connects the base **2002** with the float ball **2006**. In the exemplary embodiment the arm **2004** is manufactured of G10 plastic material. Other materials may be used to manufacture the arm **2004** with preference that those materials have sufficient high temperature resistant properties. Other materials may include, but are not limited to stainless steel, plastic, RADEL®, titanium, and copper-nickel. The length of the arm is governed by the size of the level sensor reservoirs. In addition, the exemplary embodiment has a plurality of apertures located along and perpendicular to the arm's longitudinal axis. These apertures reduce the weight of the arm and allow the arm to be more sensitive to level changes.

Still referring to FIGS. 20-20A, affixed to the other end of the arm **2004** is a float ball **2006**. The float ball **2006** provides surface area for the flow of water to contact. The forces applied to the float ball **2006** by the water cause the level sensor assembly **2000** to pivot about the small diameter shaft. This change in position of the arm will indicate the amount of water in the apparatus. The float ball may be manufactured from any material having corrosion and thermal resistant properties. In addition, the material preferably has a low rate of water absorption. In the exemplary embodiment the float ball is manufactured from hollow stainless steel. For applications where the source water is highly concentrated, such as sea water, the float ball **2006** may be manufactured from any highly corrosion resistant material including but not limited to plastic, titanium and copper-nickel. Furthermore, the float ball **2006** is preferably of the proper size to be positioned within the level sensor housing **1904**, such that the float is capable of freely moving. In addition, the size of the float ball **2006** is governed by the size of the level sensor reservoirs.

Referring now to FIGS. 21-21A, connected to the supply port **1926** of the bearing feed-water reservoir **1916** may be a bearing feed-water pump **2100** (also identified as **110** on FIGS. 1-1A). The pump **2100** enables the product water to flow from the bearing feed-water reservoir **1916** to the regenerative blower. In the exemplary embodiment, the flow rate is 60 ml/min with a pressure ranging from 2 psi to 2-1/4 psi. Any type of pump may be used with preference that the pump can supply a sufficient quantity of water to maintain the proper lubricating flow to the bearings within the regenerative blower. In addition, the pump **2100** preferably is heat resistant to withstand the high temperature of the surrounding environment and of the high-temperature product water passing through the pump. In the exemplary embodiment the bearing feed-water pump 110 is a GOTEC linear positive displacement pump, model number ETX-50-VIC. In alternate embodiments, other pump types such as a centrifugal pump may be used with preference that the pump is capable of operating in high temperatures.

## CONTROLS

The apparatus may also include a control manifold having a plurality of control valves for the different water flow paths. Typically, this manifold may include a control valve within the inlet piping for the source water to controls the amount of water that enters the apparatus. At excessive pressures the control valve could fail to open or once open may fail to close thus a regulator may be included in inlet piping to regulate the pressure of the source water.

Similarly, the manifold may also include a control valve within the outlet piping carrying blowdown water out of the apparatus. This valve may allow the operator to control the amount of blowdown water leaving the apparatus.

The control manifold may also include a control valve within the outlet piping for the product water. This valve may allow the operator to control the amount of product water leaving the apparatus. In the exemplary embodiment, there is one control valve for each section of outlet piping. Similarly, the apparatus includes a vent valve to release gaseous compounds from the evaporator/condenser. The vent valve maintains operating conditions of the apparatus by venting off small amounts of steam. Releasing steam prevents the apparatus from overheating. Similarly, releasing steam also prevents the buildup of compounds in the condenser space that may prevent the apparatus from functioning.

Typically, the control valves may be same type. In the exemplary embodiment, the controls are solenoid type valves Series 4BKR manufactured from SPARTAN SCIENTIFIC, Boardman, Ohio 44513, model number 9-4BKR-55723-1-002. In alternate embodiments, the controls may be but are not limited to proportional valves. The control valves are electronically operated using an electrical input of zero to five volts.

Moreover, the apparatus may include a backpressure regulator as described in U.S. Patent Application Publication No. US 2005/0194048 A1 published on September 8, 2005 entitled "Backpressure Regulator," the contents of which are hereby incorporated by reference herein.

The water vapor distillation apparatus may include a voltage regulator. Typically, the apparatus may receive single-phase power provided from a traditional wall outlet. In other countries, however, the voltage may differ. To account for this difference in voltage, a voltage regulator may be included in the apparatus to ensure the proper type of voltage is supplied to the electrical components of the apparatus.

In addition, a battery may be included within the system to provide electrical energy to the apparatus. When electrical energy is supplied from a battery the apparatus will preferably include an electrical inverter to change incoming electricity from direct current to alternating current. In other embodiments, the apparatus may receive electrical energy from a Stirling and internal combustion engine. These embodiments may also require an electrical inverter. In other embodiments, the apparatus may

include a boost loop to increase the amount of voltage supplied to the apparatus to power the electrical components.

## METHOD OF DISTILLING WATER

Also disclosed herein is a method of water vapor distillation including the steps of straining the source water, heating the source water using a heat exchanger, transforming the source water into low-pressure steam, removing water from the source vapor to create dry low-pressure steam, compressing the dry low-pressure steam into high-pressure steam, and condensing the high-pressure steam into product water.

Referring now to FIGS. 22-22A, source water is contaminated water that is transformed into a vapor and later condenses into clean and pure water called, product water. FIG. 22 illustrates the source water fluid paths within the apparatus disclosed previously. The source water enters the apparatus through an inlet tube connected to the heat exchanger as illustrated in FIG. 22A. Typically, a pump may be installed to cause the source water to flow through the inlet tube into the heat exchanger. Within the inlet tube there may be a strainer **2202** installed between where the source water enters the tube and the connection with the heat exchanger, see FIG. 22A. In other embodiments, a regulator **2204** may be positioned within the inlet tube to regulate the flow of the source water into the apparatus. Similarly, in one embodiment, a valve **2206** may be positioned within the inlet tube to isolate the apparatus from the water source.

Referring still to FIGS. 22-22A, in operation, source water passes through a strainer **2202** to remove large particulates. These large particulates may adversely affect the operation of the apparatus, by clogging the inlet and blowdown valves or the inner tubes of the heat exchanger. In addition, particulate may be deposited onto the tubes of the evaporator/condenser reducing the efficiency of the apparatus. In the exemplary embodiment the strainer **2202** is located before the control valves. In other embodiments the strainer may be positioned before the inlet pump (not shown). In the exemplary embodiment the strainer **2202** has a 50 micron user-cleaner unit. In alternate embodiments the apparatus may not include a strainer **2202**. After the source water passes through the strainer **2202**, the water enters the heat exchanger **2208**.

Referring now to FIG. 22B, upon entering the heat exchanger **2208**, the source water may fill the outer tube of the heat exchanger **2208**. In the exemplary embodiment, the heat exchanger is a counter-flow tube-in-tube heat exchanger. The source water enters the heat exchanger at approximately ambient temperature. Conversely, the product and blowdown water enter the heat exchanger having temperature greater than

ambient. The source water enters the heat exchanger at one end and the product and blowdown water enter the heat exchanger at the opposite end. As the source water flows through the heat exchanger the high thermal energy of the product and blowdown water is conducted outwardly from the inner tubes of the heat exchanger to the source water. This increase in the temperature of the source water enables the water to more efficiently change into steam in the evaporator/condenser.

Referring now to FIGS. 22C-D, once the source water passes through the counter-flow tube-in-tube heat exchanger, the water exits the heat exchanger and enters the regenerative blower motor cooling loop. During operation, the regenerative blower motor **2210** creates thermal energy. This thermal energy must be removed from blower motor **2210** for the blower to operate properly. As the source water passes through the blower motor cooling loop the thermal energy created by the blower motor is transferred to the source water. The heat transfer allows the blower motor to maintain a lower operating temperature and raises the temperature of the source water. The higher temperature of the source water increases the efficiency of the apparatus, because less energy is required to produce the phase change of the source water to a vapor. The source water leaves the regenerative blower motor cooling loop enters the evaporator/condenser through the sump **2212**, illustrated in FIG. 22E.

Referring now to FIGS. 23-23A, also present in the apparatus is highly concentrated source water, called blowdown water. This water removes particulate from the apparatus to prevent scaling on the tubes of the evaporator/condenser. This fluid may contain any non-volatile contaminants that were present in the source water. These contaminants may include but are not limited to be scale from foulants, heavy metals or organic compounds. Specifically, these foulants may include but not limited to calcium carbonate, magnesium carbonate In addition, blowdown water transfers thermal energy to the source water when passing through the heat exchanger. FIG. 23 shows the blowdown water fluid paths within the apparatus disclosed previously. The blowdown water is collected in the steam chest **2302** as shown in FIG. 23A. As the low-pressure water vapor passes through the steam chest **2302**, water droplets are separated from the water vapor. These droplets accumulate in the bottom of the steam chest **2302** and are added to the existing blowdown water. As the level of blowdown water increases, the water exits the steam chest **2302** through a port. Through this port, the blowdown water leaves the steam chest **2302** and enters the level sensor housing **2304**, illustrated in FIG. 23A.

Referring now to FIGS. 23B-C, the blowdown water enters the level sensor housing **2304** and fills the settling tank **2306**. As the blowdown water passes through the settling tank **2306** particulate within the water settles to the bottom of the tank and thus separating the water from the particulate. Separating the particulate from the water prevents the particulate from entering the heat exchanger. The heat exchanger may be adversely affected by the presence of particulate in the water. Particulate may collect in the inner tubes of the heat exchanger causing the heat exchanger to have a lower efficiency. Particulate may reduce flow of blowdown through the inner tubes reducing the amount of thermal energy capable of being transferred to the source water. In some instances, the collection of particulate may produce a blockage within the inner tubes preventing the flow of blowdown water through the heat exchanger. As blowdown water fills the settling tank **2306**, the water may also fill the blowdown level sensor reservoir **2308**, illustrated in FIG. 23C.

Referring now to FIGS. 23D-G, upon exiting the level sensor housing **2304**, the blowdown water may pass through a strainer **2310** before entering the heat exchanger **2312** shown on FIG. 23E. The strainer **2310** removes particulates within the blowdown water that remain after flowing through the settling tank **2306** of the level sensor housing **2304**. Removing particulates from the blowdown water reduces particulate build-up in the heat exchanger and valves within the system. The blow down water enters the heat exchanger **2312** fills one of the inner tubes as shown in FIG. 23E. The water fills the heat exchanger **2312** as shown in FIG. 23F. As the blowdown water passes through the heat exchanger, thermal energy is conducted from the higher temperature blowdown water to the lower temperature source water through the tube containing the blowdown water. The blowdown water exits the heat exchanger illustrated on FIG. 23G. After leaving the heat exchanger, blowdown fluid may pass through a mixing can **2314** to prevent steam being released from the apparatus potentially harming a person or adjacent object. Steam may be periodically vented from the condenser space to maintain the apparatus energy balance. Similarly, gaseous vapors (ex. volatile organic compounds, air) must be purged from the condenser space to maintain proper operation of the apparatus. Both the steam and gaseous vapors are released into the mixing can **2314** having low-temperature blowdown water. By mixing the steam into the blowdown water the steam condenses allowing for steam to be released safely. In other embodiments, there may be a valve positioned in the tubing

connecting the heat exchanger **2312** and mixing can **2314** to isolate the mixing can from the apparatus or adjust the flow rate of the blowdown water exiting the apparatus.

Referring now to FIGS. 24-24A, product water is formed when high-pressure steam condenses when contacting the outer surface of the tubes within the evaporator/condenser. FIG. 24 shows the product water fluid paths within the apparatus disclosed previously. The product water is created in the evaporator/condenser **2402** as shown in FIG. 24A. As the high-pressure steam condenses against the outer surface of the tubes of the evaporator/condenser forming water droplets. These droplets accumulate in the bottom of the evaporator/condenser **2402** creating product water. As the level of product water increases, the water exits the evaporator/condenser **2402** through a port and enters the level sensor housing **2404**, illustrated in FIG. 24A.

Referring now to FIGS. 24B-24E, the product water may enter the level sensor housing **2404** through a port connected to the product level sensor reservoir **2406** shown on FIG. 24B. This reservoir collects incoming product water and measures the amount of water created by the apparatus. The water exits the product level sensor reservoir **2406** and enters the heat exchanger **2408** illustrated in FIG. 24C. While passing through the heat exchanger **2408**, the high-temperature product water transfers thermal energy to the low-temperature source water through the inner tubes of the heat exchanger **2408**. FIG. 24D illustrates the product water passing through the heat exchanger **2408**. After passing through the heat exchanger **2408**, the product water exits the apparatus as illustrated in FIG. 24E. In the exemplary embodiment the apparatus may include a product-divert valve **2410** and product valve **2412**. The product valve **2412** allows the operator to adjust the flow rate of product water leaving the apparatus. Typically, the once the reservoir is 50 percent full, then the product valve **2412** is cycled such that the amount of water entering the reservoir is equal to the amount leaving the reservoir. During initial start-up of the system the first several minutes of production the product water produced is rejected as waste by opening the product-divert valve **2410**. Once it has been determined that the product is of sufficient quality the product-divert valve **2410** closes and the product valve **2412** begins operation.

Referring now to FIGS. 24F-24H, as product water fills the product level sensor reservoir **2406**, water may also enter the bearing feed-water reservoir **2410**. The bearing feed-water reservoir **2410** collects incoming product water for lubricating the bearings within the regenerative blower **2412**. Product water exits the bearing feed-water tank **2410** and may enter a pump **2414** as shown in FIG. 24G. The pump **2414** moves the

product water to the regenerative blower. After leaving the pump **2414**, the product water enters the regenerative blower **2412** illustrated on FIG. 24H.

Referring now to FIGS. 24H-24I, upon entering the blower **2412**, the product water provides lubrication between the bearings and the shaft of the blower. After exiting the regenerative blower **2412**, the product water may re-enter the level sensor housing **2404** through the bearing feed-water reservoir **2410**, see FIG. 24I.

Now referring to FIGS. 25-25C, to support the flow of the water throughout the apparatus vent paths may be provided. These paths support the flow of the water through the apparatus by removing air or steam from the apparatus. The vent paths are shown in FIG. 25. FIG. 25A illustrates a vent path from the blowdown level sensor reservoir **2502** to the steam chest **2504** of the evaporator/condenser **2508**. This path allows air within the reservoir to exit allowing more blowdown water to enter the reservoir. Similarly, FIG. 25B illustrates a vent path from the product level sensor reservoir **2506** to the evaporator/condenser **2508**. This path allows air within the reservoir to exit allowing product water to enter the reservoir. Finally, FIG. 25C shows a vent path from the condenser area of the evaporator/condenser **2508** to allow air within the apparatus to exit the apparatus to the surrounding atmosphere through a mixing can **2510**. In addition, this vent path assists with maintaining the apparatus' equilibrium by venting small quantities of steam from the apparatus.

Referring now to FIG. 26, in operation, source water enters the sump **2602** of the evaporator/condenser **2608** in the manner described in FIGS. 22-22E. When source water initially enters the sump **2602**, additional thermal energy may be transferred to the water using a heating element. Typically, the heating element may be used during initial start up of the water vapor distillation apparatus. Otherwise the heater will not typically be used. As the amount of source water in the sump increases, the water flows out of the sump and into the tubes **2604** of the evaporator/condenser through ports within a plate **2606** positioned between the sump **2602** and the evaporator/condenser **2608**, illustrated in FIG. 26. During initial start-up of the apparatus, the evaporator section of the evaporator/condenser **2608** is flooded with source water until there is sufficient amount of water in the blowdown level sensor reservoir. After initial start-up the tubes **2604** remain full of source water.

Referring now to FIGS. 26A-26E, once in the tubes **2604**, the source water is heated from conduction of thermal energy through the tube walls from the high-pressure steam present on the outside of the tubes **2604**. FIG. 26A illustrates the wet low-

pressure steam flowing through the tubes **2604** of the evaporator/condenser **2608**. The wet low-pressure steam travels through the tubes **2604** of the evaporator/condenser **2608** and enters the steam chest **2610** illustrated in FIG. 26B. As steam flows through the interior of the steam chest **2610**, the water droplet within the steam are separated from the steam. These droplets collect at the base of the steam chest **2610** and are added to the blowdown water already present in the base, see FIGS. 26C-D. Blowdown water flows out of the apparatus in manner described in FIGS. 23-23G. The dry low-pressure steam exits the steam chest **2610** and enters the regenerative blower **2612** as shown on FIGS. 26E-F.

Now referring to FIGS. 26F-H, once in the regenerative blower **2612**, the dry low-pressure steam is compressed creating dry high-pressure steam. After the dry steam is compressed, the high-pressure steam exits the regenerative blower **2612** and enters the steam tube **2614** of the steam chest **2610**. See FIGS. 26G-H illustrating the steam exiting the blower **2612** and entering the steam tube **2614** of the steam chest **2610**.

Now referring to FIGS. 26H-J, the steam tube **2614** is in fluid connection with the inner cavity of the evaporator/condenser **2608**. The steam tube **2614** provides an isolated pathway for the steam to enter the condenser side of the evaporator/condenser **2608** from the blower **2612**. The high-pressure steam is isolated to maintain the pressure of the steam and to ensure that the steam has no contaminants. The dry high-pressure steam exits the steam tube **2614** of the steam chest **2610** and enters the inner cavity of the evaporator/condenser **2608**. See FIG. 26I showing the inner cavity of the evaporator/condenser **2608** containing high-pressure steam. As the high-pressure steam contacts the outer surfaces tubes **2604** of the evaporator/condenser **2608**, the steam transfers thermal energy to the tubes **2604**. This energy is conducted through the tube walls to the source water located within the tubes **2604**. When the energy is transferred from the steam to the tube walls, the steam condenses from a vapor to a fluid. This fluid is known as product water. As water droplets form on the outside of the tube walls, these droplets flow down to the base of the evaporator/condenser **2608**. See FIG. 26J showing the formation of product water within the inner cavity of the evaporator/condenser **2608**. When the amount of product water within the cavity is sufficient, product water may flow out of the evaporator/condenser as illustrated in FIGS. 24-24I.

Referring now to FIG. 27, there are several factors that may affect the performance of the apparatus described. One of these factors is pressure difference

across the regenerative blower. FIG. 27 is a chart illustrating the relationship between the amount energy required to produce one liter of product water and the change in pressure across the regenerative blower. Ideally, one would want to operate the blower, such that, the most product water is produce using the least amount electricity. From this graph, operating the blower with a pressure differential between 1.5 psi and 2 psi produces a liter of product water using the least amount of energy. Operating the blower at pressures above or below this range increases the amount of energy that is needed to produce one liter of water.

Now referring to FIG. 28, another factor that may affect the performance of the apparatus is the number of heat transfer tubes installed within the inner cavity of the evaporator/condenser assembly. FIG. 28 illustrates the relationship between the number of heat transfer tubes and the rate of production of product water for a given change in pressure across the regenerative blower. From this chart, it is determined that having a greater number of heat transfer tubes increases the production of product water. In this graph, the configuration producing the largest amount of product water per hour is the assembly having 85 tubes. The configuration producing the least amount of water is the assembly having only 43 tubes for pressures below 2 psi.

Referring now to FIG. 29, this figure illustrates the amount of product water created by different heat transfer tube configurations. In this graph, the configuration having 102 heat transfer tubes generated the highest amount of product water. In contrast, the configuration having a shorter tube length and only 48 tubes produced the least amount of product water.

Now referring to FIG. 30, despite having a lower number of tubes than other configurations, the 48 heat transfer tube configuration produces more water per surface area. FIG. 30 illustrates the relationship between the amount of product created and the size of the heat transfer surface area. This chart shows that the 48 heat transfer tube configuration having a tube length of 15 inches is the most efficient design. The least efficient configuration is the 102 heat transfer tube design. Thus, having a large number of tubes within the evaporator/condenser may produce more water, but a design having a lower number of tubes may provide the most efficient use of resources.

Referring now to FIG. 31, this figure illustrates the difference of the performance two 48 heat transfer tube designs. In this chart the difference in the designs is the tube lengths. At various pressure changes across the regenerative blower, this graph contrasts the amount of energy used and rate of production of water for the

two configurations. The configuration having the 20 inch long tubes produces slightly more product while consuming slightly less energy at equal pressure differences across the regenerative blower.

## METHODS OF CONTROL

The pressure difference across the compressor directly determines the amount of product water that the apparatus may generate. To ensure a particular amount of product water output from the apparatus, one can adjust the pressure difference across the compressor. Increasing the speed of the compressor will typically result in an increase in pressure differential across the two sides of the evaporator/condenser. Increasing the pressure differential increases rate at which source water is evaporated into clean product water.

One of the limiting factors in controlling the water vapor distillation apparatus **100** is the amount of blowdown water that is required to operate the machine. Without sufficient blowdown water, particulate separated from the source water will remain in the apparatus. This build-up of particulate will adversely affect the operation and efficiency of the apparatus.

To ensure that particulate is removed from the apparatus, there must be a sufficient amount of blowdown water present to carry the particulate out of the apparatus. To determine how much blowdown water is required to operate the apparatus in a particular environment, one must know the quality of the water entering the apparatus (source water). If the source water has a high concentration of particulate then more blowdown water will be needed to absorb and remove the particulate from the apparatus. Conversely, if the source water has a low concentration of particulate then less blowdown water will be required.

To control and observe the amount of product and blowdown water generated by the apparatus a couple of different control methods may be implemented. These schemes may include but are not limited to measuring the level of product and blowdown water within reservoirs located in the apparatus, measuring the flow rate of the product and blowdown water created by the apparatus, measuring the quality of the incoming source water and measuring the output quality of the product water.

The level sensor assembly of the exemplary embodiment may measure both the level of and the flow rate of water. The water level may be measured by the movement of the level sensor assembly. As the water fills the reservoir, the water produces a change in position of the level sensor assembly.

One may determine the flow rate of water by knowing the change in position of the level sensor assembly, the area of the reservoir and the time associated with the change in water level. Using a float sensor to determine flow is advantageous because there is no pressure drop resulting from the use of a float sensor. The flow rate may indicate the performance of the apparatus and whether that performance is consistent with normal operation of the apparatus. This information allows the operator to determine whether the apparatus is functionally properly. For example, if the operator determines the flow rate is below normal operating conditions, then the operator may check the strainer within the inlet piping for impurities or the tubes of the evaporator/condenser for scaling. Similarly, the operator may use the flow rate to make adjustments to the apparatus. These adjustments may include changing the amount of blowdown and product water created. Although a flow rate may indicate performance of the apparatus, this measurement is not required.

The water quality of either the inlet source water or the outlet product water may be used to control the operation of the water vapor distillation apparatus. This control method determines the operation of the machine based on the quality of the water. In one embodiment the conductivity of the product water is monitored. When the conductivity exceeds a specified limit than the sensor sends a signal to shut down the apparatus. In some embodiments the sensors may be, but are not limited to a conductivity sensor. In an alternate embodiment, may include monitoring the conductivity of the blowdown water. When the conductivity of the blowdown water exceeds a specified limit then the sensor sends a signal to increase the amount of source water entering the apparatus. The increase in source water will reduce the conductivity of the blowdown water. In another embodiment, the conductivity of the source water may be monitored. When the conductivity exceeds a specified limit than the sensor sends a signal to adjust the flow rate of the source water. The higher the source water conductivity may result in higher flow rates for the source and blowdown water.

In alternate embodiments, the apparatus may include a control scheme where the apparatus has a steady-state mode. During this mode, the apparatus reduces the amount of power consumed. In other embodiments, the heating elements may remain operating during this mode to maintain a particular temperature or temperature range of the source water in the sump. Maintaining the temperature of the source water in the sump reduces the amount of time for the machine to start generating more product water. In addition,

during this mode the regenerative blower is not functioning and the inlet and outlet valves are closed.

Examples of tests that may be performed on a source water sample to analyze the quality of the source water include, but are not limited to, bacterial testing, mineral testing, and chemical testing. Bacterial tests indicate the amount of bacteria that may be present within the sample. The most common type of bacterial test is total coliform.

Mineral testing results may indicate the amount of mineral impurities in the water. Large amounts of minerals and other impurities may pose a health hazard and affect the appearance and usefulness of the water.

Another type of water testing that may be accomplished is chemical testing. Many man-made chemicals may contaminate a water supply and pose health hazards to potential consumers of the water. Unless a specific chemical or type of chemical is suspected to be in the water, this type of test may not be routinely performed as the testing is expensive for unspecified chemical contaminants. However, if a particular chemical is suspected to be present in the source water, a test may be performed. Examples of some specific water quality tests are described below.

**pH** - measures the relative acidity of the water. A pH level of 7.0 is considered neutral. Pure water has a pH of 7.0. Water with a pH level less than 7.0 is considered to be acidic. The lower the pH, the more acidic the water. Water with a pH greater than 7.0 is considered to be basic or alkaline. The greater the pH, the greater its alkalinity. In the US, the pH of natural water is usually between 6.5 and 8.5. Fresh water sources with a pH below 5 or above 9.5 may not be able to sustain plant or animal species. pH may be determined using any known method in the art for testing.

The pH is preferably measured immediately at the source water test site as changes in temperature affect pH value. Preferably, the water sample is taken at the source at a location away from the “bank”, if using a lake, stream, river, puddle, etc, and below the water surface.

**Nitrate** - Nitrogen is an element required by all living plants and animals to build protein. In aquatic ecosystems, nitrogen is present in many forms. It may combine with oxygen to form a compound called nitrate. Nitrates may come from fertilizers, sewage, and industrial waste. They may cause eutrophication of lakes or ponds. Eutrophication occurs when nutrients (such as nitrates and phosphates) are added to a body of water. These nutrients usually come from runoff from farmlands and

lawns, sewage, detergents, animal wastes, and leaking septic systems. The presence of nitrate may be determined using any known method in the art for testing

**Turpidity** - Turbidity refers to how clear or how cloudy the water is. Clear water has a low turbidity level and cloudy or muddy water has a high turbidity level. High levels of turbidity may be caused by suspended particles in the water such as soil, sediments, sewage, and plankton. Soil may enter the water by erosion or runoff from nearby lands. Sediments may be stirred up by too much activity in the water, for example, by fish or humans. Sewage is a result of waste discharge and high levels of plankton may be due to excessive nutrients in the water.

Where the turbidity of the water is high, there will be many suspended particles in it. These solid particles will block sunlight and prevent aquatic plants from getting the sunlight they need for photosynthesis. The plants will produce less oxygen thereby decreasing the DO levels. The plants will die more easily and be decomposed by bacteria in the water, which will reduce the DO levels even further. Turbidity may be determined using any known method in the art for testing

**Coliform** - Where coliform bacteria are present in the water supply it is an indication that the water supply may be contaminated with sewage or other decomposing waste. Usually coliform bacteria are found in greater abundance on the surface film of the water or in the sediments on the bottom.

Fecal coliform, found in the lower intestines of humans and other warm-blooded animals, is one type of coliform bacteria. The presence of fecal coliform in a water supply is a good indication that sewage has polluted the water. Testing may be done for fecal coliform specifically or for total coliform bacteria which includes all coliform bacteria strains and may indicate fecal contamination. The presence of coliform may be determined using any known method in the art for testing.

In operation the water machine may perform conductivity testing of the source water and/or the product water to determine the quality of the water entering and exiting the system. This testing may be accomplished using conductivity sensors installed within the inlet and outlet piping of the system. Water having a high conductivity indicates that the water has greater amount of impurities. Conversely, water having a lower amount of conductivity indicates that water has a lower level of impurities. This type of testing is generic and provides only a general indication of the purity/quality of the water being analyzed.

Other types of testing may be accomplished for analyzing specific levels of the following water impurities/characteristics include but are not limited to pH, hardness, chlorides, color, turbidity, sulfate, chlorine, nitrites nitrates, and coliforms. Typically to analyze the water entering or exiting the machine the operator may first obtain a sample of the water. After obtaining the desired sample the water may then be tested using a water testing kit available from Hach Company, Loveland, Colorado 80539-0389. Other methods of testing the purity of water may include sending the water to laboratory for analysis.

## SYSTEMS FOR DISTILLING WATER

Also disclosed herein is where the apparatus for distilling water described previously may be implemented into a distribution system as described in U.S. Publication No. US 2007/0112530 A1 published on May 17, 2007 entitled "Systems and Methods for Distributed Utilities," the contents of which are hereby incorporated by reference herein. Furthermore, a monitoring and/or communications system may also be included within the distribution system as described in U.S. Publication No. US 2007/0112530 A1 published on May 17, 2007 entitled "Systems and Methods for Distributed Utilities," the contents of which are hereby incorporated by reference herein.

## ALTERNATE EMBODIMENTS

Although the exemplary embodiment of the still/water vapor distillation apparatus has been described, alternate embodiments of still, including alternate embodiments of particular elements of the still (i.e., heat exchanger, evaporator condenser, compressor, etc) are contemplated. Thus, in some alternate embodiments, one of more of the elements are replaced with alternate embodiment elements described herein. In some embodiments, the entire still is replaced by an alternate embodiment, for example, the system as described in one embodiment utilizes the exemplary embodiment as the still while in other embodiments, the system utilizes an alternate embodiment.

Referring to FIGS. 32-32C, alternate embodiments of the water vapor distillation apparatus having a liquid ring pump **3200** disclosed. The ring pump may include a fully rotatable housing that provides maximum reduction in frictional loss yet maintains simplicity of design and cost-effectiveness of production is shown in FIGS. 32 through 32C. As can be seen in FIG. 32, stator **3202** is stationary relative to rotor **3204**, and comprises an intake **3206** and exit **3208**. Steam is drawn in at pressure $P_1$ and passes into rotor chamber **3210**. Rotor **3204** is off-set from a central axis Z upon which the

rotating housing and the liquid ring pump are centered. As rotor **3204** turns about central shaft **3212** with rotor bearings **3214**, the effective volume of chamber **3210** decreases. Steam is thereby compressed to pressure $P_2$ as it is carried along a rotational path into exit **3208**, to be routed to an evaporator/condenser **104** of FIG. 1. Preferably, a rotatable housing (not shown) rotates with the liquid ring in the liquid ring pump, to reduce energy loss due to friction.

Referring to FIGS. 32A-B, the stator **3202** has support structures **3216** in the input and output regions. The individual vanes **3218** of rotor **3204** can be seen below the support structures **3216** in the top view of stator **3202** shown in FIGS. 32A-B, as well as the concentric placement of rotor **3204** about the central axis. This particular embodiment of a liquid ring pump is both axially fed and axially ported and may have a vertical, horizontal, or other orientation during operation. FIG. 32C shows yet another view of this embodiment.

The liquid ring pump **3200** is designed to operate within a fairly narrow range of input and output pressure, such that generally, the apparatus operates in the range of from 5 to 15 psig. Apparatus pressure may be regulated using check valves to release steam from chamber **3210** of FIGS. 32-32C. Improved apparatus performance is preferably achieved by placing exit **3208** of the exhaust port at a specific angle of rotation about the rotor axis, wherein the specific angle corresponds to the pressure rise desired for still operation. One embodiment of a specific port opening angle to regulate apparatus pressure is shown in FIG. 32A. Exit **3208** is placed at approximately 90 degrees of rotation about the rotor access, allowing steam from chamber **3210** to vent. Placing exit **3208** at a high angle of rotation about the stator axis would raise the apparatus pressure and lower pump throughput, while placing exit **3208** at a lower angle of rotation about the stator axis would result in lower apparatus pressure and increased pump throughput. Choosing the placement of exit **3208** to optimize apparatus pressure may yield improved pump efficiency. Further, the placement of exit **3208** to maintain apparatus pressure may minimize apparatus complexity by eliminating check valves at the exhaust ports to chamber **3210**, thereby providing a simpler, more cost-effective compressor.

Referring now to FIG. 32D, during operation, it may be desirable to measure the depth of the liquid ring in the compressor, to optimize performance. In the embodiments herein disclosed, liquid ring pump housing **3232** rotates with the liquid ring in the pump, and the temperature of the fluid is typically around 110 degrees C. Methods of

measuring ring depth include any one of the usual methods, such as using ultra-sound, radar, floats, fluid conductivity, and optical sensors. Because of the complexities of the rotating housing, use of a capacitive sensor is a preferred embodiment for this measurement, wherein as the depth of the fluid in the capacitor changes, the capacitance of the capacitor also changes.

Still referring to FIG. 32D, a disc-shaped capacitor sensor plate **3234** is mounted to the bottom of rotating housing **3232**, equidistant from the bottom surface **3232A** of rotating housing **3232**, and the bottom surface **3204A** of rotor **3204**. The capacitor is thus defined by housing **3232**, rotor **3204**, and capacitor sensor **3234**. Leads **3240** connect the capacitor, from capacitor sensor **3234**, through a passageway **3236A** in rotating housing shaft **3236**, to the secondary **3242** of a core transformer, preferably of ferrite (not shown). In one embodiment, the secondary **3242** is rotating at the same speed as the capacitor plate, and is in inductive communication with the primary of the ferrite core transformer. The primary winding **3238** is stationary, and signals to and from the level-measuring capacitor are communicated through the transformer, in this way enabling depth information to be transmitted from a rotating position to a stationary position. Capacitance is measure by determining the LC resonance of the capacitor (C) with the inductance (L) of the transformer secondary. In an exemplary embodiment, an LC oscillator circuit is constructed and the oscillation frequency is used as a measure of the capacitance.

Referring to FIG. 32E, this figure illustrates an alternate design of the pump **3200** to prevent contaminated fluid droplets from being entrained and carried along with vapor to evaporator/condenser **104** of FIG. 1. In such an embodiment, the liquid ring pump **3200** is within the head space of the evaporator/condenser **104**, and mist is eliminated as rotating housing **3232** rotates, wherein the rotation creates a cyclone effect, flinging mist and water droplets off by centrifugal force to collide with the still housing and run down to the water in the sump. There may also be fins **3244** extending from the outside of rotating housing **3232** to enhance circulation and rotation of vapor in the annular space between rotating housing **3232** and fixed housing **3228**. A steam exit **3242** is provided for passage of steam to evaporator/condenser **104**.

Referring now to FIGS. 32F-G, an alternative embodiment for a liquid ring pump **3200** may include a ring pump **3252** with an outer rotatable housing **3254** that encloses a single two-channel stator/body **3256**, and a rotor **3258**, wherein the seal surface between the rotatable housing **3254** and stationary stator/body **3256** is a

cylinder. Two-channel stator/body **3256** is kept stationary in reference to a chamber **3260** of pump **3252** as well as to rotor **3258** and rotatable housing **3254**, and comprises an intake **3262** and an exit **3264**. Steam is drawn in at pressure $P_1$ and passes through an intake orifice **3266**. When the intake orifice **3266** lines up with an intake hole **3268** in rotor **3258** as the rotor spins around stationary stator **3256**, the steam passes through intake hole **3268** into a rotor chamber **3270**. Rotor **3258** is offset from a central axis Z so that, as rotor **3258** turns, the effective volume of rotor chamber **3270** decreases. In this way, steam is compressed to pressure $P_2$ as it is carried along a rotational path to an exit hole **3272** in rotor **3258**. As rotor **3258** turns, exit hole **3272** lines up with an exit orifice **3274** of stationary exit **3264**, and the steam at pressure $P_2$ passes through exit orifice **3274** into exit **3264** to be routed to the evaporator/condenser. In such an embodiment, rotatable housing **3254** rotates with water **3276** present in chamber **3260** thereby reducing frictional energy losses due to windage. There may also be a small hole **3278** present in the housing **3254** to permit water **3276** to leave and/or enter chamber **3260**, thereby controlling the fluid level in the pump. In addition, rotor **3258** has multiple vanes **3280** that are readily apparent when rotor **3258** is viewed from above, as in FIG. 32G. Individual rotor chamber **3270**, and individual intake hole **3268** and exit hole **3272** for each rotor chamber **3270**, are also easily seen in this view.

Referring to FIG. 32H, Another alternative embodiment of a liquid ring pump, wherein the interface between rotatable housing **3254** and stator **3256** is conical rather than cylindrical. In this embodiment, a rotor drive shaft **3282** has an end **3286** situated upon a bearing **3284** that allows rotatable rotor housing **3254** to rotate with rotor **3258**. Intake **3262** and exit **3264**, with corresponding intake orifice **3266** and exit orifice **3274**, are kept stationary with respect to rotor **3258** and rotor housing **3254**.

Referring now to FIGS. 32F, H and I, other further embodiments may include either a conical or axial seal **3282** present between stationary sections **3264** and **3262** and rotor **3258**. In the conical embodiment seen most clearly in FIG. 32I, seal **3282** thereby separates intake orifice **3266** from exit orifice **3274** of rotor **3258** to prevent leaks. The liquid ring pumps shown in FIGS. 32E-I and 7 are both axially fed and radially ported, in contrast with the embodiment of a liquid ring pump, discussed with reference to FIGS. 32-32C (vide supra), which is axially fed and axially ported.

In alternate embodiments, the water vapor distillation apparatus may include a backpressure regulator. Backpressure regulators may assist with maintaining the safe and optimal operation of processes conducted under pressure. In operation the water

vapor distillation apparatus may include a backpressure regulator to purify brackish or sea water into drinking water, excess apparatus pressure from start-up volatile components, or created from compressors running off-specification, may constitute a danger to operators if such pressure is not relieved in a safe manner. As well, volatile components present in feed streams at start-up may present contaminants that interfere with proper operation of the apparatus. Backpressure regulators may serve to relieve excess pressure, and to return an operating apparatus to a desired operating pressure.

The water vapor distillation apparatus embodiments described previously generally operate above atmospheric pressure, typically around 10 psig. Such an apparatus advantageously provides higher steam density at the higher pressure, thereby allowing more steam to be pumped through a positive displacement pump than at lower pressure. The resulting higher throughput provides overall improved system efficiency. Further, the higher throughput and higher system pressure reduces the power needed for compressor, and eliminates the need for two additional pumps--one for pumping condensed product and another for pumping blowdown stream. Overall construction is simplified, as many shapes withstand internal pressure better than external pressure. Importantly, operating at super-atmospheric pressure reduces the impact of minor leaks on the overall efficiency and performance. Non-condensable gases such as air inhibit the condensation process, and would be magnified at sub-atmospheric pressure, where minor leaks would serve to suck in air, something which will not occur in a system operating at super-atmospheric pressure.

Referring now to FIGS. 33 and 33A, these figures depict views of a backpressure regulator that may be incorporated into the water vapor distillation apparatus **100** when operating the apparatus above atmospheric pressure. The backpressure regulator **3300** has a vessel **3302** containing an orifice **3304**. One side of the orifice is connected to a pressurized conduit of an apparatus (e.g., the outlet of a compressor in a vapor compression distillation apparatus) which may be exposed to the fluctuating elevated pressure. The other side of the orifice terminates in a port **3306**. The port **3306** is covered by a movable stop **3308**, in the shape of a ball. The stop **3308** is retained to an arm **3310** by means of a retainer **3312** at a fixed distance from a pivot pin **3314**. The arm **3310** is attached by a hinge via the pivot pin **3314** to a point with a fixed relation to the orifice port **3306**. The arm **3310** includes a counter mass **3316** suspended from the arm that is movable along an axis **3318** such that the distance between the counter mass **3316** and the pivot pin **3314** may be varied. In the embodiment shown in FIG. 33, the axial

direction of the orifice **3304** is perpendicular to the direction of the gravitational vector **3320**. The backpressure regulator may also include a housing, which prevents foreign matter from entering the regulator and interfering with the function of the internal components.

Still referring to FIGS. 33 and 33A, in operation the arm **3310** maintains a horizontal position with respect to the direction of gravity **3320** when the pressure in the pressurized conduit is below a given set point; this arm position, in this embodiment, is known as the closed position, and corresponds to the stop **3308** covering the port **3306**. When the pressure in the conduit exceeds the set point, a force acts on the stop **3308**, which results in a torque acting around the pivot pin **3314**. The torque acts to rotate the arm **3310** around the pivot pin 3314 in a counter-clockwise direction, causing the arm to move away from its closed position and exposing the port **3306**, which allows fluids to escape from the orifice **3304**. When the pressure in the conduit is relieved below the set point, the force of gas is no longer sufficient to keep the arm **3310** away from its closed position; thus, the arm **3310** returns to the closed position, and the stop **3308** covers the port **3306**.

Still referring to FIGS. 33 and 33A, the arm **3310** acts as a lever in creating adjustable moments and serves to multiply the force applied by the counter mass **3316** through the stop **3308** to the port **3306**. This force multiplication reduces the weight needed to close the orifice **3304** as opposed to a design where the stop **3308** alone acts vertically on top of the orifice **3304**, as in a pressure cooker. Thus a large port size, to promote expedited venting from a pressurized conduit, may be covered by a relatively lightweight, large-sized stop, the counter mass acting to adjust the desired set point; less design effort may be expended in choosing specific port sizes and stop properties. The addition of an axis **3318** for adjusting the position of the counter mass **3316**, in the present embodiment, allows for changes in the multiplier ratio. As the counter mass **3316** is moved to a position closer to the pivot pin **3314**, the multiplier ratio is reduced, creating a lower closing force. If the counter mass **3316** is moved farther from the pivot pin **3314**, the multiplier ratio is increased, hence increasing the closing force. Therefore, the position of the counter mass **3316** effectively acts to adjust the set point of the backpressure regulator.

Adjustment of the backpressure regulator set point may be useful, when the backpressure regulator is utilized in apparatus at higher altitudes. When the atmospheric pressure is lower, the apparatus operating pressure is commensurately lower. As a result,

the temperature of the distillation apparatus is lowered, which may adversely affect apparatus performance. As well, such adjustment allows one to identify set points for the backpressure regulator that are desired by the end user. The use of a counter mass to apply the closing force may also lower cost of the backpressure regulator and reduce component fatigue. In a particular embodiment, the adjustable counter mass is designed to allow a range of set points with a lowest set point substantially less than or equal to 10 psig and a highest set point substantially greater than or equal to 17 psig. Thus various embodiments allow for precise apparatus pressure regulation, unlike devices which act simply as safety relief valves.

Referring now to FIGS. 33B-C, these figures illustrate an alternate embodiment of the back pressure regulator **3300** having an orifice **3326** configured such that the port **3328** is oriented vertically with respect to the direction of gravity **3320**. Thus other embodiments may accommodate any orifice orientation while maintaining the use of an adjustable counter mass.

The backpressure regulator may be configured to allow a small leakage rate below the set point in order to purge the build up of volatile gases that act to insulate heat exchange and suppress boiling in a system; the regulator is designed, however, to allow-pressure to build in the pressurized conduit despite this small leakage. In one embodiment release of volatile components from a pressurized conduit, below the set point of the backpressure regulator, may also be achieved through a specifically-designed leak vent while the arm of the backpressure regulator is in the closed position. The leak vent is configured to allow a certain leakage rate from the port or the orifice while the pressure in the conduit is below the set point. Such leak vent may be designed by a variety of means known to those skilled in the art. Non-limiting examples include specific positioning of the stop and port to allow a small opening while the arm is in the closed position; designing the port such that a small opening, not coverable by the stop, is always exposed; specifying a particular rigid, non-compliant seal configuration between the stop and port when the arm is in the closed position; and configuring the orifice leading to the port to have a small opening to allow leakage of fluids.

Referring now FIGS. 33D-G, these figures illustrate alternate embodiments of the back pressure regulator **3300** allowing the leakage of volatiles below the set point. In one alternate embodiment, the port **3332** has a notch **3334** as shown in FIG. 33D and the close-up of region C of FIG. 33D depicted in FIG. 33E. Thus, when a stop is in contact with the port **3332**, and the arm of the backpressure regulator is in the closed

position, a leak vent is present at the position of the notch **3334** that allows a leakage of fluid. In another alternate embodiment of the backpressure regulator **3300**, orifice **3336** has a small opening **3338**, as depicted in FIG. 33F and blow up of region E of FIG. 33F depicted in FIG. 33G. The opening **3338** is configured such that a leak vent is created when the stop covers the port **3336** since fluids may leak through the opening **3338**.

Various features of a backpressure regulator may be altered or modified. For example, stops to be used with backpressure regulators may have any shape, size, or mass consistent with desired operating conditions, such stops need not be ball-shaped as shown in some embodiments discussed herein. As well, stops of different weight but similar sizes may be utilized with the retainer to alter the set point of the regulator. Similarly, counter masses of different sizes, shapes and masses may be utilized with various embodiments with preference that they are accommodated by the axis and arm configurations (compare **3316** in FIGS. 33 and 33A with **3330** in FIGS. 33B and 33C); such counter masses may be attached and oriented relative to the arm by any of a variety of techniques apparent to those skilled in the art. The pivot pin placement need not be positioned as shown in FIGS. 33-33C, but may be positioned wherever advantageous to provide the mechanical advantage required to achieve a particular pressure set point.

Referring back to FIG. 33, other embodiments of the backpressure regulator **3300** may optionally utilize the drain orifice feature described earlier. Also, embodiments of the backpressure regulator **3300** may not utilize the counter mass force adjustment feature, relying on the specific properties of a stop to provide the set point for the backpressure regulator.

Other embodiments of the water vapor distillation apparatus may not utilize a vessel, but rely on orifices that are intrinsically part of the system. In such instances, the backpressure regulator arm may be directly attached to a portion of the system such that the arm, stop, and counter mass are appropriately oriented for the operation of the regulator.

Now referring to FIG. 34, the vessel **3302** includes a drain orifice **3322**. Since the backpressure regulator **3300** may operate within a bounded region **3402** of a large system **3400**, the drain orifice **3322** acts as a pathway to release fluids that are purged from the pressurized conduit **3404** through orifice **3304** into the bounded region **3402**. The drain orifice **3322** may connect the bounded region **3402** to another area of the larger system, or to the external environment **3406**. In addition, the build-up of gases in the bounded region **3402** may result in condensation of such gases. Also, gases purged

through the orifice **3304** may be entrained with droplets of fluid that may accumulate in the bounded region **3402**. Thus the drain orifice **3322** may also be used to purge any build up of condensables that accumulate in the bounded region **3402**; the condensables may also be released from the bounded region using a separate orifice **3408**.

Referring now to FIG. 35, in alternate embodiments the apparatus may maintain a constant blowdown water flow to prevent scaling and other accumulation in the apparatus as follows. Water level **3502** in head chamber **3504** is adjusted through a feedback control loop using level sensor L1, valve V1, and source pump **3506**, to maintain proper water flow through the blowdown stream **3508**. The three-way source pump fill valve **3510** is set to pump water into sump **3512**, which causes water level **3502** in head chamber **3504** to rise. As fluid level **3502** rises in head chamber **3504**, fluid overflows past a dam-like barrier **3514** into blowdown control chamber **3516** containing blowdown level sensor L1. As required, blowdown valve V1 is controlled to allow water flow from blowdown control chamber **3516** through heat exchanger **3518**, to extract heat and cool blowdown stream **3508**, and flow out valve V1, through volatile mixer **3520** allowing cooling of hot gases and steam **3522** from the evaporator section **3524**, and then completing the blowdown stream, out to waste **3526**.

Still referring to FIG. 35, the apparatus may also maintain proper product flow as follows. Product level **3528** builds up in condenser chamber **3530**, and enters into product control chamber **3532**, where product level sensor L2 is housed. Using a feedback control loop with level sensor L2 and valve V2, product stream **3534** is controlled to flow from product control chamber **3532** through heat exchanger **3518**, to extract heat and cool product stream **3534**, then through valve V2 and on out to complete the product stream as product water outlet **3536**.

The system may preferably be configured to maintain proper liquid ring pump **3538** water level by the use of a fluid recovery system to replenish fluid loss. There are several ways that fluid from the ring pump may be depleted during system operation, including leakage into lower reservoir **3540**, expulsion through exhaust port **3542**, and evaporation. The leakage and expulsion losses may be large depending on operational parameters, such as the speed of rotation and liquid ring pump **3538** throughput. These leakage and expulsion losses could require total replacement of the fluid in the pump several times per hour. The evaporation loss is typically small.

Referring to FIG. 35, the fluid level in the ring pump **3538** may be maintained by adding additional source water, product water, or preferably by re-circulating liquid

water lost from the liquid ring pump for improved system efficiency. In one embodiment the fluid level in the ring pump **3538** is primarily maintained by re-circulation of the fluid accumulated in lower reservoir **3540**. Fluid may accumulate in lower reservoir **3540** from leakage from the liquid ring pump **3538** and from fluid expelled in exhaust **3542**, captured in mist eliminator **3544** and pumped to lower reservoir **3540**. Alternatively, fluid expelled in exhaust **3542** and captured in mist eliminator **3544** may be returned via the liquid ring pump exhaust port. Fluid accumulated in lower reservoir may be re-circulated by one of several pumping mechanisms. One exemplary method is to use a siphon pump.

Still referring to FIG. 35, a minimum depth of water is preferably maintained in the lower reservoir for the siphon pump to perform properly. In one embodiment liquid ring pump control chamber **3546**, which houses liquid ring pump level sensor L3 may be used to control the liquid ring pump level and control the level of water in the lower reservoir **3540**. Liquid ring pump control chamber **3546** is fluidly connected to liquid ring pump **3538** and lower reservoir **3540**. Liquid ring pump **3538** is connected to the three-way source fill valve **3510**, which is set to open when the liquid ring pump **3538** requires more water and it is also connected to the liquid ring pump drain valve V3, which opens when it is required to drain water from liquid ring pump **3538** into blowdown stream **3508**.

Still referring to FIG. 35, if re-circulated water front lower reservoir **3540** is not primarily used to maintain the fluid level in the liquid ring pump **3538**, then either cold source water or product water could to be used. In the event source water were used, the introduction of cold water (which could be approximately 85 degrees C colder than system temperature) to the liquid ring pump **3538** would decrease system efficiency or alternatively the use of a pre-heater for such cold source water would increase the energy budget of the system. Alternatively, the use of product water, while not adversely affecting system temperature, could decrease production level and, thus, also lead to system inefficiency. At startup, the initial fluid level for the liquid ring pump is preferably supplied from source water.

Now referring to FIG. 35A, in one embodiment the start-up time may be reduced by using an external connecting valve **3550** between source **3548** and blowdown **3508** fluid lines, located adjacent to heat exchanger **3518**, on the cold side. To determine the level of fluid in evaporator head **3504** during the initial fill, connecting valve **3550** would be open, blowdown valve BV would be closed, and fluid would be pumped into

the system through source line **3548**. Connecting blowdown **3508** and source **3548** lines results in equal fluid height in the blowdown level sensor housing **3516** and evaporator head **3504**, thereby permitting a determination of fluid level in evaporator head **3504** and enabling the evaporator to be filled to the minimum required level at startup. Using the minimum level required shortens initial warm-up time and prevents spill-over from the evaporator head **3504** through the liquid ring pump **3538** to the condenser **3552** when the liquid ring pump **3538** starts illustrated on FIG. 35.

Still referring to FIG. 35A, the concentration of solids in blowdown stream **3508** may be monitored and controlled to prevent precipitation of materials from solution and thus clogging of the system. Also during start-up, circulating pump **3554** may circulate water through heat exchanger **3518** to pre-heat the heat exchanger to the proper temperature for normal operation. A conductivity sensor (not shown) may be used to determine total dissolved solid (TDS) content by measuring the electrical conductivity of the fluid. In a particular embodiment, the sensor is an inductive sensor, whereby no electrically conductive material is in contact with the fluid stream. If the TDS content in blowdown stream **3508** rises above a prescribed level, for example, during distillation of sea water, the fluid source feed rate is increased. Increasing the fluid source feed rate will increase the rate of blowdown stream **3508**, because distilled water production changes only slightly as a function of fluid feed rate, and an increased blowdown stream rate results in reduced concentration of TDS, thereby maintaining overall efficiency and productivity of the system.

Alternate embodiments may also include a fluid control system using level sensors and variable flow valves in a feedback configuration. Optimal operation of the still requires total fluid flow in to closely match total fluid flow out. Maintaining fluid levels in the still at near constant levels accomplishes this requirement. In a particular embodiment, the sensors are capacitive level sensors, a particularly robust sensor for measuring fluid levels. Capacitive level sensors have no moving parts and are insensitive to fouling, and manufacture is simple and inexpensive. Opening of a variable flow valve is controlled by the level of fluid measured by the capacitive level sensor, whereby the fluid level is adjusted at the level sensor location. A rising fluid level causes the valve to open more, increasing flow out of the sensor volume. Conversely, a falling fluid level causes the valve to close more, decreasing flow out of the sensor volume.

Flow rate through the variable flow control valves and from the input pump may be determined using an in-situ calibration technique. The level sensors and associated level sensor volume may be used to determine the fill or empty rate of the sensor volume. By appropriately configuring the control valves, the flow rate calibration of each valve and also of the source pump may be determined.

In one embodiment, a valve block (not shown) may be utilized to consolidate all control valves for the system into a single part, which may be integrated with the fluid flow manifold. A control system comprising a sensor for total dissolved solids and blowdown stream may also be incorporated, as well as a float valve or other device for controlling the height/level of fluid in the head.

Referring back to FIG. 35, there is additionally a steam flow line **3554** from head **3504** to compressor **3538**, a steam outlet **3542** for diverting steam to evaporator/condenser, a hot product line **3534** from evaporator/condenser leading through exchanger **3518**, which also allows for collection of hot purified condensed product **3528**, and a line (not shown) for diverting hot product to compressor **3538** to allow adjustment of water level to keep it constant. There may also be a drain line (not shown), for when the system is shut down.

Referring now to FIGS. 36-36C, alternate embodiments may also include a fluid distribution manifold **3600**. FIG. 36 shows one face of the pump side of one particular embodiment of a fluid distribution manifold **3600**. Input, in the form of raw source feed, flows through port **3602**, and blowdown stream (output) flows through port **3604**. Additional output in the form of product flows through port **3606**, while port/chamber **3608** provides the vent for volatiles (output) and port **3610** provides the drain (output) for liquid ring pump. FIG. 36A shows the other face of the pump side of the same particular embodiment of fluid distribution manifold **3600**. Port/chamber **3608**, for output of volatiles, is apparent, as is the drain **3610** for a liquid ring pump. In this view of this particular embodiment, a condenser steam mist eliminator chamber **3612** is visible, as is a mist collector and drain area **3614**.

Referring specifically to FIG. 36B, this figure illustrates one face of the evaporator/condenser side of the same particular embodiment of fluid distribution manifold **3600**. Raw source feed port **3602**, as well as blowdown passage ports **3604** and product passage ports **3606** are readily visible in this view. In addition, evaporator steam passage port **3616** and condenser steam passage port **3618** may be seen.

Referring specifically to FIG. 36B, this figure illustrates the other face of the evaporator/condenser side of the same particular embodiment of fluid distribution manifold **3600**. Again blowdown passage port **3604** is visible, as is liquid ring pump drain port **3606**, a second condenser steam mist eliminator **3612**, evaporator steam mist eliminator **3620**, and mist collector and drain area **3614**. Also, a sump level control chamber can be seen in this view, along with a product level control chamber **3622** and a liquid ring pump supply feed **3624**.

Still referring to FIGS. 36-36C, a fluid distribution manifold **3600** is capable of eliminating most plumbing in a fluid purification system, advantageously incorporating various functionality in one unit, including flow regulation, mist removal, and pressure regulation, thereby simplifying manufacture and significantly reducing overall component parts. The core plates and manifolds may be made of, for example, plastic, metal, or ceramic plates, or any other non-corrosive material capable of withstanding high temperature and pressure. Methods of manufacture for the core plates and manifolds include brazing and over-molding.

Referring now to FIGS. 37-37A, these figures illustrate a fitting assembly that allows fluid interfacing throughout the system in a particular embodiment. For example, there may be a floating fluid interface between the exchanger **3518** (shown on FIG. 35) and the intake/exhaust ports **3220** and **3208** (shown on FIG. 32). FIG. 37A illustrates a connector **3702** that may be welded to the heat exchanger ports (not shown), wherein the connector **3702** connects to the fluid interface **3704** which is in turn in communication with the fluid distribution manifold. FIG. 37A shows a sectional view across line A-A (see FIG. 37). The connector **3702** has the ability to float to compensate for shifts in registration, possibly caused by temperature or manufacturing variations. Sealing is accomplished by the o-ring **3706**. As can be seen in the view depicted in FIG. 37, the o-ring seal **3706**, upon rotation of line A-A 90 degree about a central axis, the connector **3702** and the fluid interface **3704** lock together to make a fluid interface connection.

Referring now to FIGS. 38-38A, these figures illustrate another embodiment of the evaporator/condenser **3800**. As seen in FIG. 38, evaporator/condenser **3800** is a flat evaporator/condenser and contains multiple parallel core layers **3802** and **3804**, typically made of copper-nickel alloy or other heat-transferable material, with rib sections **3806** creating channels **3810** and **3812** for directing steam and condensed fluid flow. Steam intake **3814** and product exit **3816** manifolds (as well as dirty intake and volatile exit manifolds, not shown) may connect via a fluid interface to a liquid ring

pump/compressor. Bolts **3818** secure core evaporator/condenser **3800** to brackets of external housing of the liquid ring pump/compressor. In operation, every alternating horizontal (as shown in FIGS. 38 and 38A) row **3802** and **3804** comprises evaporator channels **3810** and condenser channels **3812**, such that the two functions never overlap on any given layer. FIG. 38A, a detail of FIG. 38, shows more clearly how the combined evaporator/condenser manifolds works. As indicated, rows **3802** do not interact with rows **3804**, they are closed off to each other, thereby separating the functions of evaporation and condensation in the horizontal core layers.

Referring now to FIG. 39, this figure illustrates alternate embodiment of the heat exchanger used in the water vapor distillation apparatus, wherein such heat exchangers capitalize on available systemic and heat sources. In one particular embodiment, heat from at least one of a plurality of sources passes through a multi-line heat exchanger **3902** such as depicted in FIG. 39, wherein a series of two-channel heat exchangers such as **3904**, **3906**, **3908**, and **3910** are plumbed to produce a multi-line effect. Note that in the particular multi-line heat exchanger embodiment shown in FIG. 39, the flow of cold intake **3912** passes through all heat exchanger units **3904**, **3906**, **3908**, and **3910**; one heat source, for example hot product **3914**, flows through heat exchanger units **3904** and **3908**; and another heat source, for example hot blowdown stream **3916**, flows through heat exchange units **3906** and **3910**. In this way, multiple heat sources may be used to exchange with the cold intake flow **3912**.

Now referring to FIG. 39A, this figure illustrates an alternate embodiment of the heat exchanger. In this embodiment, the heat exchanger may be a single multi-channel heat exchanger **3918**. In this particular embodiment, cold intake **3912**, and heat sources such as hot product **3914** and hot blowdown stream **3916**, for example, flow through exchanger **3918** simultaneously, but in opposite directions, thereby enabling heat exchange with cold intake **3912** from both heat sources **3914** and **3916** within a single heat exchanger **3912**.

Referring now to FIG. 40, one alternate embodiment may include measuring the evaporator and condenser pressures to assess overall system performance and/or provide data to a control system. To avoid the use of expensive sensors that would be required to withstand the elevated temperatures of evaporator/condenser **4002**, pressure sensors $P_E$ and $P_C$ are mounted on fluid lines between the cold side of heat exchanger 4004 and corresponding control valves $V_E$ and $V_C$. To avoid measuring a pressure less than the actual pressure of the system, which would occur when fluid is flowing for pressure

sensors located at this position, the control valve would be closed momentarily to stop flow. During the "no-flow" period, pressure will be constant from the control valve back to the evaporator or condenser, enabling accurate measurement of the system pressure. No adverse effects on still performance will occur from these short "no-flow" periods.

Referring now to FIGS. 41-41B, this figure illustrates another embodiment of the present disclosure including a filtering mechanism within intake to increase the purity of the final product fluid. A multi unit flip-filter **4100**, having a pivot joint **4102** joining at least two filter units **4104** and **4106**, is situated within a filter housing **4108** which directs fluid through filter units **4104** and **4106** and facilitates rotation of filter units **4104** and **4106** about central pivot joint **4102**. As shown, blowdown stream **4109** passes through flip-filter unit **4104**, while intake fluid stream **4110** simultaneously flows from intake through flip-filter unit **4106** en route to purification. After some interval a flip-filter switch (not shown), rotates flip-filter **4100** around its central axis, shown by the dotted line, at flip-filter pivot joint **4102**, such that filter unit **4106**, now fouled with contaminates filtered from dirty intake fluid, is backwashed by blowdown stream **4109**, and filter unit **4104** becomes the filter unit which filters intake fluid stream **4110**. In such an embodiment, o-ring gaskets **4112** and **4114** may be utilized as seals between filter units **4104** and **4106** and the fluid flow routes of blowdown stream **4109** and intake fluid stream **4110**, respectively.

Referring now to FIGS. 41C-D, the multi-unit flip filter may be a multi-sected circular filter **4112**. Multi unit flip-filter **4112**, having a pivot point **4114** about which multiple flip-filter units such as **4116** and **4118** pivot, may also be situated within filter housing **4120** that directs fluid flow through individual filter units **4116** and **4118** and facilitates rotation of filter **4112** about pivot point **4114**. As shown, blowdown stream **4109** passing through one flip-filter unit **4116**, while intake fluid stream **4110** simultaneously flows from intake through flip-filter unit **4118** en route to purification. As in FIG. 41, a flip-filter switch (not shown), rotates flip-filter **4112** around its central axis, shown by the dotted line, at flip-filter pivot point **4114**, such that filter unit **4118**, now fouled with contaminates filtered from dirty intake fluid, is backwashed by blowdown stream **4109**, and filter unit **4116** becomes the filter unit which filters intake fluid stream **4110**. A series of seals, as indicated by **4122** and **4124**, are utilized between individual filter units **4116** and **4118**, to partition blowdown stream **4109** flowing through one filter section, from intake fluid stream **4110** flowing through another filter section.

Now referring to FIGS. 41E-41F, other embodiments may include a manual valve **4122** to change the direction of water flow. Such a valve allows use of, for example, blowdown stream **4109** to continuously clean one unit of each flip-filter, and with a single operation effectively switches which unit is being filtered and which unit is being back-washed, thereby back-washing filter units **4104** or **4106** without the need to actually flip filter **4100** itself. In one particular embodiment when valve **4122** is in position A, filter unit **4104** is filtering intake fluid **4110**, and filter unit **4106** is being back-washed with blowdown stream **4109**. Upon switching valve **4100** to position B, filter unit **4104** is now being backwashed by blowdown stream **4108**, and filter unit **4106** is now filtering input fluid **4110**.

## STIRLING CYCLE ENGINE

The various embodiments of the water vapor distillation apparatus described above may, in some embodiment, may be powered by a Stirling cycle machine (also may be referred to as a Stirling engine). In the exemplary embodiment, the Stirling cycle machine is a Stirling engine described in pending U.S. Patent Application Serial No.12/105,854 having Attorney Docket No. 170 filed on April 18, 2008, which is herein incorporated by reference in its entirety. However, in other embodiments, the Stirling cycle machine may be any of the Stirling cycle machines described in the following references, all of which are incorporated by reference in their entirely: U.S. Patent Nos. 6,381,958; 6,247,310; 6,536,207; 6,705,081; 7,111,460; and 6,694,731.

Stirling cycle machines, including engines and refrigerators, have a long technological heritage, described in detail in Walker, Stirling Engines, Oxford University Press (1980), incorporated herein by reference. The principle underlying the Stirling cycle engine is the mechanical realization of the Stirling thermodynamic cycle: isovolumetric heating of a gas within a cylinder, isothermal expansion of the gas (during which work is performed by driving a piston), isovolumetric cooling, and isothermal compression. Additional background regarding aspects of Stirling cycle machines and improvements thereto is discussed in Hargreaves, The Phillips Stirling Engine (Elsevier, Amsterdam, 1991), which is herein incorporated by reference.

The principle of operation of a Stirling cycle machine is readily described with reference to FIGS. 45A-45E, wherein identical numerals are used to identify the same or similar parts. Many mechanical layouts of Stirling cycle machines are known in the art,

and the particular Stirling cycle machine designated generally by numeral **5110** is shown merely for illustrative purposes. In FIGS. 45A to 45D, piston **5112** and a displacer **5114** move in phased reciprocating motion within the cylinders **5116** which, in some embodiments of the Stirling cycle machine, may be a single cylinder, but in other embodiments, may include greater than a single cylinder. A working fluid contained within cylinders **5116** is constrained by seals from escaping around piston **5112** and displacer **5114**. The working fluid is chosen for its thermodynamic properties, as discussed in the description below, and is typically helium at a pressure of several atmospheres, however, any gas, including any inert gas, may be used, including, but not limited to, hydrogen, argon, neon, nitrogen, air and any mixtures thereof. The position of the displacer **5114** governs whether the working fluid is in contact with the hot interface **5118** or the cold interface **5120**, corresponding, respectively, to the interfaces at which heat is supplied to and extracted from the working fluid. The supply and extraction of heat is discussed in further detail below. The volume of working fluid governed by the position of the piston **5112** is referred to as the compression space **5122**.

During the first phase of the Stirling cycle, the starting condition of which is depicted in FIG. 45A, the piston **5112** compresses the fluid in the compression space **5122**. The compression occurs at a substantially constant temperature because heat is extracted from the fluid to the ambient environment. The condition of the Stirling cycle machine **5110** after compression is depicted in FIG. 45B. During the second phase of the cycle, the displacer **5114** moves in the direction of the cold interface **5120**, with the working fluid displaced from the region of the cold interface **5120** to the region of the hot interface **5118**. This phase may be referred to as the transfer phase. At the end of the transfer phase, the fluid is at a higher pressure since the working fluid has been heated at constant volume. The increased pressure is depicted symbolically in FIG. 45C by the reading of the pressure gauge **5124**.

During the third phase (the expansion stroke) of the Stirling cycle machine, the volume of the compression space **5122** increases as heat is drawn in from outside the Stirling cycle machine **5110,** thereby converting heat to work. In practice, heat is provided to the fluid by means of a heater head (not shown) which is discussed in greater detail in the description below. At the end of the expansion phase, the compression space **5122** is full of cold fluid, as depicted in FIG. 45D. During the fourth phase of the Stirling cycle machine **5110**, fluid is transferred from the region of the hot

interface **5118** to the region of the cold interface **5120** by motion of the displacer **5114** in the opposing sense. At the end of this second transfer phase, the fluid fills the compression space **5122** and cold interface **5120**, as depicted in FIG. 45A, and is ready for a repetition of the compression phase. The Stirling cycle is depicted in a P-V (pressure-volume) diagram as shown in FIG. 45E.

Additionally, on passing from the region of the hot interface **5118** to the region of the cold interface **5120.** In some embodiments, the fluid may pass through a regenerator (shown as **5408** in FIG. 48). A regenerator is a matrix of material having a large ratio of surface area to volume which serves to absorb heat from the fluid when it enters from the region of the hot interface **5118** and to heat the fluid when it passes from the region of the cold interface **5120**.

Stirling cycle machines have not generally been used in practical applications due to several daunting challenges to their development. These involve practical considerations such as efficiency and lifetime. Accordingly, there is a need for more Stirling cycle machines with minimal side loads on pistons, increased efficiency and lifetime.

The principle of operation of a Stirling cycle machine or Stirling engine is further discussed in detail in U.S. Patent No. 6,381,958, issued May 7, 2002, to *Kamen et al.*, which is herein incorporated by reference in its entirety.

**Rocking Beam Drive**

Referring now to FIGS. 46-48, embodiments of a Stirling cycle machine, according to one embodiment, are shown in cross-section. The engine embodiment is designated generally by numeral **5300**. While the Stirling cycle machine will be described generally with reference to the Stirling engine **5300** embodiments shown in FIGS. 46-48, it is to be understood that many types of machines and engines, including but not limited to refrigerators and compressors may similarly benefit from various embodiments and improvements which are described herein, including but not limited to, external combustion engines and internal combustion engines.

FIG. 46 depicts a cross-section of an embodiment of a rocking beam drive mechanism **5200** (the term "rocking beam drive" is used synonymously with the term "rocking beam drive mechanism") for an engine, such as a Stirling engine, having linearly reciprocating pistons **5202** and **5204** housed within cylinders **5206** and **5208**, respectively. The cylinders include linear bearings **5220**. Rocking beam drive **5200** converts linear motions of pistons **5202** and **5204** into the rotary motion of a crankshaft

**5214**. Rocking beam drive **5200** has a rocking beam **5216**, rocker pivot **5218**, a first coupling assembly **5210**, and a second coupling assembly **5212**. Pistons **5202** and **5204** are coupled to rocking beam drive **5200**, respectively, via first coupling assembly **5210** and second coupling assembly **5212**. The rocking beam drive is coupled to crankshaft **5214** via a connecting rod **5222**.

In some embodiments, the rocking beam and a first portion of the coupling assembly may be located in a crankcase, while the cylinders, pistons and a second portion of the coupling assembly is located in a workspace.

In FIG. 48 a crankcase **5400** most of the rocking beam drive **5200** is positioned below the cylinder housing **5402**. Crankcase **5400** is a space to permit operation of rocking beam drive **5200** having a crankshaft **5214**, rocking beam **5216**, linear bearings **5220**, a connecting rod **5222**, and coupling assemblies **5210** and **5212**. Crankcase **5400** intersects cylinders **5206** and **5208** transverse to the plane of the axes of pistons **5202** and **5204**. Pistons **5202** and **5204** reciprocate in respective cylinders **5206** and **5208**, as also shown in FIG 46. Cylinders **5206** and **5208** extend above crankshaft housing **5400**. Crankshaft **5214** is mounted in crankcase **5400** below cylinders **5206** and **5208**.

FIG. 46 shows one embodiment of rocking beam drive **5200**. Coupling assemblies **5210** and **5212** extend from pistons **5202** and **5204,** respectively, to connect pistons **5202** and **5204** to rocking beam **5216**. Coupling assembly **5212** for piston **5204**, in some embodiments, may comprise a piston rod **5224** and a link rod **5226**. Coupling assembly **5210** for piston **5202**, in some embodiments, may comprise a piston rod **5228** and a link rod **5230**. Piston **5204** operates in the cylinder **5208** vertically and is connected by the coupling assembly **5212** to the end pivot **5232** of the rocking beam **5216**. The cylinder **5208** provides guidance for the longitudinal motion of piston **5204**. The piston rod **5224** of the coupling assembly **5212** attached to the lower portion of piston **5204** is driven axially by its link rod **5226** in a substantially linear reciprocating path along the axis of the cylinder **5208**. The distal end of piston rod **5224** and the proximate end of link rod **5226**, in some embodiments, may be jointly hinged via a coupling means **5234**. The coupling means **5234**, may be any coupling means known in the art, including but not limited to, a flexible joint, roller bearing element, hinge, journal bearing joint (shown as **5600** in FIG. 50), and flexure (shown as **5700** in FIGS. 51A and 51B). The distal end of the link rod **5226** may be coupled to one end pivot **5232** of rocking beam **5216**, which is positioned vertically and perpendicularly under the proximate end of the link rod **5226**. A stationary linear bearing **5220** may be

positioned along coupling assembly **5212** to further ensure substantially linear longitudinal motion of the piston rod **5224** and thus ensuring substantially linear longitudinal motion of the piston **5204**. In an exemplary embodiment, link rod **5226** does not pass through linear bearing **5220.** This ensures, among other things, that piston rod **5224** retains a substantially linear and longitudinal motion.

In the exemplary embodiment, the link rods may be made from aluminum, and the piston rods and connecting rod are made from D2 Tool Steel. Alternatively, the link rods, piston rods, connecting rods, and rocking beam may be made from 4340 steel. Other materials may be used for the components of the rocking beam drive, including, but not limited to, titanium, aluminum, steel or cast iron. In some embodiments, the fatigue strength of the material being used is above the actual load experienced by the components during operation.

Still referring to FIGS. 46-48, piston **5202** operates vertically in the cylinder **5206** and is connected by the coupling assembly **5210** to the end pivot **5236** of the rocking beam **5216**. The cylinder **5206** serves, amongst other functions, to provide guidance for longitudinal motion of piston **5202**. The piston rod **5228** of the coupling assembly **5210** is attached to the lower portion of piston **5202** and is driven axially by its link rod **5230** in a substantially linear reciprocating path along the axis of the cylinder **5206**. The distal end of the piston rod **5228** and the proximate end of the link rod **5230**, in some embodiments, is jointly hinged via a coupling means **5238**. The coupling means **5238**, in various embodiments may include, but are not limited to, a flexure (shown as **5700** in FIGS. 51A and 51B, roller bearing element, hinge, journal bearing (shown as **5600** in FIG. 50), or coupling means as known in the art. The distal end of the link rod **5230**, in some embodiments, may be coupled to one end pivot **5236** of rocking beam **5216**, which is positioned vertically and perpendicularly under the proximate end of link rod **5230**. A stationary linear bearing **5220** may be positioned along coupling assembly **5210** to further ensure linear longitudinal motion of the piston rod **5228** and thus ensuring linear longitudinal motion of the piston **5202**. In an exemplary embodiment, link rod **5230** does not pass through linear bearing **5220** to ensure that piston rod **5228** retains a substantially linear and longitudinal motion.

The coupling assemblies **5210** and **5212** change the alternating longitudinal motion of respective pistons **5202** and **5204** to oscillatory motion of the rocking beam **5216**. The delivered oscillatory motion is changed to the rotational motion of the crankshaft **5214** by the connecting rod **5222,** wherein one end of the connecting rod

**5222** is rotatably coupled to a connecting pivot **5240** positioned between an end pivot **5232** and a rocker pivot **5218** in the rocking beam **5216**, and another end of the connecting rod **5222** is rotatably coupled to crankpin **5246.** The rocker pivot **5218** may be positioned substantially at the midpoint between the end pivots **5232** and **5236** and oscillatorily support the rocking beam **5216** as a fulcrum, thus guiding the respective piston rods **5224** and **5228** to make sufficient linear motion. In the exemplary embodiment, the crankshaft **5214** is located above the rocking beam **5216**, but in other embodiments, the crankshaft **5214** may be positioned below the rocking beam **5216** (as shown in FIGS. 49B and 49D) or in some embodiments, the crankshaft **5214** is positioned to the side of the rocking beam **5216**, such that it still has a parallel axis to the rocking beam **5216**.

Still referring to FIGS. 46-48, the rocking beam oscillates about the rocker pivot **5218**, the end pivots **5232** and **5236** follow an arc path. Since the distal ends of the link rods **5226** and **5230** are connected to the rocking beam **5216** at pivots **5232** and **5236**, the distal ends of the link rods **5226** and **5230** also follow this arc path, resulting in an angular deviation **5242** and **5244** from the longitudinal axis of motion of their respective pistons **5202** and **5204**. The coupling means **5234** and **5238** are configured such that any angular deviation **5244** and **5242** from the link rods **5226** and **5230** experienced by the piston rods **5224** and **5228** is minimized. Essentially, the angular deviation **5244** and **5242** is absorbed by the coupling means **5234** and **5238** so that the piston rods **5224** and **5228** maintain substantially linear longitudinal motion to reduce side loads on the pistons **5204** and **5202**. A stationary linear bearing **5220** may also be placed inside the cylinder **5208** or **5206,** or along coupling assemblies **5212** or **5210**, to further absorb any angular deviation **5244** or **5242** thus keeping the piston push rod **5224** or **5228** and the piston **5204** or **5202** in linear motion along the longitudinal axis of the piston **5204** or **5202**.

Therefore, in view of reciprocating motion of pistons **5202** and **5204**, it is necessary to keep the motion of pistons **5202** and **5204** as close to linear as possible because the deviation **5242** and **5244** from longitudinal axis of reciprocating motion of pistons **5202** and **5204** causes noise, reduction of efficiency, increase of friction to the wall of cylinder, increase of side-load, and low durability of the parts. The alignment of the cylinders **5206** and **5208** and the arrangement of crankshaft **5214**, piston rods **5224** and **5228**, link rods **5226** and **5230**, and connecting rod **5222**, hence, may influence on, amongst other things, the efficiency and/or the volume of the device. For the purpose of

increasing the linearity of the piston motion as mentioned, the pistons (shown as **5202** and **5204** in FIGS. 46-48) are preferably as close to the side of the respective cylinders **5206** and **5208** as possible.

In another embodiment reducing angular deviation of link rods, link rods **5226** and **5230** substantially linearly reciprocate along longitudinal axis of motion of respective pistons **5204** and **5202** to decrease the angular deviation and thus to decrease the side load applied to each piston **5204** and **5202**. The angular deviation defines the deviation of the link rod **5226** or **5230** from the longitudinal axis of the piston **5204** or **5202**. Numerals **5244** and **5242** designate the angular deviation of the link rods **5226** and **5230**, as shown in FIG. 46. Therefore, the position of coupling assembly **5212** influences the angular displacement of the link rod **5226**, based on the length of the distance between the end pivot **5232** and the rocker pivot **5218** of the rocking beam **5216**. Thus, the position of the coupling assemblies may be such that the angular displacement of the link rod **5226** is reduced. For the link rod **5230**, the length of the coupling assembly **5210** also may be determined and placed to reduce the angular displacement of the link rod **5230**, based on the length of the distance between the end pivot **5236** and the rocker pivot **5218** of the rocking beam **5216**. Therefore, the length of the link rods **5226** and **5230**, the length of coupling assemblies **5212** and **5210**, and the length of the rocking beam **5216** are significant parameters that greatly influence and/or determine the angular deviation of the link rods **5226** and **5230** as shown in FIG. 46.

The exemplary embodiment has a straight rocking beam **5216** having the end points **5232** and **5236**, the rocker pivot **5218**, and the connecting pivot **5240** along the same axis. However, in other embodiments, the rocking beam **5216** may be bent, such that pistons may be placed at angles to each other, as shown in FIGS. 49C and 49D.

Referring now to FIGS. 46-48 and FIGS. 51A-51B, in some embodiments of the coupling assembly, the coupling assemblies **5212** and **5210**, may include a flexible link rod that is axially stiff but flexible in the rocking beam **5216** plane of motion between link rods **5226** and **5230,** and pistons **5204** and **5202**, respectively. In this embodiment, at least one portion, the flexure (shown as **5700** in FIGS. 51A and 51B), of link rods **5226** and **5230** is elastic. The flexture **5700** acts as a coupling means between the piston rod and the link rod. The flexure **5700** may absorb the crank-induced side loads of the pistons more effectively, thus allowing its respective piston to maintain linear longitudinal movement inside the piston's cylinder. This flexure **5700** allows small

rotations in the plane of the rocking beam **5216** between the link rods **5226** and **5230** and pistons **5204** or **5202**, respectively. Although depicted in this embodiment as flat, which increases the elasticity of the link rods **5226** and **5230**, the flexure **5700**, in some embodiments, is not flat. The flexure **5700** also may be constructed near to the lower portion of the pistons or near to the distal end of the link rods **5226** and **5230**. The flexure **5700**, in one embodiment, may be made of #D2 Tool Steel Hardened to 58-62 RC. In some embodiments, there may be more than one flexure (not shown) on the link rod **5226** or **5230** to increase the elasticity of the link rods.

In alternate embodiment, the axes of the pistons in each cylinder housing may extend in different directions, as depicted in FIGS. 49C and 49D. In the exemplary embodiment, the axes of the pistons in each cylinder housing are substantially parallel and preferably substantially vertical, as depicted in FIGS. 46- 48, and FIGS. 49A and 49B. FIGS. 49A-49D include various embodiments of the rocking beam drive mechanism including like numbers as those shown and described with respect to FIGS. 2-4. It will be understood by those skilled in that art that changing the relative position of the connecting pivot **5240** along the rocking beam **5216** will change the stroke of the pistons.

Accordingly, a change in the parameters of the relative position of the connecting pivot **5240** in the rocking beam **5216** and the length of the piston rods **5224** and **5228**, link rods **5230** and **5226**, rocking beam **5216**, and the position of rocker pivot **5218** will change the angular deviation of the link rods **5226** and **5230**, the phasing of the pistons **5204** and **5202,** and the size of the device **5300** in a variety of manner. Therefore, in various embodiments, a wide range of piston phase angles and variable sizes of the engine may be chosen based on the modification of one or more of these parameters. In practice, the link rods **5224** and **5228** of the exemplary embodiment have substantially lateral movement within from -0.5 degree to +0.5 degree from the longitudinal axis of the pistons **5204** and **5202.** In various other embodiments, depending on the length of the link rod, the angle may vary anywhere from approaching 0 degrees to .75 degrees. However, in other embodiments, the angle may be higher including anywhere from approaching 0 to the approximately 20 degrees. As the link rod length increases, however, the crankcase/overall engine height increases as well as the weight of the engine.

One feature of the exemplary embodiment is that each piston has its link rod extending substantially to the attached piston rod so that it is formed as a coupling

assembly. In one embodiment, the coupling assembly **5212** for the piston **5204** includes a piston rod **5224,** a link rod **5226**, and a coupling means **5234** as shown in FIG. 46. More specifically, one proximal end of piston rod **5224** is attached to the lower portion of piston **5204** and the distal end piston rod **5224** is connected to the proximate end of the link rod **5226** by the coupling means **5234**. The distal end of the link rod **5226** extends vertically to the end pivot **5232** of the rocking beam **5216**. As described above, the coupling means 5**234** may be, but is not limited to, a joint, hinge, coupling, or flexure or other means known in the art. In this embodiment, the ratio of the piston rod **5224** and the link rod **5226** may determine the angular deviation of the link rod **5226** as mentioned above.

In one embodiment of the machine, an engine, such as a Stirling engine, employs more than one rocking beam drive on a crankshaft. Referring now to FIG. 52, an unwrapped "four cylinder" rocking beam drive mechanism **5800** is shown. In this embodiment, the rocking beam drive mechanism has four pistons **5802**, **5804**, **5806**, and **5808** coupled to two rocking beam drives **5810** and **5812**. In the exemplary embodiment, rocking beam drive mechanism **5800** is used in a Stirling engine comprising at least four pistons **5802**, **5804**, **5806**, and **5808**, positioned in a quadrilateral arrangement coupled to a pair of rocking beam drives **5810** and **5812**, wherein each rocking beam drive is connected to crankshaft **5814**. However, in other embodiments, the Stirling cycle engine includes anywhere from 1-4 pistons, and in still other embodiments, the Stirling cycle engine includes more than 4 pistons. In some embodiments, rocking beam drives **5810** and **5812** are substantially similar to the rocking beam drives described above with respect to FIGS. 46- 48 (shown as **5210** and **5212** in FIGS. 46-48). Although in this embodiment, the pistons are shown outside the cylinders, in practice, the pistons would be inside cylinders.

Still referring to FIG. 52, in some embodiments, the rocking beam drive mechanism **5800** has a single crankshaft **5814** having a pair of longitudinally spaced, radially and oppositely directed crank pins **5816** and **5818** adapted for being journalled in a housing, and a pair of rocking beam drives **5810** and **5812**. Each rocking beam **5820** and **5822** is pivotally connected to rocker pivots **5824** and **5826**, respectively, and to crankpins **5816** and **5818**, respectively. In the exemplary embodiment, rocking beams **5820** and **5822** are coupled to a rocking beam shaft **5828**.

In some embodiments, a motor/generator may be connected to the crankshaft in a working relationship. The motor may be located, in one embodiment, between the

rocking beam drives. In another embodiment, the motor may be positioned outboard. The term "motor/generator" is used to mean either a motor or a generator.

FIG. 53 shows one embodiment of crankshaft **5814**. Positioned on the crankshaft is a motor/generator **5900**, such as a Permanent Magnetic ("PM") generator. Motor/generator **5900** may be positioned between, or inboard of the rocking beam drives (not shown, shown in FIG. 52 as **5810** and **5812**), or may be positioned outside, or outboard of, rocking beam drives **5810** and **5812** at an end of crankshaft **5814**, as depicted by numeral **51000** in FIG. 54A.

When motor/generator **5900** is positioned between the rocking beam drives (not shown, shown in FIG. 52 as **5810** and **5812**), the length of motor/generator **5900** is limited to the distance between the rocking beam drives. The diameter squared of motor/generator **5900** is limited by the distance between the crankshaft **5814** and the rocking beam shaft **5828**. Because the capacity of motor/generator **5900** is proportional to its diameter squared and length, these dimension limitations result in a limited-capacity "pancake" motor/generator **5900** having relatively short length, and a relatively large diameter squared. The use of a "pancake" motor/generator **5900** may reduce the overall dimension of the engine, however, the dimension limitations imposed by the inboard configuration result in a motor/generator having limited capacity.

Placing motor/generator **5900** between the rocking beam drives exposes motor/generator 5**900** to heat generated by the mechanical friction of the rocking beam drives. The inboard location of motor/generator **5900** makes it more difficult to cool motor/generator **5900**, thereby increasing the effects of heat produced by motor/generator **5900** as well as heat absorbed by motor/generator **5900** from the rocking beam drives. This may lead to overheating, and ultimately failure of motor/generator **5900**.

Referring to both FIGS. 52 and 53, the inboard positioning of motor/generator **5900** may also lead to an unequilateral configuration of pistons **5802**, **5804**, **5806**, and **5808**, since pistons **5802**, **5804**, **5806**, and **5808** are coupled to rocking beam drives **5810** and **5812**, respectively, and any increase in distance would also result in an increase in distance between pistons **5802**, **5804**, and pistons **5806** and **5808**. An unequilateral arrangement of pistons may lead to inefficiencies in burner and heater head thermodynamic operation, which, in turn, may lead to a decrease in overall engine efficiency. Additionally, an unequilateral arrangement of pistons may lead to larger heater head and combustion chamber dimensions.

The exemplary embodiment of the motor/generator arrangement is shown in FIG. 54A. As shown in FIG. 54A, the motor/generator **51000** is positioned outboard from rocking beam drives **51010** and **51012** (shown as **5810** and **5812** in FIGS. 52) and at an end of crankshaft 5**1006**. The outboard position allows for a motor/generator **51000** with a larger length and diameter squared than the "pancake" motor/generator described above (shown as **5900** in FIG. 53). As previously stated, the capacity of motor/generator **51000** is proportional to its length and diameter squared, and since outboard motor/generator **51000** may have a larger length and diameter squared, the outboard motor/generator **51000** configuration shown in FIG. 54A may allow for the use of a higher capacity motor/generator in conjunction with engine.

By placing motor/generator **51000** outboard of drives **51010** and **51012** as shown in the embodiment in FIG. 54A, motor/generator **51000** is not exposed to heat generated by the mechanical friction of drives **51010** and **51012**. Also, the outboard position of motor/generator **1000** makes it easier to cool the motor/generator, thereby allowing for more mechanical engine cycles per a given amount of time, which in turn allows for higher overall engine performance.

Also, as motor/generator **51000** is positioned outside and not positioned between drives **51010** and **51012**, rocking beam drives **51010** and **51012** may be placed closer together thereby allowing the pistons which are coupled to drives **51010** and **51012** to be placed in an equilateral arrangement. In some embodiments, depending on the burner type used, particularly in the case of a single burner embodiment, equilateral arrangement of pistons allows for higher efficiencies in burner and heater head thermodynamic operation, which in turn allows higher overall engine performance. Equilateral arrangement of pistons also advantageously allows for smaller heater head and combustion chamber dimensions.

Referring again to FIGS. 52 and 53, crankshaft **5814** may have concentric ends **5902** and 5**904**, which in one embodiment are crank journals, and in various other embodiments, may be, but are not limited to, bearings. Each concentric end **5902**, **5904** has a crankpin **5816**, **5818** respectively, that may be offset from a crankshaft center axis. At least one counterweight **5906** may be placed at either end of crankshaft **5814** (shown as **51006** in FIG. 54A), to counterbalance any instability the crankshaft **5814** may experience. This crankshaft configuration in combination with the rocking beam drive described above allows the pistons (shown as **5802**, **5804**, **5806**, and **5808** in FIG. 52) to do work with one rotation of the crankshaft **5814**. This characteristic will be further

explained below. In other embodiments, a flywheel (not shown) may be placed on crankshaft **5814** (shown as **51006** in FIG. 54A) to decrease fluctuations of angular velocity for a more constant speed.

Still referring to FIGS. 52 and 53, in some embodiments, a cooler (not shown) may be also be positioned along the crankshaft **5814** (shown as **51006** in FIG. 54A) and rocking beam drives **5810** and **5812** (shown as **51010** and **51012** in FIG. 54A) to cool the crankshaft **5814** and rocking beam drives 5**810** and 5**812**. In some embodiments, the cooler may be used to cool the working gas in a cold chamber of a cylinder and may also be configured to cool the rocking beam drive. Various embodiments of the cooler are discussed in detail below.

FIGS. 54A -54G depict some embodiments of various parts of the machine. As shown in this embodiment, crankshaft **51006** is coupled to motor/generator **51000** via a motor/generator coupling assembly. Since motor/generator **51000** is mounted to crankcase **51008**, pressurization of crankcase with a charge fluid may result in crankcase deformation, which in turn may lead to misalignments between motor/generator **51000** and crankshaft **51006** and cause crankshaft **51006** to deflect. Because rocking beam drives **51010** and **51012** are coupled to crankshaft **51006**, deflection of crankshaft **51006** may lead to failure of rocking beam drives **51010** and **51012**. Thus, in one embodiment of the machine, a motor/generator coupling assembly is used to couple the motor/generator **51000** to crankshaft **51006**. The motor/generator coupling assembly accommodates differences in alignment between motor/generator **51000** and crankshaft **51006** which may contribute to failure of rocking beam drives **51010** and **51012** during operation.

Still referring to FIGS. 54A -54G, in one embodiment, the motor/generator coupling assembly is a spline assembly that includes spline shaft **51004**, sleeve rotor **51002** of motor/generator **51000**, and crankshaft **51006**. Spline shaft **51004** couples one end of crankshaft **51006** to sleeve rotor **51002**. Sleeve rotor **51002** is attached to motor/generator **51000** by mechanical means, such as press fitting, welding, threading, or the like. In one embodiment, spline shaft **51004** includes a plurality of splines on both ends of the shaft. In other embodiments, spline shaft **51004** includes a middle splineless portion **51014**, which has a diameter smaller than the outer diameter or inner diameter of splined portions **51016** and **51018**. In still other embodiments, one end portion of the spline shaft **51016** has splines that extend for a longer distance along the shaft than a second end portion **51018** that also includes splines thereon.

In some embodiments, sleeve rotor **51002** includes an opening **51020** that extends along a longitudinal axis of sleeve rotor **51002**. The opening **51020** is capable of receiving spline shaft 5**1004**. In some embodiments, opening **51020** includes a plurality of inner splines **51022** capable of engaging the splines on one end of spline shaft **51004**. The outer diameter **51028** of inner splines **51022** may be larger than the outer diameter **51030** of the splines on spline shaft **51004**, such that the fit between inner splines **51022** and the splines on spline shaft **51004** is loose (as shown in FIG. 54E). A loose fit between inner splines **51022** and the splines on spline shaft **51004** contributes to maintain spline engagement between spline shaft **51004** and rotor sleeve **51002** during deflection of spline shaft **51004**, which may be caused by crankcase pressurization. In other embodiments, longer splined portion **51016** of spline shaft **51004** may engage inner splines **51022** of rotor **51002**.

Still referring to FIGS. 54A -54G, in some embodiments, crankshaft **51006** has an opening 51024 on an end thereof, which is capable of receiving one end of spline shaft **51004**. Opening **51024** preferably includes a plurality of inner splines **51026** that engage the splines on spline shaft **51004**. The outer diameter **51032** of inner splines **51026** may be larger than the outer diameter **51034** of the splines on spline shaft **51004**, such that the fit between inner splines **51026** and the splines on spline shaft **51004** is loose (as shown in FIG. 54F). As previously discussed, a loose fit between inner splines **51026** and the splines on spline shaft **51004** contributes to maintain spline engagement between spline shaft **51004** and crankshaft **51006** during deflection of spline shaft **51004**, which may be caused by crankcase pressurization. The loose fit between the inner splines **51026** and **51022** on the crankshaft **51006** and the sleeve rotor **51002** and the splines on the spline shaft **51004** may contribute to maintain deflection of spline shaft **51004**. This may allow misalignments between crankshaft **51006** and sleeve rotor **51002**. In some embodiments, shorter splined portion **51018** of spline shaft **51004** may engage opening **51024** of crankshaft **51006** thus preventing these potential misalignments.

In some embodiments, opening **51020** of sleeve rotor **51002** includes a plurality of inner splines that extend the length of opening **51020**. This arrangement contributes to spline shaft 5**1004** being properly inserted into opening **51020** during assembly. This contributes to proper alignment between the splines on spline shaft **51004** and the inner splines on sleeve rotor **51002** being maintained.

Referring now to FIG. 48, one embodiment of the engine is shown. Here the pistons **5202** and **5204** of engine **5300** operate between a hot chamber **5404** and a cold chamber **5406** of cylinders **5206** and **5208** respectively. Between the two chambers there may be a regenerator **5408**. The regenerator **5408** may have variable density, variable area, and, in some embodiments, is made of wire. The varying density and area of the regenerator may be adjusted such that the working gas has substantially uniform flow across the regenerator **5408**. Various embodiments of the regenerator **5408** are discussed in detail below, and in U.S. Patents No. 6,591,609, issued July 17, 2003, to *Kamen et al.*, and No. 6,862,883, issued March 8, 2005, to *Kamen et al.*, which are herein incorporated by reference in their entireties. When the working gas passes through the hot chamber **5404**, a heater head **5410** may heat the gas causing the gas to expand and push pistons **5202** and **5204** towards the cold chamber **5406**, where the gas compresses. As the gas compresses in the cold chamber **5406**, pistons **5202** and **5204** may be guided back to the hot chamber to undergo the Stirling cycle again. The heater head **5410** may be a pin head, a fin head, a folded fin head, heater tubes as shown in FIG. 48, or any other heater head embodiment known, including, but not limited to, those described below. Various embodiments of heater head **5410** are discussed in detail below, and in U.S. Patents No. 6,381,958, issued May 7, 2002, to *Kamen et al.*, No. 6,543,215, issued April 8, 2003, to *Langenfeld et al.*, No. 6,966,182, issued November 22, 2005, to *Kamen et al,* and No. 7,308,787, issued December 18, 2007, to *LaRocque et al.*, which are herein incorporated by reference in their entireties.

In some embodiments, a cooler **5412** may be positioned alongside cylinders **5206** and **5208** to further cool the gas passing through to the cold chamber **5406**. Various embodiments of cooler **5412** are discussed in detail in the proceeding sections, and in U.S. Patent No. 7,325,399, issued Feb. 5, 2008, to *Strimling et al*, which is herein incorporated by reference in its entirety.

In some embodiments, at least one piston seal **5414** may be positioned on pistons **5202** and **5204** to seal the hot section **5404** off from the cold section **5406**. Additionally, at least one piston guide ring **5416** may be positioned on pistons **5202** and **5204** to help guide the pistons' motion in their respective cylinders. Various embodiments of piston seal **5414** and guide ring **5416** are described in detail below, and in U.S. Patent Application Ser. No. 10/175,502, filed June 19, 2002, published February 6, 2003 (now abandoned), which is herein incorporated by reference in its entirety.

In some embodiments, at least one piston rod seal **5418** may be placed against piston rods **5224** and **5228** to prevent working gas from escaping into the crankcase **5400,** or alternatively into airlock space **5420**. The piston rod seal **5418** may be an elastomer seal, or a spring-loaded seal. Various embodiments of the piston rod seal **5418** are discussed in detail below.

In some embodiments, the airlock space may be eliminated, for example, in the rolling diaphragm and/or bellows embodiments described in more detail below. In those cases, the piston rod seals **5224** and **5228** seal the working space from the crankcase.

In some embodiments, at least one rolling diaphragm/bellows **5422** may be located along piston rods **5224** and **5228** to prevent airlock gas from escaping into the crankcase **5400**. Various embodiments of rolling diaphragm **5422** are discussed in more detail below.

Although FIG. 48 shows a cross section of engine **5300** depicting only two pistons and one rocking beam drive, it is to be understood that the principles of operation described herein may apply to a four cylinder, double rocking beam drive engine, as designated generally by numeral **5800** in FIG. 52.

**Piston Operation**

Referring now to FIGS. 52 and 55, the operation of pistons **5802**, **5804**, **5806**, and **5808** during one revolution of crankshaft **5814** is shown. With a ¼ revolution of crankshaft **5814**, piston **5802** is at the top of its cylinder, otherwise known as top dead center, piston **5806** is in upward midstroke, piston **5804** is at the bottom of its cylinder, otherwise known as bottom dead center, and piston **5808** is in downward midstroke. With a ½ revolution of crankshaft **5814**, piston **5802** is in downward midstroke, piston **5806** is at top dead center, piston **5804** is in upward midstroke, and piston **5808** is at bottom dead center. With ¾ revolution of crankshaft **5814**, piston **5802** is at bottom dead center, piston **5806** is in downward midstroke, piston **5804** is at top dead center, and piston **5808** is in upward midstroke. Finally, with a full revolution of crankshaft **5814**, piston **5802** is in upward midstroke, piston **5806** is at bottom dead center, piston **5804** is in downward midstroke, and piston **5808** is at top dead center. During each ¼ revolution, there is a 90 degree phase difference between pistons **5802** and **5806**, a 180 degree phase difference between pistons **5802** and **5804**, and a 270 degree phase difference between pistons **5802** and **5808**. FIG. 56A illustrates the relationship of the pistons being approximately 90 degrees out of phase with the preceding and succeeding piston. Additionally, FIG. 55 shows the exemplary embodiment machine means of

transferring work. Thus, work is transferred from piston **5802** to piston **5806** to piston **5804** to piston **5808** so that with a full revolution of crankshaft **5814**, all pistons have exerted work by moving from the top to the bottom of their respective cylinders.

Referring now to FIG. 55, together with FIGS. 56A-56C, illustrate the 90 degree phase difference between the pistons in the exemplary embodiment. Referring now to FIGS. 56A, although the cylinders are shown in a linear path, this is for illustration purposes only. In the exemplary embodiment of a four cylinder Stirling cycle machine, the flow path of the working gas contained within the cylinder working space follows a figure eight pattern. Thus, the working spaces of cylinders **51200**, **51202**, **51204**, and **51206** are connected in a figure eight pattern, for example, from cylinder **51200** to cylinder **51202** to cylinder **51204** to cylinder **51208**, the fluid flow pattern follows a figure eight. Still referring to FIG. 56A, an unwrapped view of cylinders **51200**, **51202**, **51204**, and **51206**, taken along the line B-B (shown in FIG. 56C) is illustrated. The 90 degree phase difference between pistons as described above allows for the working gas in the warm section **51212** of cylinder **51204** to be delivered to the cold section **51222** of cylinder **51206**. As piston **5802** and **5808** are 90 degrees out of phase, the working gas in the warm section **51214** of cylinder **51206** is delivered to the cold section **51216** of cylinder **51200**. As piston **5802** and piston **5806** are also 90 degrees out of phase, the working gas in the warm section **51208** of cylinder **51200** is delivered to the cold section **51218** of cylinder **51202**. And as piston **5804** and piston **5806** are also 90 degrees out of phase, so the working gas in the warm section **51210** of cylinder **51202** is delivered to the cold section **51220** of cylinder **51204**. Once the working gas of a warm section of a first cylinder enters the cold section of a second cylinder, the working gas begins to compress, and the piston within the second cylinder, in its down stroke, thereafter forces the compressed working gas back through a regenerator **51224** and heater head **51226** (shown in FIG. 56B), and back into the warm section of the first cylinder. Once inside the warm section of the first cylinder, the gas expands and drives the piston within that cylinder downward, thus causing the working gas within the cold section of that first cylinder to be driven through the preceding regenerator and heater head, and into the cylinder. This cyclic transmigration characteristic of working gas between cylinders **51200**, **51202**, **51204**, and **51206** is possible because pistons **5802**, **5804**, **5806**, and **5808** are connected, via drives **5810** and **5812**, to a common crankshaft **5814** (shown in FIG. 55), in such a way that the cyclical movement of each piston is

approximately 90 degrees in advance of the movement of the proceeding piston, as depicted in FIG. 56A.

**Rolling Diaphragm, Metal Bellows, Airlock, and Pressure Regulator**

In some embodiments of the Stirling cycle machine, lubricating fluid is used. To prevent the lubricating fluid from escaping the crankcase, a seal is used.

Referring now to FIGS. 57A-59, some embodiments of the Stirling cycle machine include a fluid lubricated rocking beam drive that utilizes a rolling diaphragm **51300** positioned along the piston rod **51302** to prevent lubricating fluid from escaping the crankcase, not shown, but the components that are housed in the crankcase are represented as **51304**, and entering areas of the engine that may be damaged by the lubricating fluid. It is beneficial to contain the lubricating fluid for if lubricating fluid enters the working space, not shown, but the components that are housed in the working space are represented as **51306**, it would contaminate the working fluid, come into contact with the regenerator **51308**, and may clog the regenerator **51308**. The rolling diaphragm **51300** may be made of an elastomer material, such as rubber or rubber reinforced with woven fabric or non-woven fabric to provide rigidity. The rolling diaphragm **51300** may alternatively be made of other materials, such as fluorosilicone or nitrile with woven fabric or non-woven fabric. The rolling diaphragm **51300** may also be made of carbon nanotubes or chopped fabric, which is non-woven fabric with fibers of polyester or KEVLAR®, for example, dispersed in an elastomer. In the some embodiments, the rolling diaphragm **51300** is supported by the top seal piston **51328** and the bottom seal piston **51310**. In other embodiments, the rolling diaphragm **51300** as shown in FIG. 57A is supported via notches in the top seal piston **51328**.

In some embodiments, a pressure differential is placed across the rolling diaphragm **51300** such that the pressure above the seal **51300** is different from the pressure in the crankcase **51304**. This pressure differential inflates seal **51300** and allows seal **51300** to act as a dynamic seal as the pressure differential ensures that rolling diaphragm maintains its form throughout operation. FIGS. 57A, and FIGS. 57C-57H illustrate how the pressure differential effects the rolling diaphragm. The pressure differential causes the rolling diaphragm **51300** to conform to the shape of the bottom seal piston **51310** as it moves with the piston rod **51302**, and prevents separation of the seal **51300** from a surface of the piston **51310** during operation. Such separation may cause seal failure. The pressure differential causes the rolling diaphragm **51300** to maintain constant contact with the bottom seal piston **51310** as it moves with the piston

rod **51302**. This occurs because one side of the seal **51300** will always have pressure exerted on it thereby inflating the seal **51300** to conform to the surface of the bottom seal piston **51310**. In some embodiments, the top seal piston **51328** 'rolls over' the corners of the rolling diaphragm **51300** that are in contact with the bottom seal piston **51310**, so as to further maintain the seal **51300** in contact with the bottom seal piston **51310**. In the exemplary embodiment, the pressure differential is in the range of 10 to 15 PSI. The smaller pressure in the pressure differential is preferably in crankcase **51304**, so that the rolling diaphragm **51300** may be inflated into the crankcase **51304**. However, in other embodiments, the pressure differential may have a greater or smaller range of value.

The pressure differential may be created by various methods including, but not limited to, the use of the following: a pressurized lubrication system, a pneumatic pump, sensors, an electric pump, by oscillating the rocking beam to create a pressure rise in the crankcase **51304**, by creating an electrostatic charge on the rolling diaphragm **51300**, or other similar methods. In some embodiments, the pressure differential is created by pressurizing the crankcase **51304** to a pressure that is below the mean pressure of the working space **51306**. In some embodiments the crankcase **51304** is pressurized to a pressure in the range of 10 to 15 PSI below the mean pressure of the working space **51306**, however, in various other embodiments, the pressure differential may be smaller or greater. Further detail regarding the rolling diaphragm is included below.

Referring now to FIGS. 57C, 57G, and 57H, however, another embodiment of the Stirling machine is shown, wherein airlock space **51312** is located between working space **51306** and crankcase **51304**. Airlock space **51312** maintains a constant volume and pressure necessary to create the pressure differential necessary for the function of rolling diaphragm **51300** as described above. In one embodiment, airlock **51312** is not absolutely sealed off from working space **51306**, so the pressure of airlock **51312** is equal to the mean pressure of working space **51306**. Thus, in some embodiments, the lack of an effective seal between the working space and the crankcase contributes to the need for an airlock space. Thus, the airlock space, in some embodiments, may be eliminated by a more efficient and effective seal.

During operation, the working space **51306** mean pressure may vary so as to cause airlock **51312** mean pressure to vary as well. One reason the pressure may tend to vary is that during operation the working space may get hotter, which in turn may increase the pressure in the working space, and consequently in the airlock as well since

the airlock and working space are in fluid communication. In such a case, the pressure differential between airlock **51312** and crankcase **51304** will also vary, thereby causing unnecessary stresses in rolling diaphragms **51300** that may lead to seal failure. Therefore, some embodiments of the machine, the mean pressure within airlock **51312** is regulated so as to maintain a constant desired pressure differential between airlock **51312** and crankcase **51304**, and ensuring that rolling diaphragms **51300** stay inflated and maintains their form. In some embodiments, a pressure transducer is used to monitor and manage the pressure differential between the airlock and the crankcase, and regulate the pressure accordingly so as to maintain a constant pressure differential between the airlock and the crankcase. Various embodiments of the pressure regulator that may be used are described in further detail below, and in U.S. Patent No. 7,310,945, issued Dec. 25, 2007, to *Gurski et al.*, which is herein incorporated by reference in its entirety.

A constant pressure differential between the airlock **51312** and crankcase **51304** may be achieved by adding or removing working fluid from airlock **51312** via a pump or a release valve. Alternatively, a constant pressure differential between airlock **51312** and crankcase **51304** may be achieved by adding or removing working fluid from crankcase **51304** via a pump or a release valve. The pump and release valve may be controlled by the pressure regulator. Working fluid may be added to airlock **51312** (or crankcase **51304**) from a separate source, such as a working fluid container, or may be transferred over from crankcase **51304**. Should working fluid be transferred from crankcase **51304** to airlock **51312**, it may be desirable to filter the working fluid before passing it into airlock **51312** so as to prevent any lubricant from passing from crankcase **51304** into airlock **51312**, and ultimately into working space **51306**, as this may result in engine failure.

In some embodiments of the machine, crankcase **51304** may be charged with a fluid having different thermal properties than the working fluid. For example, where the working gas is helium or hydrogen, the crankcase may be charged with argon. Thus, the crankcase is pressurized. In some embodiments, helium is used, but in other embodiments, any inert gas, as described herein, may be used. Thus, the crankcase is a wet pressurized crankcase in the exemplary embodiment. In other embodiments where a lubricating fluid is not used, the crankcase is not wet.

In the exemplary embodiments, rolling diaphragms **51300** do not allow gas or liquid to pass through them, which allows working space **51306** to remain dry and

crankcase **51304** to be wet sumped with a lubricating fluid. Allowing a wet sump crankcase **51304** increases the efficiency and life of the engine as there is less friction in rocking beam drives **51316**. In some embodiments, the use of roller bearings or ball bearings in drives **51316** may also be eliminated with the use of lubricating fluid and rolling diaphragms **51300**. This may further reduce engine noise and increase engine life and efficiency.

FIGS. 58A-58E show cross sections of various embodiments of the rolling diaphragm (shown as **51400**, **51410**, **51412**, **51422** and **51424**) configured to be mounted between top seal piston and bottom seal piston (shown as **51328** and **51310** in FIGS. 57A and 57H), and between a top mounting surface and a bottom mounting surface (shown as **51320** and **51318** in FIG. 57A). In some embodiments, the top mounting surface may be the surface of an airlock or working space, and the bottom mounting surface may be the surface of a crankcase.

FIG. 58A shows one embodiment of the rolling diaphragm **51400**, where the rolling diaphragm **51400** includes a flat inner end **51402** that may be positioned between a top seal piston and a bottom seal piston, so as to form a seal between the top seal piston and the bottom seal piston. The rolling diaphragm **51400** also includes a flat outer end **51404** that may be positioned between a top mounting surface and a bottom mounting surface, so as to form a seal between the top mounting surface and the bottom mounting surface. FIG. 58B shows another embodiment of the rolling diaphragm, wherein rolling diaphragm **51410** may include a plurality of bends **51408** leading up to flat inner end **51406** to provide for additional support and sealing contact between the top seal piston and the bottom seal piston. FIG. 58C shows another embodiment of the rolling diaphragm, wherein rolling diaphragm **51412** includes a plurality of bends **51416** leading up to flat outer end **51414** to provide for additional support and sealing contact between the top mounting surface and the bottom mounting surface.

FIG. 58D shows another embodiment of the rolling diaphragm where rolling diaphragm **51422** includes a bead along an inner end **51420** thereof, so as to form an 'o-ring' type seal between a top seal piston and a bottom seal piston, and a bead along an outer end **51418** thereof, so as to form an 'o-ring' type seal between a bottom mounting surface and a top mounting surface. FIG. 58E shows another embodiment of the rolling diaphragm, wherein rolling diaphragm **51424** includes a plurality of bends **51428** leading up to beaded inner end **51426** to provide for additional support and sealing contact between the top seal piston and the bottom seal piston. Rolling diaphragm

**51424** may also include a plurality of bends **51430** leading up to beaded outer end **51432** to provide for additional support and sealing contact between the top seal piston and the bottom seal piston.

Although FIGS. 58A through 58E depict various embodiments of the rolling diaphragm, it is to be understood that rolling diaphragms may be held in place by any other mechanical means known in the art.

Referring now to FIG. 59A, a cross section shows one embodiment of the rolling diaphragm embodiment. A metal bellows **51500** is positioned along a piston rod **51502** to seal off a crankcase (shown as **51304** in FIG. 57G) from a working space or airlock (shown as **51306** and **51312** in FIG. 57G). Metal bellows **51500** may be attached to a top seal piston **51504** and a stationary mounting surface **51506**. Alternatively, metal bellows **51500** may be attached to a bottom seal piston (not shown), and a top stationary mounting surface. In one embodiment the bottom stationary mounting surface may be a crankcase surface or an inner airlock or working space surface, and the top stationary mounting surface may be an inner crankcase surface, or an outer airlock or working space surface. Metal bellows **51500** may be attached by welding, brazing, or any mechanical means known in the art.

FIGS. 59B-59G depict a perspective cross sectional view of various embodiments of the metal bellows, wherein the metal bellows is a welded metal bellows **51508**. In some embodiments of the metal bellows, the metal bellows is preferably a micro-welded metal bellows. In some embodiments, the welded metal bellows **51508** includes a plurality of diaphragms **51510**, which are welded to each other at either an inner end **51512** or an outer end **51514**, as shown in FIGS. 59C and 59D. In some embodiments, diaphragms **51510** may be crescent shaped **51516**, flat **51518**, rippled **51520**, or any other shape known in the art.

Additionally, the metal bellows may alternatively be formed mechanically by means such as die forming, hydroforming, explosive hydroforming, hydramolding, or any other means known in the art.

The metal bellows may be made of any type of metal, including but not limited to, steel, stainless steel, stainless steel 374, AM-350 stainless steel, Inconel, Hastelloy, Haynes, titanium, or any other high-strength, corrosion-resistant material.

In one embodiment, the metal bellows used are those available from Senior Aerospace Metal Bellows Division, Sharon, MA, or American BOA, Inc., Cumming, GA.

## Rolling Diaphragm and/or Bellows Embodiments

Various embodiments of the rolling diaphragm and/or bellows, which function to seal, are described above. Further embodiments will be apparent to those of skill in the art based on the description above and the additional description below relating to the parameters of the rolling diaphragm and/or bellows.

In some embodiments, the pressure atop the rolling diaphragm or bellows, in the airlock space or airlock area (both terms are used interchangeably), is the mean-working-gas pressure for the machine, which, in some embodiments is an engine, while the pressure below the rolling diaphragm and/or bellows, in the crankcase area, is ambient/atmospheric pressure. In these embodiments, the rolling diaphragm and/or bellows is required to operate with as much as 3000psi across it (and in some embodiments, up to 1500psi or higher). In this case, the rolling diaphragm and/or bellows seal forms the working gas (helium, hydrogen, or otherwise) containment barrier for the machine (engine in the exemplary embodiment). Also, in these embodiments, the need for a heavy, pressure-rated, structural vessel to contain the bottom end of the engine is eliminated, since it is now required to simply contain lubricating fluid (oil is used as a lubricating fluid in the exemplary embodiment) and air at ambient pressure, like a conventional internal combustion ("IC") engine.

The capability to use a rolling diaphragm and/or bellows seal with such an extreme pressure across it depends on the interaction of several parameters. Referring now to FIG. 59H, an illustration of the actual load on the rolling diaphragm or bellows material is shown. As shown, the load is a function of the pressure differential and the annular gap area for the installed rolling diaphragm or bellows seal.

**Region 1** represents the portions of the rolling diaphragm and/or bellows that are in contact with the walls formed by the piston and cylinder. The load is essentially a tensile load in the axial direction, due to the pressure differential across the rolling diaphragm and/or bellows. This tensile load due to the pressure across the rolling diaphragm and/or bellows can be expressed as:

$$L_t = P_d * A_a$$

Where

$L_t$ = Tensile Load and

$P_d$ = Pressure Differential

$A_a$ = Annular Area

and

$A_a = p / 4 * (D^2 - d^2)$

Where

D = Cylinder Bore and

d = Piston Diameter

The tensile component of stress in the bellows material can be approximated as:

$S_t = L_t / (p * (D+d) * t_b)$

Which reduces to:

$S_t = P_d /4 * (D-d) / tb$

Later, we will show the relationship of radius of convolution, $R_c$, to Cylinder bore (D) and Piston Diameter (d) to be defined as:

$R_c = (D-d)/4$

So, this formula for St reduces to its final form:

$S_t = P_d * R_c / t_b$

Where

$t_b$ = thickness of bellows material

Still referring to FIG. 59H, **Region 2** represents the convolution. As the rolling diaphragm and/or bellows material turns the corner, in the convolution, the hoop stress imposed on the rolling diaphragm and/or bellows material may be calculated. For the section of the bellows forming the convolution, the hoop component of stress can be closely approximated as:

$S_h = P_d * R_c / t_b$

The annular gap that the rolling diaphragm and/or bellows rolls within is generally referred to as the convolution area. The rolling diaphragm and/or bellows fatigue life is generally limited by the combined stress from both the tensile (and hoop) load, due to pressure differential, as well as the fatigue due to the bending as the fabric rolls through the convolution. The radius that the fabric takes on during this 'rolling' is defined here as the radius of convolution, Rc.

$R_c = (D-d)/4$

The bending stress, Sb, in the rolling diaphragm and/or bellows material as it rolls through the radius of convolution, Rc, is a function of that radius, as well as the thickness of the materials in bending. For a fiber-reinforced material, the stress in the fibers themselves (during the prescribed deflection in the exemplary embodiments) is reduced as the fiber diameter decreases. The lower resultant stress for the same level of bending allows for an increased fatigue life limit. As the fiber diameter is further

reduced, flexibility to decrease the radius of convolution Rc is achieved, while keeping the bending stress in the fiber under its endurance limit. At the same time, as Rc decreases, the tensile load on the fabric is reduced since there is less unsupported area in the annulus between the piston and cylinder. The smaller the fiber diameter, the smaller the minimum Rc , the smaller the annular area, which results in a higher allowable pressure differential.

For bending around a prescribed radius, the bending moment is approximated by:

$M = E * I / R$

Where:

M = Bending Moment

E = Elastic Modulus

I = Moment of Inertia

R = Radius of Bend

Classical bending stress, $S_b$ , is calculated as:

$S_b = M * Y / I$

Where:

Y = Distance above neutral axis of bending

Substituting yields:

$S_b = (E * I / R) * Y / I$

$S_b = E * Y / R$

Assuming bending is about a central neutral axis:

$Y_{max} = t_b / 2$

$S_b = E * t_b / (2 * R)$

In some embodiments, rolling diaphragm and/or bellows designs for high cycle life are based on geometry where the bending stress imposed is kept about one order of magnitude less than the pressure-based loading (hoop and axial stresses). Based on the equation: Sb = E * tb / (2 * R), it is clear that minimizing tb in direct proportion to Rc should not increase the bending stress. The minimum thickness for the exemplary embodiments of the rolling diaphragm and/or bellows material or membrane is directly related to the minimum fiber diameter that is used in the reinforcement of the elastomer. The smaller the fibers used, the smaller resultant Rc for a given stress level.

Another limiting component of load on the rolling diaphragm and/or bellows is the hoop stress in the convolution (which is theoretically the same in magnitude as the

axial load while supported by the piston or cylinder). The governing equation for that load is as follows:

Sh = Pd * Rc / tb

Thus, if Rc is decreased in direct proportion to tb, then there is no increase of stress on the membrane in this region. However, if this ratio is reduced in a manner that decreases Rc to a greater ratio than tb then parameters must be balanced. Thus, decreasing tb with respect to Rc requires the rolling diaphragm and/or bellows to carry a heavier stress due to pressure, but makes for a reduced stress level due to bending. The pressure-based load is essentially constant, so this may be favorable---since the bending load is cyclic, therefore it is the bending load component that ultimately limits fatigue life.

For bending stress reduction, tb ideally should be at a minimum, and Rc ideally should be at a maximum. E ideally is also at a minimum. For hoop stress reduction, Rc ideally is small, and tb ideally is large.

Thus, the critical parameters for the rolling diaphragm and/or bellows membrane material are:

E, Elastic Modulus of the membrane material;

tb, membrane thickness (and/or fiber diameter);

Sut, Ultimate tensile strength of the rolling diaphragm and/or bellows; and

Slcf, The limiting fatigue strength of the rolling diaphragm and/or bellows.

Thus, from E, tb and Sut, the minimum acceptable Rc may be calculated. Next, using Rc, Slcf, and tb, the maximum Pd may be calculates. Rc may be adjusted to shift the bias of load (stress) components between the steady state pressure stress and the cyclic bending stress. Thus, the ideal rolling diaphragm and/or bellows material is extremely thin, extremely strong in tension, and very limber in flexion.

Thus, in some embodiments, the rolling diaphragm and/or bellows material (sometimes referred to as a "membrane"), is made from carbon fiber nanotubes. However, additional small fiber materials may also be used, including, but not limited to nanotube fibers that have been braided, nanotube untwisted yarn fibers, or any other conventional materials, including but not limited to KEVLAR, glass, polyester, synthetic fibers and any other material or fiber having a desirable diameter and/or other desired parameters as described in detail above.

**Piston Seals and Piston Rod Seals**

Referring now to FIG. 57G, an embodiment of the machine is shown wherein an engine **51326**, such as a Stirling cycle engine, includes at least one piston rod seal **51314**, a piston seal **51324**, and a piston guide ring **51322**, (shown as **51616** in FIG. 60). Various embodiments of the piston seal **51324** and the piston guide ring **51322** are further discussed below, and in U.S. Patent Application Publication No. US 2003/0024387 A1 to Langenfeld et al., February 6, 2003 (now abandoned), which, as mentioned before, is incorporated by reference.

FIG. 60 shows a partial cross section of the piston **51600**, driven along the central axis **51602** of cylinder, or the cylinder **51604**. The piston seal (shown as **51324** in FIG. 57G) may include a seal ring **51606**, which provides a seal against the contact surface **51608** of the cylinder **51604**. The contact surface **51608** is typically a hardened metal (preferably 58-62 RC) with a surface finish of 12 RMS or smoother. The contact surface **51608** may be metal which has been case hardened, such as 8260 hardened steel, which may be easily case hardened and may be ground and/or honed to achieve a desired finish. The piston seal may also include a backing ring **51610**, which is sprung to provide a thrust force against the seal ring **51606** thereby providing sufficient contact pressure to ensure sealing around the entire outward surface of the seal ring **51606**. The seal ring **51606** and the backing ring **51610** may together be referred to as a piston seal composite ring. In some embodiments, the at least one piston seal may seal off a warm portion of cylinder **51604** from a cold portion of cylinder **51604**.

Referring now to FIG. 61, some embodiments include a piston rod seal (shown as **51314** in FIG. 57G) mounted in the piston rod cylinder wall **51700**, which, in some embodiments, may include a seal ring **51706**, which provides a seal against the contact surface **51708** of the piston rod **51604** (shown as **51302** in FIG. 57G). The contact surface **51708** in some embodiments is a hardened metal (preferably 58-62 RC) with a surface finish of 12 RMS or smoother. The contact surface **51708** may be metal which has been case hardened, such as **58260** hardened steel, which may be easily case hardened and may be ground and/or honed to achieve a desired finish. The piston seal may also include a backing ring **51710**, which is sprung to provide a radial or hoop force against the seal ring **51706** thereby providing sufficient contact hoop stress to ensure sealing around the entire inward surface of seal ring **51706**. The seal ring **51706** and the backing ring **51710** may together be referred to as a piston rod seal composite ring.

In some embodiments, the seal ring and the backing ring may be positioned on a piston rod, with the backing exerting an outward pressure on the seal ring, and the seal

ring may come into contact with a piston rod cylinder wall **51702**. These embodiments require a larger piston rod cylinder length than the previous embodiment. This is because the contact surface on the piston rod cylinder wall **51702** will be longer than in the previous embodiment, where the contact surface **51708** lies on the piston rod itself. In yet another embodiment, piston rod seals may be any functional seal known in the art including, but not limited to, an o-ring, a graphite clearance seal, graphite piston in a glass cylinder, or any air pot, or a spring energized lip seal. In some embodiments, anything having a close clearance may be used, in other embodiments, anything having interference, for example, a seal, is used. In the exemplary embodiment, a spring energized lip seal is used. Any spring energized lip seal may be used, including those made by BAL SEAL Engineering, Inc., Foothill Ranch, CA. In some embodiments, the seal used is a BAL SEAL Part Number X558604.

The material of the seal rings **51606** and **51706** is chosen by considering a balance between the coefficient of friction of the seal rings **51606** and **51706** against the contact surfaces **51608** and **51708**, respectively, and the wear on the seal rings **51606** and **51706** it engenders. In applications in which piston lubrication is not possible, such as at the high operating temperatures of a Stirling cycle engine, the use of engineering plastic rings is used. The embodiments of the composition include a nylon matrix loaded with a lubricating and wear-resistant material. Examples of such lubricating materials include PTFE/silicone, PTFE, graphite, etc. Examples of wear-resistant materials include glass fibers and carbon fibers. Examples of such engineering plastics are manufactured by LNP Engineering Plastics, Inc. of Exton, PA. Backing rings **51610** and **51710** is preferably metal.

The fit between the seal rings **51606** and **51706** and the seal ring grooves **51612** and **51712**, respectively, is preferably a clearance fit (about 0.002"), while the fit of the backing rings **51610** and **51710** is preferably a looser fit, of the order of about 0.005" in some embodiments. The seal rings **51606** and **51706** provide a pressure seal against the contact surfaces **51608** and **51708**, respectively, and also one of the surfaces **51614** and **51714** of the seal ring grooves **51612** and **51712**, respectively, depending on the direction of the pressure difference across the rings **51606** and **51706** and the direction of the piston **51600** or the piston rod **51704** travel.

FIGS. 62A and 62B show that if the backing ring **51820** is essentially circularly symmetrical, but for the gap **51800**, it will assume, upon compression, an oval shape, as shown by the dashed backing ring **51802**. The result may be an uneven radial or hoop

force (depicted by arrows **51804**) exerted on the seal ring (not shown, shown as **51606** and **51706** in FIGS. 60 and 61), and thus an uneven pressure of the seal rings against the contact surfaces (not shown, shown as **51608** and **51708** in FIGS. 60 and 61) respectively, causing uneven wear of the seal rings and in some cases, failure of the seals.

A solution to the problem of uneven radial or hoop force exerted by the piston seal backing ring **51820**, in accordance with an embodiment, is a backing ring **51822** having a cross-section varying with circumferential displacement from the gap **51800**, as shown in FIGS. 62C and 62D. A tapering of the width of the backing ring **51822** is shown from the position denoted by numeral **51806** to the position denoted by numeral **51808**. Also shown in FIGS. 62C and 62D is a lap joint **51810** providing for circumferential closure of the seal ring **51606**. As some seals will wear significantly over their lifetime, the backing ring **51822** should provide an even pressure (depicted by numeral **51904** in FIG. 63B) of a range of movement. The tapered backing ring **51822** shown in FIGS. 62C and 62D may provide this advantage.

FIGS. 63A and 63B illustrate another solution to the problem of uneven radial or hoop force of the piston seal ring against the piston cylinder, in accordance with some embodiments. As shown in FIG. 63A, backing ring **51910** is fashioned in an oval shape, so that upon compression within the cylinder, the ring assumes the circular shape shown by dashed backing ring **51902**. A constant contact pressure between the seal ring and the cylinder contact surface may thus be provided by an even radial force **51904** of backing ring **51902**, as shown in FIG. 63B.

A solution to the problem of uneven radial or hoop force exerted by the piston rod seal backing ring, in accordance with some embodiments, is a backing ring **51824** having a cross-section varying with circumferential displacement from gap **51812**, as shown in FIGS. 62E and 62F. A tapering of the width of backing ring **51824** is shown from the position denoted by numeral **51814** to the position denoted by numeral **51816**. Also shown in FIGS. 62E and 62F is a lap joint **51818** providing for circumferential closure of seal ring **51706**. As some seals will wear significantly over their lifetime, backing ring **51824** should provide an even pressure (depicted by numeral **52004** in FIG. 64B) of a range of movement. The tapered backing ring **51824** shown in FIGS. 62E and 62F may provide this advantage.

FIGS. 64A and 64B illustrate another solution to the problem of uneven radial or hoop force of the piston rod seal ring against the piston rod contact surface, in

accordance with some embodiments. As shown in FIG. 64A, backing ring (shown by dashed backing ring **52000**) is fashioned as an oval shape, so that upon expansion within the cylinder, the ring assumes the circular shape shown by backing ring **52002**. A constant contact pressure between the seal ring **51706** and the cylinder contact surface may thus be provided by an even radial thrust force **52004** of backing ring **52002**, as shown in FIG. 64B.

Referring again to FIG. 60, at least one guide ring **51616** may also be provided, in accordance with some embodiments, for bearing any side load on piston **51600** as it moves up and down the cylinder **51604**. Guide ring **51616** is also preferably fabricated from an engineering plastic material loaded with a lubricating material. A perspective view of guide ring **51616** is shown in FIG. 65. An overlapping joint **52100** is shown and may be diagonal to the central axis of guide ring **51616**.

## Lubricating Fluid Pump and Lubricating Fluid Passageways

Referring now to FIG. 66, a representative illustration of one embodiment of the engine **52200** for the machine is shown having a rocking beam drive **52202** and lubricating fluid **52204**. In some embodiments, the lubricating fluid is oil. The lubricating fluid is used to lubricate engine parts in the crankcase **52206**, such as hydrodynamic pressure fed lubricated bearings. Lubricating the moving parts of the engine **52200** serves to further reduce friction between engine parts and further increase engine efficiency and engine life. In some embodiments, lubricating fluid may be placed at the bottom of the engine, also known as an oil sump, and distributed throughout the crankcase. The lubricating fluid may be distributed to the different parts of the engine **52200** by way of a lubricating fluid pump, wherein the lubricating fluid pump may collect lubricating fluid from the sump via a filtered inlet. In the exemplary embodiment, the lubricating fluid is oil and thus, the lubricating fluid pump is herein referred to as an oil pump. However, the term "oil pump" is used only to describe the exemplary embodiment and other embodiments where oil is used as a lubricating fluid, and the term shall not be construed to limit the lubricating fluid or the lubricating fluid pump.

Referring now to FIGS. 67A and 67B, one embodiment of the engine is shown, wherein lubricating fluid is distributed to different parts of the engine **52200** that are located in the crankcase **52206** by a mechanical oil pump **52208**. The oil pump **52208** may include a drive gear **52210** and an idle gear **52212**. In some embodiments, the mechanical oil pump **52208** may be driven by a pump drive assembly. The pump drive assembly may include a drive shaft **52214** coupled to a drive gear **52210**, wherein the drive shaft **52214** includes an intermediate gear **52216** thereon. The intermediate gear **52216** is preferably driven by a crankshaft gear **52220**, wherein the crankshaft gear **52220** is coupled to the primary crankshaft **52218** of the engine **52200**, as shown in FIG. 524. In this configuration, the crankshaft **52218** indirectly drives the mechanical oil pump **52208** via the crankshaft gear **52220**, which drives the intermediate gear **52216** on the drive shaft **52214**, which, in turn, drives the drive gear **52210** of the oil pump **52208**.

The crankshaft gear **52220** may be positioned between the crankpins **52222** and **52224** of crankshaft **52218** in some embodiments, as shown in FIG. 68. In other embodiments, the crankshaft gear **52220** may be placed at an end of the crankshaft **52218**, as shown in FIGS. 69A - 69C.

For ease of manufacturing, the crankshaft **52218** may be composed of a plurality of pieces. In these embodiments, the crankshaft gear **52220** may be to be inserted between the crankshaft pieces during assembly of the crankshaft.

The drive shaft **52214**, in some embodiments, may be positioned perpendicularly to the crankshaft **52218**, as shown in FIGS. 67A and 69A. However, in some embodiments, the drive shaft **52214** may be positioned parallel to the crankshaft **52218**, as shown in FIGS. 69B and 69C.

In some embodiments, the crankshaft gear **52234** and the intermediate gear **52232** may be sprockets, wherein the crankshaft gear **52234** and the intermediate gear **52232** are coupled by a chain **52226**, as shown in FIGS. 69C and 70C. In such an embodiments, the chain **52226** is used to drive a chain drive pump (shown as **52600** in FIGS. 70A through 70C).

In some embodiments, the gear ratio between the crankshaft **52218** and the drive shaft **52214** remains constant throughout operation. In such an embodiment, it is important to have an appropriate gear ratio between the crankshaft and the drive shaft, such that the gear ratio balances the pump speed and the speed of the engine. This achieves a specified flow of lubricant required by a particular engine RPM (revolutions per minute) operating range.

In some embodiments, lubricating fluid is distributed to different parts of an engine by an electric pump. The electric pump eliminates the need for a pump drive assembly, which is otherwise required by a mechanical oil pump.

Referring back to FIGS. 67A and 67B, the oil pump **52208** may include an inlet **52228** to collect lubricating fluid from the sump and an outlet **52230** to deliver lubricating fluid to the various parts of the engine. In some embodiments, the rotation of the drive gear **52212** and the idle gear **52210** cause the lubricating fluid from the sump to be drawn into the oil pump through the inlet **52228** and forced out of the pump through the outlet **52230**. The inlet **52228** preferably includes a filter to remove particulates that may be found in the lubricating fluid prior to its being drawn into the oil pump. In some embodiments, the inlet **52228** may be connected to the sump via a tube, pipe, or hose. In some embodiments, the inlet **52228** may be in direct fluid communication with the sump.

In some embodiments, the oil pump outlet **52230** is connected to a series of passageways in the various engine parts, through which the lubricating fluid is delivered to the various engine parts. The outlet **52230** may be integrated with the passageways so

as to be in direct communication with the passageways, or may be connected to the passageways via a hose or tube, or a plurality of hoses or tubes. The series of passageways are preferably an interconnected network of passageways, so that the outlet **52230** may be connected to a single passageway inlet and still be able to deliver lubricating fluid to the engine's lubricated parts.

FIGS 71A-71D show one embodiments, wherein the oil pump outlet (shown as **52230** in FIG. 67B) is connected to a passageway **52700** in the rocker shaft **52702** of the rocking beam drive **52704**. The rocker shaft passageway **52700** delivers lubricating fluid to the rocker pivot bearings **52706**, and is connected to and delivers lubricating fluid to the rocking beam passageways (not shown). The rocking beam passageways deliver lubricating fluid to the connecting wrist pin bearings **52708**, the link rod bearings **52710**, and the link rod passageways **52712**. The link rod passageways **52712** deliver lubricating fluid to the piston rod coupling bearing **52714**. The connecting rod passageway (not shown) of the connecting rod **52720** delivers lubricating fluid to a first crank pin **52722** and the crankshaft passageway **52724** of the crankshaft **52726**. The crankshaft passageway **52724** delivers lubricating fluid to the crankshaft journal bearings **52728**, the second crank pin bearing **52730**, and the spline shaft passageway **52732**. The spline shaft passageway **52732** delivers lubricating fluid to the spline shaft spline joints **52734** and **52736**. The oil pump outlet (not shown, shown in FIG. 67B as **52230**) in some embodiments is connected to the main feed **52740**. In some embodiments, an oil pump outlet may also be connected to and provide lubricating fluid to the coupling joint linear bearings **52738**. In some embodiments, an oil pump outlet may be connected to the linear bearings **52738** via a tube or hose, or plurality of tubes or hoses. Alternatively, the link rod passageways 5**2712** may deliver lubricating fluid to the linear bearings **52738**.

Thus, the main feed **52740** delivers lubricating fluid to the journal bearings surfaces **52728**. From the journal bearing surfaces **52728**, the lubricating fluid is delivered to the crankshaft main passage. The crankshaft main passage delivers lubricating fluid to both the spline shaft passageway **52732** and the connecting rod bearing on the crank pin **52724**.

Lubricating fluid is delivered back to the sump, preferably by flowing out of the aforementioned bearings and into the sump. In the sump, the lubricating fluid will be collected by the oil pump and redistributed throughout the engine.

## DISTRIBUTION

As described above, various embodiments of the system, methods and apparatus may advantageously provide a low-cost, easily maintained, highly efficient, portable, and failsafe system that can provide a reliable source of drinking water for use in all environments regardless of initial water quality. The system is intended to produce a continuous stream of potable water, for drinking or medical applications, for example, on a personal or limited community scale using a portable power source and moderate power budget. As an example, in some embodiment, the water vapor distillation apparatus may be utilized to produce at least approximately 10 gallons of water per hour on a power budget of approximately 500 watts. This may be achieved through a very efficient heat transfer process and a number of sub-system design optimizations.

The various embodiments of the water vapor distillation apparatus may be powered by a battery, electricity source or by a generator, as described herein. The battery may be a stand alone battery or could be connected to a motor transport apparatus, such as a scooter, any other motor vehicle, which some cases may be a hybrid motor vehicle or a battery powered vehicle.

In one embodiment, the system may be used in the developing world or in a remote village or remote living quarters. The system is especially advantageous in communities with any one or more of the following, for example (but not by limitation): unsafe water of any kind at any time, little to no water technical expertise for installation, unreliable access to replacement supplies, limited access to maintenance and difficult operating environment.

The system acts to purify any input source and transform the input source to high-quality output, i.e., cleaner water. In some applications the water vapor distillation apparatus may be in a community that does not have any municipal infrastructure to provide source water. Thus, in these situations an embodiment of the water vapor distillation apparatus may be capable of accepting source water having varying qualities of purity.

The system is also easy to install and operate. The water vapor distillation apparatus is designed to be an autonomous system. This apparatus may operate independently without having to be monitored by operators. This is important because, in many of the locations where the water vapor distillation apparatus may be installed and or utilized, mechanics may be rare or unreliable.

The system has minimal maintenance requirement. In the exemplary embodiments, the system does not require any consumables and/or disposables, thus, the system itself may be utilized for a period of time absent replacing any elements or parts. This is important because in many applications the water vapor distillation apparatus may be located in a community that lacks people having technical expertise to maintain mechanical devices such as the water vapor distillation apparatus. The system is also inexpensive, making it an option for any community.

In addition, the water vapor distillation apparatus may be used in any community where clean drinking water is not readily or sufficiently available. For example, communities that have both a utility to provide electricity to operate the water vapor distillation device and municipal water to supply the apparatus.

Thus, the water vapor distillation apparatus may be used in communities that may have a utility grid for supply electricity but no clean drinking water. Conversely, the community may have municipal water that is not safe and no utility grid to supply electricity. In these applications, the water vapor distillation apparatus may be powered using devices including, but not limited to a Stirling engine, an internal combustion engine, a generator, batteries or solar panels. Sources of water may include but are not limited to local streams, rivers, lakes, ponds, or wells, as well as, the ocean.

In communities that have no infrastructure the challenge is to locate a water source and be able to supply power to operate the water vapor distillation apparatus. As previously discussed, the water vapor distillation apparatus may be power using several types of devices.

In this type of situation one likely place to install a water vapor distillation apparatus may be in the community clinic or health centers. These places typically have some form of power source and are accessible to the most members of the community.

Again, as described herein, sources of electricity may include a Stirling engine. This type of engine is well suited for application in the water machine because the engine provides a sufficient amount of electrical power to operate the machine without significantly affecting the size of the machine.

The water vapor distillation apparatus may supply approximately between 50 and 250 people per day with water. In the exemplary embodiment, the output is 30 liters per hour. This production rate is suitable for a small village or community's needs. The energy needs include approximately 900 Watts. Thus, the energy requirements are minimal to power the water vapor distillation apparatus. This low

power requirement is suitable to a small/remote village or community. Also, in some embodiments, a standard outlet is suitable as the electrical source. The weight of the water vapor distillation apparatus is approximately 90 Kg, in the exemplary embodiment, and the size (H x D x W) – 160 cm x 50 cm x 50 cm.

**[0151]** Knowledge of operating temperatures, TDS, and fluid flows provides information to allow production of potable water under a wide range of ambient temperatures, pressures, and dissolved solid content of the source water. One particular embodiment may utilize a control method whereby such measurements (T, P, TDS, flow rates, etc) are used in conjunction with a simple algorithm and look-up table allowing an operator or computer controller to set operating parameters for optimum performance under existing ambient conditions.

In some embodiments, the apparatus may be incorporated as part of a system for distributing water. Within this system may include a monitoring system. This monitoring system may include, but is not limited to having an input sensor for measuring one or more characteristics of the input to the generation device and an output sensor for measuring consumption or other characteristic of output from the generation device. The monitoring system may have a controller for concatenating measured input and consumption of output on the basis of the input and output sensors.

Where the generation device of a particular utility of a network is a water vapor distillation apparatus, the input sensor may be a flow rate monitor. Moreover, the output sensor may be a water quality sensor including one or more of torpidity, conductivity, and temperature sensors.

The monitoring system may also have a telemetry module for communicating measured input and output parameters to a remote site, either directly or via an intermediary device such as a satellite, and, moreover, the system may include a remote actuator for varying operating parameters of the generator based on remotely received instructions. The monitoring system may also have a self-locating device, such as a GPS receiver, having an output indicative of the location of the monitoring system. In that case, characteristics of the measured input and output may depend upon the location of the monitoring system.

The monitoring system described above may be included within a distributed network of utilities providing sources of purified water. The distributed network has devices for generating water using input sensors for measuring inputs to respective generators, output sensor for measuring consumption of output from respective

generators, and a telemetry transmitter for transmitting input and output parameters of a specified generator. Finally, the distributed network may have a remote processor for receiving input and output parameters from a plurality of utility generators.

Referring now to FIG. 42, this figure depicts monitoring generation device **4202**. Generation device **4202** may be a water vapor distillation apparatus as disclosed herein. Generation device **4202** may typically be characterized by a set of parameters that describe its current operating status and conditions. Such parameters may include, without limitation, its temperature, its input or output flux, etc., and may be subject to monitoring by means of sensors, as described in detail below.

Still referring to FIG. 42, source water enters the generation device **4202** at inlet **4204** and leaves the generation device at outlet **4206**. The amount of source water **4208** entering generation device **4202** and the amount of purified water **4210** leaving generation device **4202** may be monitored through the use of one or more of a variety of sensors commonly used to determine flow rate, such as sensors for determining them temperature and pressure or a rotometer, located at inlet sensor module **4212** and/or at outlet sensor module **4214**, either on a per event or cumulative basis. Additionally, the proper functioning of the generation device **4202** may be determined by measuring the turpidity, conductivity, and/or temperature at the outlet sensor module **4214** and/or the inlet sensor module **4212**. Other parameters, such as system usage time or power consumption, either per event or cumulatively, may also be determined. A sensor may be coupled to an alarm or shut off switch that may be triggered when the sensor detects a value outside a pre-programmed range.

When the location of the system is known, either through direct input of the system location or by the use of a GPS location detector, additional water quality tests may be run based on location, including checks for known local water contaminates, utilizing a variety of detectors, such as antibody chip detectors or cell-based detectors. The water quality sensors may detect an amount of contaminates in water. The sensors may be programmed to sound an alarm if the water quality value rises above a pre-programmed water quality value. The water quality value is the measured amount of contaminates in the water. Alternatively, a shut off switch may turn off the generation device if the water quality value rises about a pre-programmed water quality value.

Further, scale build-up in the generation device **4202**, if any, may be determined by a variety of methods, including monitoring the heat transfer properties of the system

or measuring the flow impedance. A variety of other sensors may be used to monitor a variety of other system parameters.

Still referring to FIG. 42, the sensors described above may be used to monitor and/or record the various parameters described above onboard the generation device **4202**, or in an alternative embodiment the generation device **4202** may be equipped with a communication system **4214**, such as a cellular communication system. The communication system **4214** could be an internal system used solely for communication between the generation device **4202** and the monitoring station **4216**. Alternatively, the communication system **4214** could be a cellular communication system that includes a cellular telephone for general communication through a cellular satellite system **4218**. The communication system **4214** may also employ wireless technology such as the Bluetooth open specification. The communication system **4214** may additionally include a GPS (Global Positioning System) locator.

Still referring to FIG. 42, the communication system **4214** enables a variety of improvements to the generation device **4202**, by enabling communication with a monitoring station **4216**. For example, the monitoring station **4216** may monitor the location of the generation device **4202** to ensure that use in an intended location by an intended user. Additionally, the monitoring station **4216** may monitor the amount of water and/or electricity produced, which may allow the calculation of usage charges. Additionally, the determination of the amount of water and/or electricity produced during a certain period or the cumulative hours of usage during a certain period, allows for the calculation of a preventative maintenance schedule. If it is determined that a maintenance call is required, either by the calculation of usage or by the output of any of the sensors used to determine water quality, the monitoring station **4216** may arrange for a maintenance visit. In the case that a GPS (Global Positioning System) locator is in use, monitoring station **4216** may determine the precise location of the generation device **4202** to better facilitate a maintenance visit. The monitoring station **4216** may also determine which water quality or other tests are most appropriate for the present location of the generation device **4202**. The communication system **4214** may also be used to turn the generation device **4202** on or off, to pre-heat the device prior to use, or to deactivate the system in the event the system is relocated without advance warning, such as in the event of theft.

Now referring to FIG. 43, the use of the monitoring and communication system described above facilitates the use of a variety of utility distribution systems. An

organization **43**, such as a Government agency, non-governmental agency (NGO), or privately funded relief organization, a corporation, or a combination of these, could provide distributed utilities, such as safe drinking water or electricity, to a geographical or political area, such as an entire country. The organization **43** may then establish local distributors **44A**, **44B**, and **44C**. These local distributors could preferably be a monitoring station **4216** (See FIG. 42) previously described. In one possible arrangement, organization **43** could provide some number of generation devices **4202** (See FIG. 42) to the local distributor **44**, etc. In another possible arrangement, the organization **43** could sell, loan, or make other financial arrangements for the distribution of the generation devices **4202** (See FIG. 42). The local distributor **44**, etc. could then either give these generation devices to operators **45**, etc., or provide the generation devices **4202** (See FIG. 42) to the operators though some type of financial arrangement, such as a sale or micro-loan.

Still referring to FIG. 43, the operator **45** could then provide distributed utilities to a village center, school, hospital, or other group at or near the point of water access. In one exemplary embodiment, when the generation device **4202** (See FIG. 42) is provided to the operator **45** by means of a micro-loan, the operator **45** could charge the end users on a per-unit bases, such as per watt hour in the case of electricity or per liter in the case of purified water. Either the local distributor **44** or the organization **43** may monitor usage and other parameters using one of the communication systems described above. The distributor **44** or the organization **43** could then recoup some of the cost of the generation device **45** (See FIG. 42) or effect repayment of the micro-loan by charging the operator **4312** for some portion of the per-unit charges, such as 50%. The communication systems described additionally may be used to deactivate the generation device **4202** (See FIG. 42) if the generation device is relocated outside of a pre-set area or if payments are not made in a timely manner. This type of a distribution system may allow the distribution of needed utilities across a significant area quickly, while then allowing for at least the partial recoupment of funds, which, for example, could then be used to develop a similar system in another area.

Now referring to FIG. 44, this figure illustrates a conceptual flow diagram of one possible way to incorporate an alternate embodiment of the water vapor distillation apparatus into a system. In an embodiment of this type, fluid flows through the system from an intake **4404** into an exchanger **4406** wherein exchanger **4406** receives heat from at least one of a plurality of sources including a condenser **4402**, a head **4408**, and

exhaust (not shown) from a power source such as an internal or external combustion engine. Fluid continues flowing past heat exchanger **4406** into a sump **4410** and into a core **4412** in thermal contact with condenser **4402**. In the core **4412**, the fluid is partially vaporized. From core **4412**, the vapor path proceeds into head **4408** in communication with a compressor **4414**, and from there into condenser **4402**. After the vapor has condensed, fluid proceeds from condenser **4402** through heat exchanger **4406**, and finally into an exhaust region **4416** and then out as final distilled product.

Referring to FIGS. 44 and 44A, a power source **4418** may be used to power the overall system. Power source **4418** may be coupled to a motor (not shown) that is used to drive compressor **4414**, particularly when compressor **4414** is a steam pump, such as a liquid ring pump or a regenerative blower. The power source **4418** may also be used to provide electrical energy to the other elements of the apparatus shown in FIG. 44. Power source **4418** may be, for example, an electrical outlet, a standard internal combustion (IC) generator or an external combustion generator. In one exemplary embodiment, the power source is a Stirling cycle engine. An IC generator and an external combustion generator advantageously produce both power and thermal energy as shown in FIG. 44A, where engine **4420** produces both mechanical and thermal energy. Engine **4420** may be either an internal combustion engine or an external combustion engine. A generator **4422**, such as a permanent magnet brushless motor, is coupled to a crankshaft of the engine **4420** and converts the mechanical energy produced by the engine **4420** to electrical energy, such as power **4424**. Engine **4420** also produces exhaust gases **4426** and heat **4428**. The thermal energy produced by the engine **4420** in the form of exhaust gas **4426** and heat **4428** may be advantageously used to provide heat to the system.

Referring to FIG. 44, heat from a power source **4418** may be recaptured by channeling the exhaust into the insulated cavity that surrounds the apparatus, which may lie between external housing and the individual apparatus components. In one embodiment, exhaust may blow across a finned heat exchanger that heats source fluid prior to entering the evaporator/condenser **4402**. In other embodiments, the source fluid flows past a tube-in-tube heat exchanger as described above with reference to the exemplary embodiment.

Referring now to FIG. 72A, one embodiment of the system is shown. The system includes two basic functional components that may be combined within a single integral unit or may be capable of separate operation and coupled as described herein for the purpose of local water purification. FIG. 72A depicts an of the system in which a

power unit **528010** is coupled electrically, via cable **528014**, to provide electrical power to a water vapor distillation apparatus **528012**, with exhaust gas from the power unit **528010** coupled to convey heat to the water distillation unit **528012** via an exhaust duct **528016**.

In the exemplary embodiment, the power unit **528010** is a Stirling cycle engine. The Stirling cycle engine may be any of the embodiments described herein. Thermal cycle engines are limited, by second law of thermodynamics, to a fractional efficiency, i.e., a Carnot efficiency of (TH–TC)/TH, where TH and TC are the temperatures of the available heat source and ambient thermal background, respectively. During the compression phase of a heat engine cycle, heat must be exhausted from the system in a manner not entirely reversible, thus there will always be a surfeit of exhaust heat. More significantly, moreover, not all the heat provided during the expansion phase of the heat engine cycle is coupled into the working fluid. Here, too, exhaust heat is generated that may be used advantageously for other purposes. The total heat thermodynamically available (i.e., in gas hotter than the ambient environment) in the burner exhaust is typically on the order of 10% of the total input power. For a power unit delivering on the order of a kilowatt of electrical power, as much as 700 W of heat may be available in an exhaust stream of gas at temperatures in the vicinity of 200° C. In accordance with embodiments of the present apparatus, system and methods, the exhaust heat, as well as the electrical power generated by an engine-powered generator, are used in the purification of water for human consumption, thereby advantageously providing an integrated system to which only raw water and a fuel need be provided.

Moreover, external combustion engines, such as Stirling cycle engines, are capable of providing high thermal efficiency and low emission of pollutants, when such methods are employed as efficient pumping of oxidant (typically, air, and, referred to herein and in any appended claims, without limitation, as "air") through the burner to provide combustion, and the recovery of hot exhaust leaving the heater head. In many applications, air is pre-heated, prior to combustion, nearly to the temperature of the heater head, so as to achieve the stated objectives of thermal efficiency. However, the high temperature of preheated air, desirable for achieving high thermal efficiency, complicates achieving low-emission goals by making it difficult to premix the fuel and air and by requiring large amounts of excess air in order to limit the flame temperature. Technology directed toward overcoming these difficulties in order to achieve efficient and low-emission operation of thermal engines is described, for example, in U.S. Pat.

No. 6,062,023 (Kerwin, et al.) issued May 16, 2000, and incorporated herein by reference.

External combustion engines are, additionally, conducive to the use of a wide variety of fuels, including those most available under particular local circumstances; however the teachings of the present description are not limited to such engines, and internal combustion engines are also within the scope of the current disclosure. Internal combustion engines, however, impose difficulties due to the typically polluted nature of the exhausted gases, and external combustion engines are preferably employed.

Still referring to FIG. 72A, an embodiment of a power unit **528010** is shown schematically in FIG. 72B. Power unit **528010** includes an external combustion engine **528101** coupled to a generator **528102**. In an exemplary embodiment, the external combustion engine **528101** is a Stirling cycle engine. The outputs of the Stirling cycle engine **528101** during operation include both mechanical energy and residual heat energy. Heat produced in the combustion of a fuel in a burner **528104** is applied as an input to the Stirling cycle engine **528101**, and partially converted to mechanical energy. The unconverted heat or thermal energy accounts for approximately 65 to 85% of the energy released in the burner **528104**. The ranges given herein are approximations and the ranges may vary depending on the embodiment of water vapor distillation apparatus used in the system and the embodiment of the Stirling engine (or other generator) used in the system.

This heat is available to provide heating to the local environment around the power unit **528110** in two forms: a smaller flow of exhaust gas from the burner **528104** and a much larger flow of heat rejected at the cooler **528103** of the Stirling engine. Power unit **528110** may also be referred to as an auxiliary power unit (APU). The exhaust gases are relatively hot, typically 100 to 300° C., and represent 10 to 20% of the thermal energy produced by the Stirling engine **528101**. The cooler rejects 80 to 90% of the thermal energy at 10 to 20° C above the ambient temperature. The heat is rejected to either a flow of water or, more typically, to the air via a radiator **528107**. Stirling cycle engine **528101** is preferably of a size such that power unit **528010** is transportable.

As shown in FIG. 72B, Stirling engine **528101** is powered directly by a heat source such as burner **528104**. Burner **528104** combusts a fuel to produce hot exhaust gases which are used to drive the Stirling engine **528101**. A burner control unit **528109** is coupled to the burner **528104** and a fuel canister **528110**. Burner control unit **528109** delivers a fuel from the fuel canister **528110** to the burner **528104**. The burner controller

**528109** also delivers a measured amount of air to the burner **528104** to advantageously ensure substantially complete combustion. The fuel combusted by burner 5**28104** is preferably a clean burning and commercially available fuel such as propane. A clean burning fuel is a fuel that does not contain large amounts of contaminants, the most important being sulfur. Natural gas, ethane, propane, butane, ethanol, methanol and liquefied petroleum gas ("LPG") are all clean burning fuels when the contaminants are limited to a few percent. One example of a commercially available propane fuel is HD-5, an industry grade defined by the Society of Automotive Engineers and available from Bernzomatic. In accordance with an embodiment of the system, and as discussed in more detail below, the Stirling engine **528101** and burner **528104** provide substantially complete combustion in order to provide high thermal efficiency as well as low emissions. The characteristics of high efficiency and low emissions may advantageously allow use of power unit **528010** indoors.

Generator **528102** is coupled to a crankshaft (not shown) of Stirling engine **528101**. It should be understood to one of ordinary skill in the art that the term generator encompasses the class of electric machines such as generators wherein mechanical energy is converted to electrical energy or motors wherein electrical energy is converted to mechanical energy. The generator **528102** is preferably a permanent magnet brushless motor. A rechargeable battery **528113** provides starting power for the power unit **528010** as well as direct current ("DC") power to a DC power output 528112. In a further embodiment, APU **528010** also advantageously provides alternating current ("AC") power to an AC power output 528114. An inverter **528116** is coupled to the battery **528113** in order to convert the DC power produced by battery **528113** to AC power. In the embodiment shown in FIG. 72B, the battery **528113**, inverter **528116** and AC power output **528114** are disposed within an enclosure **528120**.

Utilization of the exhaust gas generated in the operation of power unit **528010** is now described with reference to the schematic depiction of an embodiment of the system shown in FIG. 72C. Burner exhaust is directed through a heat conduit **528016** into enclosure **528504** of the water vapor distillation apparatus unit designated generally by numeral **528012**. Heat conduit **528016** is preferably a hose that may be plastic or corrugated metal surrounded by insulation, however all means of conveying exhaust heat from power unit **528010** to water purification unit **528012** are within the scope of the system. The exhaust gas, designated by arrow **528502**, blows across a heat exchanger **528506** (in the exemplary embodiment, a hose-in-hose heat exchanger is

used, in other embodiments, a finned heat exchanger is used), thereby heating the source water stream 528508 as it travels to the water vapor distillation (which is also referred to herein as a "still") evaporator **528510**. The hot gas **528512** that fills the volume surrounded by insulated enclosure **528504** essentially removes all thermal loss from the still system since the gas temperature within the insulated cavity is hotter than surface **528514** of the still itself. Thus, there is substantially no heat flow from the still to the ambient environment, and losses on the order of 75 W for a still of 10 gallon/hour capacity are thereby recovered. A microswitch **528518** senses the connection of hose **528016** coupling hot exhaust to purification unit **528012** so that operation of the unit may account for the influx of hot gas.

In accordance with alternate embodiments adding heat to exhaust stream **528502** is within the scope of the system, whether through addition of a post-burner (not shown) or using electrical power for ohmic heating.

During initial startup of the system, power unit **528010** is activated, providing both electrical power and hot exhaust. Warm-up of the still **528012** is significantly accelerated since the heat exchanger **528506** is initially below the dew point of the moisture content of the exhaust, since the exhaust contains water as a primary combustion product. The heat of vaporization of this water content is available to heat source water as the water condenses on the fins of the heat exchanger. The heat of vaporization supplements heating of the heat exchanger by convection of hot gas within the still cavity. For example, in the fin heat exchanger embodiment, heating of the fins by convection continues even after the fins reach the dew point of the exhaust.

In accordance with other embodiments of the system, power unit **528010** and still **528012** may be further integrated by streaming water from the still through the power unit for cooling purposes. The use of source water for cooling presents problems due to the untreated nature of the water. Whereas using the product water requires an added complexity of the system to allow for cooling of the power unit before the still has warmed up to full operating conditions.

Referring again to FIG. 44, other embodiments may include the use of additives in solid form, wherein such additives could be embedded in a time-release matrix inserted into the flow-through channel of intake **4404**. In one particular embodiment, replacement additive would need to be inserted periodically by the user. In yet another embodiment, a powder form of an additive could be added in a batch system wherein the powder is added, for example in tablet form, to an external reservoir containing

water to be purified wherein the additive is uniformly mixed, similar to the batch system for adding liquid additives described above.

Still referring to FIG. 44, pre-treatment of the source water may occur prior to or within intake **4404**. Pre-treatment operations may include, but is not limited to gross-filtering; treatment with chemical additives such as polyphosphates, polyacetates, organic acids, or polyaspartates; and electrochemical treatment such as an oscillating magnetic field or an electrical current; degassing; and UV treatment. Additives may be added in liquid form to the incoming liquid stream using a continuous pumping mechanism such as a roller pump or pulsatile pump, including a standard diaphragm pump or piezoelectric diaphragm pump. Alternatively, the additives may be added by a semi-continuous mechanism using, for example, a syringe pump, which would require a re-load cycle, or a batch pumping system, wherein a small volume of the additive would be pumped into a holding volume or reservoir external to the system that uniformly mixes the additive with the liquid before the liquid flows into the system. It is also envisioned that the user could simply drop a prescribed volume of the additive into, for example, a bucket containing the liquid to be purified. Liquid additive may be loaded as either a lifetime quantity (i.e., no consumables for the life of the machine), or as a disposable amount requiring re-loading after consumption.

Still referring to FIG. 44, similarly post-treatment of the product water may occur preferably within an external output region (not shown). Post-treatment operations may include, but is not limit to taste additives such as sugar-based additives for sweetening, acids for tartness, and minerals. Other additives, including nutrients, vitamins, stabilized proteins such as creatinine, and fats, and sugars may also be added. Such additives may be added either in liquid or solid form, whether as a time-release tablet through which the output liquid flows or a powder added to an external reservoir such as through a batch system. Alternatively, the additive may be added to the output liquid via an internal coating of a separate collection reservoir or container, for example, by leaching or dissolution on contact. In such embodiments, the ability to detect purified liquid with and without the additive may be preferred. Detection systems in accordance with various embodiments include pH analysis, conductivity and hardness analysis, or other standard electrical-based assays. Such detection systems allow for replacement of additives, as needed, by triggering a signal mechanism when the additive level/quantity is below a pre-set level, or is undetectable.

In another embodiment, liquid characteristics, such as for example water hardness, is monitored in the output and may be coupled with an indicator mechanism which signals that it is preferable to add appropriate additives.

In yet another embodiment, ozone is systemically generated using, for example, electric current or discharge methods, and added to the output product for improved taste. Alternatively, air may be pumped through a HEPA filter bubbling through the product water to improve palatability of the water.

Similarly, it is envisioned that other embodiments may include means for detecting nucleic acids, antigens and bio-organisms such as bacteria. Examples of such detection means include nanoscale chemistry and biochemistry micro-arrays known in the field and currently commercially available. Such arrays may also be used to monitor the presence and/or absence of nutrients and other additives in the purified product, as discussed above.

In another embodiment, UV treatment may be used post-purification, for example in a storage barrel or other container, to aid in maintenance of the purified product.

Referring again to FIG. 73, in various embodiments, the apparatus **100** may include at least one product conductivity cell **7304**. In various embodiments, the product conductivity cell **7304** may be located in the product line downstream of the liquid heat exchanger and prior to the valve manifold. As described in more detail above, the conductivity of the product may be used in one or more control systems of the apparatus. The resulting readings and/or signals of the product conductivity cell **7304** may, in some embodiments, be communicated to at least one conductivity meter (not shown) and the meter may determine the conductivity and display one or more indications on the outside of the apparatus, i.e., such that user's of the system may monitor and/or determine same. In various other embodiments, the signals from the product conductivity cell **7304** are sent to the controller to be used for one or more control systems and/or methods for the apparatus. In some embodiments, the signals from the product conductivity cell 7304 may be sent both to the conductivity meter and to the controller. In some embodiments, in addition, the signals may be sent to one or more additional receiving devices including, but not limited to, a remote device and / or remote user interface and / or remote computer. In some embodiments, the conductivity and/or information related thereto may be both displayed on the outside of the apparatus as well as used by the controller. In some embodiments, the outside display may

include, but is not limited to, one or more of the following displays: numbers (e.g., values), words, one or more colored light indicators and / or one or more symbols that may indicate one or more conditions to a user/viewer, wherein condition may include, but are not limited to, one or more of the following: condition of the apparatus and/or condition of the product.

In some embodiments, the signals from the product conductivity cell 7304 are correlated to determine the quality of product. Depending on the determined quality of the product, the product may either be diverted or will be actual product. For example, where the product does not meet a minimum threshold for quality, the product will be diverted and/or dumped and not progress to actual product. In some embodiments, the threshold may be 20 microsiemens and, for example, where the product exceeds 20 microsiemens per centimeter squared, the product is diverted. However, in various embodiments, the threshold may be higher or lower than 20 microsiemens.

In some embodiments, the conductivity meter is any conductivity meter known in the art including, but not limited to, a CDTX-90-1P made by Omega, Delaware, U.S.A. In some embodiments, the product conductivity cell **7304** may be any product conductivity cell known in the art including, but not limited to, a CDCE-90-001 made by Omega, Delaware, U.S.A. In various embodiments, the probe of the product conductivity cell **7304** is located such that it is in contact with the product in the fluid line, i.e., within the fluid pathway.

In various embodiments, the apparatus may include at least one control board wherein the various components, as described herein, are electrically connected such that a processor may control the system

In various embodiments, the apparatus may include at least one current transducer. In some embodiments, at least one current transducer may be connected to the control board and at the inlet/main power of the apparatus. The at least one current transducer may measure the current usage of the total system. Using the current usage, the system may determine the relative condition of the system, for example, but not limited to, calculating changes in power usage and / or, whether the power usage exceeded a maximum threshold or is below a minimum threshold. However, in various embodiments, the system may determine the relative condition of the system using the at least one current transducer signals in one or more various calculations and/or in some embodiments a user may determine the relative condition of the system using the at least one current transducer system log. In some embodiments, the system may, to

run a system test, actuate all of the components of the system and determine the power consumption. In some embodiments, any current transducer known in the art may be used, for example, the CR4110-15 made by CR Magnetics, St. Louis, Missouri, U.S.A.

## CONTROLS

In some embodiments, the system includes at least two processors, a motor control engine processor ("MCE") and an ARM control processor. In various embodiments, the control system controls the production of product in the apparatus **100**. The source fills the sump and the source is heated to produce steam. The steam temperature is maintained through the controls system controlling the heater and the vent valve. In some embodiments, both the product and blowdown flow to holding tanks. The product level is controlled by changing the duty cycle on the product and product divert valve duty cycles. The blowdown level is maintained, in some embodiments, by two controllers. The blowdown controller maintains its target level through adjusting the blowdown valve. The source controller also works to maintain the blowdown level. The source controller set point/target is higher, in some embodiments, than the blowdown controller set point/target. The source controller adjusts the source valve duty cycle. Maintaining the source controller set point/target higher than the blowdown set point provides continuous feeding of at least a volume of source water into the apparatus **100**.

Referring also to FIG. 75, an overview of the states **7500** of the water vapor distillation apparatus is shown. The main control system of the device controls each state. Although various other embodiments may be used, for illustration purposes, one example of an embodiment of the various states **7500** of the main control system is described below. However, in various other embodiments, additional states may be used and/or the order of states may be different as well as the targets/thresholds, etc., that are given for illustration purposes. Additionally, the names given for each states are for illustration purposes and other names may be used in various embodiments.

### Process

When the water system starts **7502**, the apparatus **100** is in the idle **7504** state. In the idle **7504** state, all controllers are turned to "off" and the apparatus is not heating. When the user presses the button to start the system it goes into the fill **7506** state. The fill **7506** state opens the source valve allowing source water to fill the sump and overflow into the blow down tank and product tank if needed. Thus, the fill **7506** state ensures that the sump is full before the system begins to heat. Once the desired level is reached in the blow down and product tanks the system enters the heat **7508** state. In the heat **7508** state, the heater in the sump is maximized to its highest state and the controller waits until the temperature rises to an appropriate/predetermined/desired

value, which, in some embodiments, may be about 100°C, and in some embodiments, may be 105°C. However, in various other embodiments, may be higher or lower than 105°C. Once the low pressure steam temperature, high pressure steam temperature and sump temperatures, reach the appropriate/predetermined/desired temperatures which, in some embodiments may be 105°C, 105°C, and 103°C, respectively, the system goes into the heat exchanger prime **7510** state.

The heat exchanger prime **7510** state controls the levels on the product and the blow down level sensors and waits for the temperature to rise to a higher degree. In some embodiments, in the heat exchanger prime **7510** state, the source valve is opened to a predetermine/fixed duty cycle, e.g., 5%, which, in various embodiments, may be higher or lower than 5%. In some embodiments, the blow down is controlled to, e.g., 50%. Thus, in various embodiments, source water moving into the system/machine becomes steam by opening the source valve and some water becomes blow down. In various embodiments, the blow down level is maintained, e.g., at 50%, by controlling the duty cycle of the valve. In the heat exchanger prime **7510** state, the heater is maintained on and is maximized, in some embodiments, to its highest state. Also, in heat exchanger prime **7510** state, source water moves into the system/machine and the blow down and product controllers are actuated/initiated/activated.

The low pressure steam temperature, high pressure steam temperature, sump temperature and motor temperature are monitored. Once the low pressure steam temperature, high pressure steam temperature, sump temperature and motor temperature reach the appropriate/predetermined/desired temperatures, which, in some embodiments, may be greater than or equal to 112°C, greater than or equal to 112°C, greater than or equal to 110°C and greater than or equal to 90°C, respectively, and the product level is greater than or equal to the minimum start level, which serves to ensure that there is some product water being generated/producing, the system goes into the start pump **7512** state.

In start pump **7512** state the bearing feed pump is commanded to run at a designated / predetermined speed. Also, in the start pump **7512** state, the blower motor is started, which starts the impeller spinning. Also, during the start pump **7512** state, in some embodiments, the vent valve is actuated at a predetermined value, for example, for example, a predetermined value, in some embodiments, is anywhere between 50-100%. This acts to vent any contained gasses that have accumulated in the condenser, of the evaporator/condenser, space. In some embodiments, it is beneficial to remove these

from the system. Thus, during start pump **7512** state, the vent valve is held anywhere between 50-100%, in various embodiments, for the duration of the start pump **7512** state.

Once the impeller reaches speed (predetermined speed) and once the blow down tank level reaches the correct level and the reported motor speed is within a "MotorErrorSpeed" (e.g., a predetermined speed that may vary in various embodiments) rpm of the commanded speed the system enters the run **7514** state. During the run **7514** state, the apparatus is producing product water.

During the run **7514** state the source valve and the blow down valve controllers maintain the system/machine with a threshold amount of source water entering, blow down and product water exiting. This ensures that the system/machine does not flood or dry out. The controllers maintain this level by actuating the source valve and the blow down valve.

Also, during run **7514** state, the low pressure steam temperature is monitored and held at a predetermined temperature, which, in some embodiments may be about 111.5 °C. The low steam pressure temperature is maintained, in some embodiments, at the predetermined temperature by actuating the sump heater if the temperature falls below the predetermined. If the temperature is above the predetermined temperature, e.g. in some embodiments, 111.5 °C, the vent valve may be actuated/opened. A heater controller and a vent valve controller controls the vent valve duty cycle and both the heater controller and a vent valve controller monitor the low pressure steam temperature. Thus, they the heater controller and a vent valve controller are controlled by the low pressure steam temperature.

In various embodiments, a minimum vent valve duty cycle is maintained. In some embodiments, if the temperature increases above a predetermined threshold, the vent duty cycle is increased to above the minimum vent valve duty cycle. This maintains a vent of gasses out of the condenser of the evaporator/condenser.

The product valve duty cycle controls the product level by receiving the product sensor readings. In various embodiments, the product valve duty cycle works to maintain the product level at a predetermined level, which, in some embodiments, may be 50% of the product level sensor. The product level is controlled by actuating the product valve, i.e., by opening or closing the product valve more or less to increase or decrease the product level.

From the run **7514** state the system will go into the flow measurement **7518** state every "FlowCheckTime" seconds (e.g., a predetermined amount of time, i.e., seconds, that may vary in various embodiments) which may be referred to as the count to flowcheck time **7516**. During this state, the control system determines both the product flow rate and the blow down rate. Once the count to flowcheck time **7516** has been met, the flow measurement **7518** is taken.

With respect to the product flow rate, the flow measurement **7518** state includes emptying a product collection container to a certain level and then proceed to a product fill state which closes the empty process and determines the amount of time it takes to fill the contained back to a preset value (e.g., to measure the amount of product the apparatus is producing in a given amount of time). In some embodiments, if the production rate / flow rate drops below a preset/predetermined/threshold value, or if the production rate / flow rate exceeds a preset/predetermined/threshold value, the system may alert the user. In some embodiments, if the product flow rate is less than 350 ml/min, a low production system warning may register to the controller. This low production system warning may be cleared, in some embodiments, once the product flow rate is greater than 350 ml/. In some embodiments, a warning does not necessarily stop the system, but in other embodiments, a warning may stop the system. After the flow measurement **7518** is taken the system reverts to the run **7414** state.

With respect to the blow down flow rate, the flow measurement **7518** state includes emptying a blow down collection container to a certain level and then proceed to a blow down fill state which closes the empty process and determines the amount of time it takes to fill the contained back to a preset value (e.g., to measure the amount of product the apparatus is producing in a given amount of time). In some embodiments, if the production rate / flow rate drops below a preset/predetermined/threshold value, or if the production rate / flow rate exceeds a preset/predetermined/threshold value, the system may alert the user. In some embodiments, if the blow down flow rate is less than 35%, the system will transition to blow down full state and if using external tanks/container/holding tanks, transition to idle **7504** state. If the blow down flow rate is greater than 50 %, the system will calculate blow down flow and calculate the average flow and if using external tanks/container/holding tanks, transition to idle **7504** state. After the flow measurement **7518** is taken the system reverts to the run **7414** state. The blowdown flow rate may be adjusted

The system will stay in the run **7514** state until the user button is pressed **7520**. The system will then go into the standby **7522** state. In the standby **7522** state the motor is turned off but the heater maintains predetermined low pressure steam temperature of, in some embodiments, about 112.5°C, however, in other embodiments, the heater may maintain a low pressure steam temperature of less than 112.5°C or greater than 112.5°C. In the standby **7522** state, the system maintains the system in a warm state and controls the source water flow but the blower is not running. In some embodiments, the system, in the standby **7522** state actuates the source valve at a low duty cycle and maintains the blow down flow. Maintaining the temperature at about 112.5°C (or the predetermined temperature, which may be greater or less than 112.5°C) maintains the system in a boiling then condensing cycle. Where the apparatus is attached to a product water holding tank, which in some embodiments may include a product level sensor, when the level sensor signals indicate to the processor that the tank is full, the controller puts the system into standby **7522** state.

From the standby **7522** state a short (e.g., less than 3 second) button press will revert the system to idle **7504** state. A button press longer than e.g., 3 seconds, will revert the system to the heat exchanger prime **7510** state. Pressing the user button for less than e.g., 3 seconds in any state but standby **7522** will take the system back to the idle **7504** state. Any system fault detected will take the system to the idle **7504** state. Recoverable system faults will attempt to restart the process once the fault state is cleared. However, as stated above, the order of steps, the times given, the button presses, etc., may vary in various embodiments are given here as examples.

The control system includes various tasks running on the processor. The various tasks communicate one to another through a shared memory block, i.e., registers that get written and read by the various tasks.

## EVENTS

In various embodiments, one or more events or conditions of the apparatus/system may cause action by the control system. The following are various events; one or more may cause action by the control system in various embodiments. In various embodiments, the event may vary and the values given may vary through various embodiments. The examples below are given as exemplary embodiments; however, the values may vary in various embodiments.

Button presses. While the UI button is being pressed a loop counter is being incremented. On button release the counter is checked. If the button is held more than 4

counts (0.2 Sec.) a short button press is signaled. If the button is held more than 40 counts (2 Sec.) a long button press is signaled.

Error Signal. If a system error has been set and the water state machine is not in the idle state an error is signaled.

RESTART Signal. In some embodiments, this is a Signal to restart the system after an error.

FRAME_TICK sig. Sent on each 50mSec. timer tick. Used for timing and checking for events.

In some embodiments, various events may not be signaled to the state machine, however, they may be checked by a handler and handled there.

SPILL event . Once the system/machine is activated, but before the system/machine begins to run, the controller first determines whether there is sufficient water in the system to enter the heat state. Thus, in the full state, this is a confirmation to ensure there is sufficient water to start the heater. In some embodiments, for example, if the blow down tank level is greater than the fill set point and the product level is greater than 30%, then the SPILL event is handled. The default fill set point is 90% in some embodiments. The spill event is only checked in some embodiments in the Fill **7506** state

HOT event. The HOT event is the transition from the heat state to the heat exchanger prime state. In some embodiments, if the low pressure steam temperature is greater than the heat exit temperature and the high pressure steam temperature is greater than the heat exit temperature and the sump temperature is greater than the heat exit temp minus a predetermine amount, e.g. 2° C, then the HOT event is signaled. In some embodiments, the hot event is only checked for in the Heat **7508** state. In some embodiments, the default heat exit temp is 105° C. However, in various other embodiments, these temperatures may vary.

PRIMED event . If the low pressure temperature is greater than the Heat Exchanger Prime **7510** exit temperature and the high pressure temperature is greater than the Heat Exchanger Prime **7510** exit temp and the sump temperature is greater than the Heat Exchanger Prime **7510** exit temperature minus 2°C and the product level is greater than the minimum product level start and the motor temp is greater than the motor run OK temperature then, in some embodiments, the PRIMED event is signaled.

In various embodiments, the default the Heat Exchanger Prime **7510** exit temp is 112°C. The minimum product level start default value is 20%. The motor run OK temp

default is 90°C. In some embodiments, the primed event is only checked for in the Heat Exchanger Prime **7510** state.

STARTED event. If the blow down tank level is less than the blow down run level set point plus the source level offset and the motor speed is within 200 rpm of the commanded value the STARTED event, in some embodiments, is signaled. In some embodiments, the blow down run level set point default value is 40%. The source level offset default value is 10%. In some embodiments, the started event is only checked for in the start pump state.

BDHigh timer event. If the blow down level has been greater than a predetermined percentage, e.g. 90%, for a predetermined time, e.g. 4 minutes, or more the BDHigh timer event is signaled. In some embodiments, the BDHigh timer event is only checked for in the run state.

BDLow timer event. If the blow down valve duty cycle has been less than or equal to a predetermined percentage, e.g., 2%, for a predetermined time, e.g., 4 minutes, or more, the BDLow timer event is signaled. The BDLow timer event is checked for in the Heat Exchanger Prime **7510**, Run **7514** and Standby **7522** states.

ProdHigh timer event. If the product level has been greater than a predetermined percentage, e.g. 90%, for a predetermined time, e.g. 5 minutes, or more, the ProdHigh timer event is signaled. In some embodiments, the ProdHigh timer event is only checked for in the Run **7514** state.

ProdLow timer event. If the product valve and the product divert valve have both had a duty cycle of less than or equal to a predetermined percentage, e.g. 2%, for a predetermine time, e.g. 5 minutes, or more, the ProdLow timer event is signaled. In some embodiments, the ProdLow timer event is only checked for in the Run state **7514**.

State timer event. If the system has been in the current state longer than the state max timer value the State timer event is signaled. In some embodiments, the State timer event is checked for in all states except Idle **7504**, Run **7514** and Standby **7522**.

LPUnderTemp event. In some embodiments, if the low pressure temperature is less than a predetermined temperature, e.g. 104° C, the LPUnderTemp event is signaled. The LPUnderTemp event, in some embodiments, is only checked for in the Run **7514** state.

Conductivity high event. In some embodiments, if the conductivity is greater than CondoLimitQ10 for more than CondoErrTime seconds the conductivity high event

is signaled. In some embodiments, the default CondoLimitQ10 is 10.0 uS/cm. In some embodiments, the default CondoErrTime is 1800 seconds. In some embodiments, the conductivity high event is only checked for in the Run **7514** state.

Slipped Coupling event. If the LP temp is less then 1.5° less than the high pressure temperature and the product and divert valve duty cycles are less than a predetermined percentage, e.g. 10%, the slipped coupling event is signaled. In some embodiments, the slipped coupling event is only checked for in the Run **7514** state.

**Controllers**

In various embodiments, one or more controllers of the apparatus/system are used by the control system to control the system. The following are various controllers; one or more may be included in various embodiments of the control system.

Blow down level control. In some embodiments, the blow down level controller in various embodiments controls the blow down valve duty cycle. This controller uses the blow down tank level for feedback. During Heat Exchanger Prime **7510** state it is run as a PI controller. During the Start Pump **7512** and Run **7514** states it is run as a P only controller. In some embodiments, the blow down level controller may be disabled in all other states. This controller uses a different P value for Heat Exchanger Prime **7510** state than Start Pump **7512** and Run **7514** states.

Heater control. The heater control controller controls the heater duty cycle. It defaults to using the low-pressure temperature for feedback. If the HeaterUseSumpTemp register is set, this controller may use the sump temperature for feedback. During the Heat **7508**, Heat Exchanger Prime **7510**, Start Pump **7512** and Run **7514** states it is run as a PI controller. In some embodiments, this controller may be disabled during other states.

Product level control. This controller controls the product level based on product level sensor and adjusts the product valve duty cycle and product diver duty cycle. During the Heat Exchanger Prime **7510**, Start Pump **7512** and Run **7514** states this controller runs as a PI controller. During other states, in some embodiments, this controller is disabled.

Source flow controller. This controller controls the source flow based on the blow down level sensor by activating or varying the source valve duty cycle. In various embodiments, this controller is run as a PID controller during the Fill **7506**, Heat **7508**, Start Pump **7512** and Run **7514**. This controller may start when entering the Heat Exchanger Prime **7510** state. In some embodiments, during the Heat Exchanger Prime

**7510** state this controller may be disabled if the blow down level is too high. In some embodiments, during the Heat Exchanger Prime **7510** state this controller may and enabled if the blow down level is too low.

Thus, the source flow controller and the blow down controller receive information from the blow down level sensor and regulate the source valve and the blow down valve, respectively, based on the blow down level sensor information, e.g., level. The gains and the controls for the source flow controller and the blow down controller ensure that the system/machine takes in a greater volume of source water compared with the volume of water boiling off as product water, such that excessive water is input into the system/machine that comes out as blow down water, wherein the system/machine does not run dry, i.e., this method prevents the system from running dry. Also, this method ensures that the system/machine does not over utilize source water and create excess blow down. Thus, the system/machine maintains a balance between the amount of source water that enters the system/machine, the amount of blow down, and the amount of product water produced by the system/machine. This balance is maintained by a single sensor, the blow down level sensor, together with two controllers, the source flow controller and the blow down controller.

In some embodiments, for example, the blow down controller may be preprogrammed to maintain the blow down level at a lower level than the source flow controller. For example, in some embodiments, the blow down controller may be preprogrammed to maintain the blow down level at 50%, and the source flow controller may be preprogrammed to maintain the blow down level at 60%. Thus, the two controllers counteract one another. However, because in various embodiments the source flow controller is a PID controller, while the blow down controller is a PI controller, overtime, the PID source flow controller ultimately may maintain the 60%, while the blow down controller will continue to attempt to maintain 50%, but will not reach the 50%. Thus, the source flow controller will open the source valve until the blow down level sensor indicates the preprogrammed level, e.g., 60%. This control system may be beneficial for many reasons, including, but not limited to, that the blow down controller will maintain a level lower than the source controller, which, in many embodiments, prevents flooding.

Vent control - In some embodiments, the vent control controls the low pressure temperature based on the low pressure temperature sensor and the vent valve duty cycle. The vent controller may be broken up into four segments. The first segment may be for

temperatures below "ventLowTempQ10", which, in some embodiments, may be 100 °C. The vent valve may behave according to state, which, in some embodiments may be heat/run at 100/0% respectively. The second segment may be for between "ventLowTempQ10", which, in some embodiments, may be 100°C and "ventMidTempQ10", 112°C. In some embodiments, in this segment, the vent valve command is generated by the equation LPSteamTemp - ventLowTempQ10 * ventLowGainQ10. In the next segment "ventMidTempQ10 to" ventHighTempQ10" the command is generated by command + (LPSteamTemp - ventMidTempQ10 ) ventHighGainQ10. In some embodiments, if the temperature is above "ventHighTempQ10" , which, in some embodiments, may be 118° C, the command is set to "highTempVentValvePct", which, in some embodiments, may be100%. During the Run **7514** state the vent valve, in the exemplary embodiments, is not fully closed, thus allowing gas venting in the system.

Motor Control Engine. In some embodiments, the system includes a motor control engine controller ("MCE") and a MCE processor. The MCE is a dedicated processor for controlling the motors. The MCE controls both the motors and the heater. MCE includes a message task which takes the information from the MCE processor and puts it into shared memory and then the safety task reads it out of shared memory and acts on it appropriately.

**Data Logging**

In various embodiments, the apparatus includes a USB port or other, for communication with external machines, e.g., computers, smart-phones and other devices having an ability to receive and / or send messages to the apparatus, and / or software or other applications (collectively referred to herein as "external applications"). The system, in some embodiments, also may include a cell modem for communication. In various embodiments, data from the control system and processors is logged and may be transferred to external applications. This may allow for external monitoring of the apparatus/system. In some embodiments, the apparatus may be preprogrammed to upload logging data at a predetermined time/intervals, e.g., every 12 hours. Below is an exemplary embodiments, however, in various embodiments, the task may vary. The terminology and names given to commands may vary in various embodiments.

In the exemplary embodiments, a data logging task handles the communications with the external applications. In various embodiments, the task first checks whether the USB port is initialized. If it is not, the task initializes the port. If the port is

initialized the task checks for and reads the message from the serial port. On a peek command the task parses the location to peek and returns the value. On a poke command the task parses the location to poke and the value to poke. The task then sets the poked value to be used in shared memory and returns the status of the poke command. On an unpoke command the task first checks to see if this is an "unpoke all" or "unpoke one" value command. Where the command is an "unpoke all" the task restores all the original values to the shared memory used values. For "unpoke one" value, the task parses the unpoke location and restores the original value to the shared memory used value and returns the OK status. On a "display poked" command the system buffers the location and value of all the poked values and returns the buffer. On a "data" command the system buffers and sends all the constant data buffers and sends all the computed values and then sends the done string. On a flash command the system saves the constants to the flash memory and returns an "OK" flag.

**Secure Digital Memory Card ("SD") Logging**

In various embodiments, the system includes an SD card and the data is logged onto the SD card. The SD card also may handles communication with the cell modem. An exemplary embodiments, of the SD task is described below.

The SD task, in some embodiments, handles the reading and writing of data on the SD card and the interface to the cell modem. All SD card access must be done through the SD logging task. On startup it initializes the file system, creates directories if needed, reads the last state and motor time files and logs an entry into the data log file. Data will be logged to the log file every SDLogTime seconds (default is 300 seconds). The log file name has the date and device ID embedded. The disk has a current directory where log data is written. There are also monthly backup directories to save old data. When the file is sent to the modem it is then moved into that months backup directory. Before writing to the log file the system checks the free space on the disk. If there is less than 1MB of space left it will start purging old data by deleting the files in the oldest months directory. It will continue to delete files until there is more than 1MB of free space.

**Shared Memory**

In various embodiments, the system software uses a shared memory class to exchange data between the tasks. In some embodiments, there are two sections of shared memory: the constants section and the computed section. In the exemplary embodiment, all data in the shared memory is stored and retrieved as 32 bit integers.

Any data filtering or scaling is done in the "putValue" function based on the index of the value being saved.

The constants section contains gains and other machine constants. These values are stored in flash memory ("flash"). When the system starts up the constant values are read from flash. If the cyclical redundancy check ("CRC") on the flash copy is correct the flash values are loaded into the random access memory ("RAM") image. If the CRC is not correct the hard coded default values are loaded in to the RAM. When the value of a constant is needed by the software it is read using the shared memory "getGain" method. It is passed in the index of the constant and the constant value is returned. In some embodiments, the only method for the software to write a constant value is to use the poke functionality. The shared memory method "copyGainToPoked" would need to be used, which received (or is "passed") the index of the constant to change and the value to change it to. The gainFlag constant may be a predetermined/preprogrammed constant set by the user. Thus, in some embodiments, the user is responsible for setting the "gainFlag" for that constant to indicate that the value in the table is a poked value. To restore the poked value to its original value the shared memory "copyPokedToGain" method is called. In some embodiments, calling this method will restore all poked constants to their original values.

In some embodiments, the computed section contains values that are read from the input/output ("IO") or calculated during normal operation. These values are periodically overwritten as new values are read or calculated. When other software tasks need to read a computed value they use the shared memory method "getValue". This method is passed the index of the value to read and returns the value at that index. In some embodiments, the software writes values into the computed section using the "putValue" method of the shared memory class. The method is passed the index of the location to write and the value to be written. Initially the written values are stored in a holding array. In some embodiments, at least once in each control loop of the water task the function is called to copy all data from the holding array into the used array. If the poked flag for that value is set the data for that value is not copied. The values for the computed section can be poked, in some embodiments, only through the "External App" interface. The "handlePoke" method of the "DataLog" class will change the value in the computed table at the specified index and set the poked flag to keep this data from being overwritten by the update loop. In some embodiments, the value may be unpoked by calling the "clearPokedComputed" method of the shared memory class. This will

unpoke all poked computed values. The poked flag will be cleared and the next data update loop will overwrite with the latest computed value.

## IO POINTS

The system includes various input and output points ("IO") where the controls receive an input and/or sends an output. In various embodiments, one or more of the following may be included as IO Points. In other embodiments, additional IO Points may be included and in some embodiments, all of the following may be included. The description below separates the Analog Input Points from the Digital IO Points. Additionally, the description below describes an exemplary embodiment and in various other embodiments, the various inputs and outputs may include additional functionality and / or meaning. The terminology may also vary in various embodiments.

### Analog Inputs

Low Pressure Steam Temperature. This input reports the temperature of the steam on the low pressure side. It is read in as AD counts and converted to temperature using a look up table.

High Pressure Steam Temperature. This input reports the temperature of the steam on the high pressure side. It is read in as AD counts and converted to temperature using a look up table.

Sump Temperature . This input reports the temperature of the sump. It is read in as AD counts and converted to temperature using a look up table.

Motor Temperature. This input reports the temperature of the motor stator. It is read in as AD counts and converted to temperature using a look up table.

Product Level. This input reports the water level in the product holding tank. The AD counts read are converted to a percent full value using a slope / intercept function.

Blow Down Level. This input reports the water level in the blow down holding tank. The AD counts read are converted to a percent full value using a slope / intercept function.

Current Sensor. This input reports the system current. The AD counts read are converted to amps using a slope / intercept function.

Conductivity. This input reports the product water conductivity. The AD counts read and converted to uS/cm using a slope / intercept function.

### Digital Inputs

MCE Awake. Signal from the MCE processor that it is running and able to process requests and commands.

UI SW. User interface switch. A 0.2 second to 2 second press is interpreted by the system as a short button press and press greater than 2 seconds is interpreted as a long button press.

Source Tank Full. An optional input to be used when the UseExternalTanks register is set. This input is attached to the source tank float. It reads a one if the tank is full and a zero if the tank is empty.

Product Tank Full. An optional input to be used when the UseExternalTanks register is set. This input is attached to the product tank float (level sensor). It reads a one if the tank is full and a zero if the tank is empty.

**Digital Outputs**

MCE Enable. Output to the MCE processor to enable it to take commands and requests. This line is connected to the MCE processors reset line. It should give a method for the ARM processor to reset the MCE processor if needed.

MUX Line. This output switches the analog input mux. When it is low: AD channel 3 is reading the Product level AD and channel 4 is reading the Blow Down level AD. When it is high: AD channel 3 is reading the conductivity sensor and channel 4 is reading the current sensor.

Source Valve. The source valve controls water into the system. It is controlled based on the desired level in the blow down tank. In some embodiments, the desired level is set a little higher that the desired blow down controllers blow down level to assure water is always coming into the system.

Blowdown Valve. This valve controls the water flow out of the blow down tank. This valve is controlled to maintain the level of the blow down tank. The valve, in the exemplary embodiment, is always set a little lower than the source valves desired tank level to maintain water flow into the system.

Product Valve. This valve controls the product flow out of the product holding tank. This valve is controlled to maintain the desired level in the product tank.

Vent Valve. This valve controls venting the system. The vent valve is used to control the Low pressure steam temperature.

Product Divert Valve. This valve is used to control the product tank level. When diverting the product is desired the product divert valve may be used instead of the product valve.

Red UI LED. In some embodiments, there is a red LED on the UI panel which is on 100% of the time when there is an active fault. If there is an active warning the red user LED will flash at a 50% duty cycle. If there is no fault it is off. However, in various other embodiments, the color of the indicator may vary.

Yellow UI LED. In some embodiments, there is a yellow LED on the UI panel. It blinks with the duty cycle of the heater. However, in various other embodiments, the color of the indicator may vary.

Green UI LED. In some embodiments, there is a green LED on the UI panel. It blinks at a 50% duty cycle if the system is not producing good/acceptable, within a predetermined threshold, water. It is on steady if the system is producing good water. However, in various other embodiments, the color of the indicator may vary.

Red Status LED. In some embodiments, there is a red LED on the PC board. In some embodiments, it remains "off" in the Heat Exchanger Prime **7510** state and all the flow measurement states. It blinks at a 50% duty cycle in the Idle **7504**, Start Pump **7512** and Standby **7522** states. It is on steady in the Fill **7506**, Heat **7508** and Run **7514** states. However, in various other embodiments, the color of the indicator may vary.

Green Status LED. In some embodiments, there is a green LED on the PC board. It remains "off" in the Fill **7506** state. It blinks at a 50% duty cycle in the Idle **7504** and Run **7514** states. It is on steady in the Heat **7508**, Heat Exchanger Prime **7510**, Start Pump **7512** flow measurement and standby states.

Counter. This output turns on the motor time counter. In some embodiments, it is turned "on" when the commanded motor speed is greater than 50 rpm. In some embodiments, it is turned "off" when the commanded motor speed is less than 50 rpm.

Bearing feed pump. This output turns the bearing feed pump "on" and "off". It is turned "on" when the motor is commanded to run. It is turned "off" when the motor is turned off.

## System Integrity Tasks

The control system as described herein uses a variety of processors, and IOs to complete events, as discussed above. Using memory the control systems logs the performance information of the apparatus and may determine system errors, inefficiencies, etc., and diagnose the causes. Additionally, the control system may either allow recovery from a system error or not. In some embodiments, the system may attempt to restart following an error if the error did not occur in the Idle **7504** state. In some embodiments, for over temperature faults the system may wait until the

temperatures drop within acceptable ranges before restarting. In some embodimenst, the software may retry starting the system at least three times. In some embodiments, after the third restart attempt, the system may stay in the Idle **7504** state. In some embodiments, if the system stays in the Run 7514 state for a predetermined amount of time, e.g., 20 minutes, or is manually turned off by the operator/ user, the retry counter may be reset to zero. In some embodiments, all of the sensor faults must persist for a predetermined amount of time, e.g., 2 seconds, before the system may consider it a true fault. In some embodiments, the system integrity tasks run in the same thread as the water and the hardware tasks. Below is Table 1 including a list of error types that may be determined using the control system. An example of the condition which triggers the error is also given, as well as whether recovery is permitted. The conditions given are for illustration purposes and although in some embodiments, these may be used, in other embodiments, the values, etc., may differ.

The system, in the exemplary embodiment, uses the ARM processor watchdog timer. The timeout may be set for 10 seconds. Each time a task goes through its main processing loop it calls the watchdog update method passing in its task id bit. When the water, hardware and system integrity bits are all set, the software tickles the watchdog and clears the watchdog bits. This may be beneficial in some embodiments as it assures that all critical tasks are running.

**Table 1**

| Error Description | Condition | Recovery |
|---|---|---|
| Low Pressure Thermistor Open | AD reading > 1005 counts | No |
| High Pressure Themistor Open | AD reading > 1005 counts | No |
| Sump Thermistor Open | AD reading > 1005 counts | No |
| Motor Thermistor Open | AD reading > 1005 counts | No |
| Low Pressure Thermistor Short | AD reading < 30 counts | No |
| High Pressure Themistor Short | AD reading < 30 counts | No |

| | | |
|---|---|---|
| Sump Thermistor Short | AD reading < 30 counts | No |
| Motor Thermistor Short | AD reading < 30 counts | No |
| Product Level Open | AD reading > 900 counts | No |
| Blow Down Level Open | AD reading > 900 counts | No |
| Product Level Short | AD reading < 250 counts | No |
| Blow Down Level Short | AD reading < 250 counts | No |
| Low Pressure Over Temp | Low Pressure temp > 125°C | Retry After Clear |
| High Pressure Over Temp | High Pressure temp > 149°C | Retry After Clear |
| Sump Over Temp | Sump temp > 125°C | Retry After Clear |
| Motor Over Temp | Motor temp > 180°C | Retry After Clear |
| IRAM Over Temp | Motor temp > 100°C | Retry After Clear |
| BD Level High | During Run state Blow Down level is > 90% for more than 4 min. | Retry After Clear |
| BD Level Low | During Run, Prime and Standby states Blow Down valve duty cycle <= 2% for more than 4 min. | Retry After Clear |
| Product Level High | During Run state Product level is > 90% for more than 5 min. | Retry After Clear |
| Product Level Low | During Run state Product and divert valves duty cycle <= 2% for more than 5 min. | Retry After Clear |
| System too Cold | During Run state Low Pressure temp < 104°C | Retry After Clear |
| Too long in State | In fill state > 12 min or<br>In heat state > 4 hours or<br>In hx prime state > 2.5 hours or<br>In start pump state > 8 min | No |
| Lack of water in sump | Sump temp > 115°C and | Retry After Clear |

| | | |
|---|---|---|
| | Sump temp - LP temp > 25°C | |
| Error Reading from Flash | CRC or data length error reading flash memory | No |
| Error Writing to Flash | Error writing constant values to flash memory | No |
| Motor Error | Commanded motor speed > 50 and actual to commanded motor speed difference is > MotorErrorSpeed rpm for > MotorErrorTime seconds | Retry After Clear |
| Magnetic coupling slipping | HPTemp – LPTemp < 1.5°C and Prod and Divert duty < 10% | Retry After Clear |
| Heater Fault | Not Implemented | Retry After Clear |
| Over Current | System current > 13A | Retry After fault |
| Conductivity Sensor Open | Not Implemented | No |
| Conductivity Sensor Short | AD reading < 150 counts | No |
| Conductivity Too High | In Run state Conductivity > CondoLimitQ10 for > CondoErrTime Seconds | No |
| MCE Communications Fault | No response from MCE after 5 retries at 10 sec per retry | No |
| MCE Fault | No MCE awake signal after reasserting MCE Enable for 20 consecutive tries | No |

**MCE**

The MCE message task handles the communications between the ARM control processor and the MCE processor. In some embodiments, there are 2 discrete digital signals between the ARM and the MCE processors: the MCEEnable line and the MCEAwake line. The MCEEnable line is an output from the ARM processor and an input to the MCE processor. This line is set to "0" to enable the MCE. While MCEEnable is a "1" the MCE processor is held in the reset state.

The MCEAwake line is an output from the MCE processor and an input to the ARM processor. In some embodiments, the MCE_msg task will only process messages if the

MCEAWAKE line is active. If the MCEAwake line is not active the MCEEnable line is reset to the enable state. If after a predetermined amount of time, e.g., 60 seconds, of asserting the MCEEnable line the MCEAwake line does not become active an MCE Fault may be issued.

The MceMsg process function creates the processing signals as events occur. It will then distribute them to a heater command state machine. If the heater command state machine does not handle the signal it is then passed to the motor command state machine. If the MCE state machine does not handle the event, e.g., if the event is a response that was not expected, an error message is sent to the MCE. However, if the MCE state machine does handle the event, a status request is sent to the MCE. If a response to the command is not received within a predetermined time, e.g.10 seconds, the command is reissued. If no response is received after a predetermined number of attempts, e.g. 5 retries, the MCE Communications Fault is signaled. MCE status is returned in the command response packets.

Therefore, the control system described above may be used to determine the integrity of the apparatus/system and also, with information relating to the rate of water product production, the control system may signal when the system should undergo maintenance, including, but not limited to, cleaning/de-scaling. In some embodiments, the system may signal that the maintenance is needed, e.g., post a message to the external application and/or indicate same on a User Interface on the machine, including, but not limited to, one or more of: LEDs, text message, symbol/icon, etc. In some embodiments, the system may automatically undergo a maintenance procedure, e.g., cleaning/de-scaling, however, in other embodiments, the maintenance procedure may be performed manually and then confirmed through, e.g., a user interface, that the maintenance was completed.

Communication with an external application also presents many methods for controlling the apparatus remotely. For example, with regular logs and software communication, a user may determine which apparatus needs maintenance and may schedule same remotely. This may be desirable/beneficial for many reasons, including, but not limited to, running one or more water vapor distillation apparatus/machines remotely in various countries/regions including, but not limited to, areas that are very remote or scarcely populated.

In various embodiments, the one or more water vapor distillation apparatus/machines may include communications with a remote device or server, e.g., a web site or a remote computer. The communication may be established using one or more,

but not limited to, the following: cell modem, internet, Ethernet, and/or land line/telephone line. In various embodiments, bi-directional communications may be established between a remote device or server and the one or more water vapor distillation apparatus/machines.

Referring now also to FIG. 76, in some embodiments, the at least one water vapor distillation apparatus/machine/system may include a system for communications which may, in some embodiments, include a "backend" and an external manager. In some embodiments, the backend may be a HTTP server and SMS Dispatcher with interfaces for connecting the at least one water vapor distillation apparatus/machine/system as well as External Manager(s). The Backend acts as a bridge between the External Manager and the at least one water vapor distillation apparatus/machine/system. In some embodiments, the Backend may be configured by the External Manager to provide automated interactions with the device. In some embodiments, the Backend may act as a go-between entity to provide interactivity between the at least one water vapor distillation apparatus/machine/system and the External Manager.

In various embodiments, the External Manager may be a process that configures the server to indirectly configure and interact with at least one water vapor distillation apparatus/machine/system.

The at least one water vapor distillation apparatus/machine/system, in some embodiments, is an HTTP client. These embodimenst may be used in many situations, including, but not limited to, when the at least one water vapor distillation apparatus/machine/system is remotely located and connected via cell modem. In this embodiment, the at least one water vapor distillation apparatus/machine/system may not, in some embodiments, always be connected to lower costs, and also, where the cell model infrastructure may not be 100% reliable. In these embodiments, the server is always be running. Therefore, in these embodiments, the at least one water vapor distillation apparatus/machine/system is the client and the backend is the server.

In some embodiments, the backend may wake the at least one water vapor distillation apparatus/machine/system by issuing an SMS "shoulder tap" message. In various embodiments, this message contains no data, but may indicate that the device may connect to the server to receive instructions, updated, communications, etc.

In various embodiments, the External Manager directly interacts solely with the Backend via its HTTP server interface through a special "External Manager" interface. In some embodiments, the external interface to the at least one water vapor distillation apparatus/machine/system is an HTTP interface implemented over an SSL security layer

using TCP/IP sockets. In some embodiments, the API may be compatible with the AJAX "web services" pattern used in many web based technologies.

In various embodiments, connections to the at least one water vapor distillation apparatus/machine/system are stateless. Correspondingly, in these embodiments, all commands are synchronous. Any changes in state on the at least one water vapor distillation apparatus/machine/system are realized by the calling client making multiple synchronous requests and computing the difference between those calls.

In various embodiments, each request comes into the at least one water vapor distillation apparatus/machine/system in the form of an XML message. A request is processed and its response is sent back to the caller in the form of an XML message.

In some embodiments, a manual cleaning/de-scaling may be performed by using pressurized clean water and flushing to system. In some embodiments, the apparatus may be connected to an acid cleaning solution for flushing/cleaning. In some embodiments, a pump is used to pump the water and/or cleaning solution through the apparatus/machine.

A system for providing product water may include a source tank, containing a volume of source water, and a product tank, containing a volume of product water. Both the source tank and the product tank may include level sensors to determine the level of water. In these embodiments, the control system enters the water task Fill 7506, etc., states only when there is a sufficient volume of water in the source tank and if the product tank is not full. The water task will then run until either the product tank is full or the source tank is below a predetermined volume. The machine then enters into the Idle 7504 state. In some embodiments, the source tank may be fluidly connected to a pressurizing pump which pumps the water into the apparatus.

Referring now also to FIG. 77, in some embodiments, the water vapor distillation apparatus may be housed within a shell/case 7700 (which may also be referred to as a housing). In some embodiments, the shell/case may be as shown in FIG. 77. Referring now also to FIG. 78, in some embodiments, a filter/strainer assembly 7704 may be located in a compartment area that, in some embodiments, may be easily accessible by users. In some embodiments, the filter/strainer assembly 7704 may be used to strain debris from the source water prior to the water entering the water vapor distillation apparatus. In various embodiments, the source water enters the filter/strainer assembly 7704 through an input nozzle assembly 7732. In some embodiments, it may be desirable that users have access to the filter/strainer assembly 7704 to remove, empty/clean the filter/strainer, then replace. However, in some embodiments, the filter/strainer assembly 7704 may be located within the

case/shell 7700 and behind a door, or other. In some embodiments of these embodiments, the filter/strainer assembly 7704 may be accessible, but may require the opening of a door or latch. In other embodiments of this embodiment, the filter/strainer assembly 7704 may be accessible by removal of one or more sections of the case/shell 7700 (discussed in further detail below). In various embodiments of the system, however, a filter and/or a strainer may be located outside of the system and/or outside of the case/shell, but positioned such that a source water fluid passes through the filter and/or strainer before entering the apparatus.

Referring now also to FIG. 78, in some embodiments, the case/shell 7700 may include a user interface 7702, which, in some embodiments may include, but is not limited to, one or more of the following: one or more LEDs, one or more buttons, one or more screens, including, but not limited to, a touch screen which may include, but is not limited to, a 3D, or 3-dimmensional, touch screen. In some embodiments, the user interface 7702 may also include an overlay or other to protect the one or more features of the user interface. In some embodiments, the overlay or other may provide protection from water and/or temperatures, e.g., hot or cold.

Referring now also to FIGS. 79A-79E, various views of one embodiments of the case/shell 7700 are shown. In various embodiments, including the embodiments shown in these FIGS., the case/shell 7700 includes one or more sections, which, in some embodiments, may include two sections, but in other embodiments, may include two or more sections. In some embodiments, the case/shell 7700 may include a cold section 7706 and at least one hot section 7708. As shown in the embodiment shown in FIGS. 79A-79E, the hot section 7708 may include two sections 7710, 7712. In some embodiments this may be desirable for a user and/or technician to gain entry to one side of the hot section without having to remove the other side of the hot section. In some embodiments, this may be desirable/beneficial for many reasons, including, but not limited to, the efficiency and/or reduced cost to manufacture. In various embodiments, the various embodiments of the case/shell 7700 may be made from any materials, including, but not limited to, one or more of the following: fiberglass, plastic, metal.

In various embodiments, the cold section 7706 may be the section covering the electronics assembly, the hydraulic manifold, including, but not limited to, the valve manifold and the conductivity cell. These embodiments include one or more sections of the case/shell 7700 may be desirable for many reasons, including, but not limited to, ease

and safety of a user and/or service technician gaining entrance to the cold section to service the electronic assemblies, valves, etc., without being exposed to the very hot section 7708.

As shown in FIGS. 79A-79E, in various embodiments, the case/shell 7700 includes a drain 1 port 7716 and a drain 2 port 7718 for draining the blow down and the product water. In various embodiments, the case/shell 7700 includes at least one electrical cord input 7714, allowing for an electrical cord to plug into the input 7714 and provide electricity to the electronics assembly, etc.

Referring now to FIG. 80, in various embodiments, the shape of the case/shell 7720 may be as shown. In some embodiments of these embodiments of the case/shell 7722, as shown, for example, in FIG. 81, the case/shell 7720 may include a filter/strainer assembly 7724 that may be located in a compartment area that, in some embodiments, may be easily accessible by users. In some embodiments, the filter/strainer assembly 7724 may be used to strain debris from the source water prior to the water entering the water vapor distillation apparatus. In some embodiments, it may be desirable that users have access to the filter/strainer assembly 7724 to remove, empty/clean the strainer/filter, then replace. In some embodiments, however, the filter/strainer assembly 7724 may be located within the case/shell 7722 and behind a door, or other. In some embodiments of these embodiments, the filter/strainer assembly 7724 may be accessible, but may require the opening of a door or latch. In other embodiments of this embodiment, the filter/strainer assembly 7724 may be accessible by removal of one or more sections of the case/shell (discussed in further detail below). In various embodiments of the system, however, a filter and/or a strainer may be located outside of the system and/or outside of the case/shell, but positioned such that a source water fluid passes through the filter and/or strainer before entering the apparatus.

Referring now also to FIGS. 81 and 82, in some embodiments, the case/shell 7722 may include a user interface 7726, which, in some embodiments may include, but is not limited to, one or more of the following: one or more LEDs, one or more buttons, one or more screens, including, but not limited to, a touch screen which may include, but is not limited to, a 3D, or 3-dimmensional, touch screen. In some embodiments, the user interface 7726 may also include an overlay or other to protect the one or more features of the user interface. In some embodiments, the overlay or other may provide protection from water and/or temperatures, e.g., hot or cold.

In some embodiments, the case/shell 7722 includes one or more sections, which, in some embodiments, may include two sections, but in other embodiments, may include two

or more sections. In some embodiments, the case/shell 7722 may include a cold section 7728 and at least one hot section 7730. In some embodiments, the hot section 7730 may include two sections. In some embodiments this may be desirable for a user and/or technician to gain entry to one side of the hot section 7730 without having to remove the other side of the hot section. In some embodiments, this may be desirable/beneficial for many reasons, including, but not limited to, the efficiency and/or reduced cost to manufacture. In various embodiments, the various embodiments of the case/shell 7722 may be made from any materials, including, but not limited to, one or more of the following: fiberglass, plastic, metal.

In various embodiments, the cold section 7728 of the case/shell 7722 may be the section covering the electronics assembly, the hydraulic manifold, including, but not limited to, the valve manifold and the conductivity cell. The embodiments include one or more sections of the case/shell 7722 may be desirable for many reasons, including, but not limited to, ease and safety of a user and/or service technician gaining entrance to the cold section 7728 of the case/shell 7722 to service the electronic assemblies, valves, etc., without being exposed to the hot section 7730 of the water vapor distillation apparatus. In some embodiments, access to one or more sections may require at least one tool.

In various embodiments, the case/shell 7722 includes a drain 1 port and a drain 2 port for draining the blow down and the product water. In various embodiments, the case/shell includes at least one electrical cord input 7714, allowing for an electrical cord to plug into the input 7714 and provide electivity to the electronics assembly, etc.

Referring now also to FIG. 83, one embodiment of the water vapor distillation apparatus 8300 is partially shown. In some embodiments, the water vapor distillation apparatus may be housed inside one or more of the embodiments of the case/shell shown herein, or may be housed inside another embodiments of a case/shell. In various embodiments, the water vapor distillation apparatus may include various components, including, but not limited to, an embodiment of a steam chest 8302, an evaporator/condenser 8304, a heat exchanger 8306, a compressor 8308 and a cap 8310 on the compressor.

Referring now also to FIGS. 84A - 84F and FIGS. 85A – 85B, various partial views of a water vapor distillation apparatus configuration are shown. In various embodiments, one or more brackets 8400, 8402 may be used to stabilize the various elements of the water vapor distillation apparatus such that, during transportation, for example, the various elements of the water vapor distillation apparatus maintain their location and connections

within the case/shell. Some embodiments of the brackets 8400, 8402 are shown in FIGS. 84A-84F and FIGS. 85A – 85B. In some embodiments of these embodiments of the brackets 8400, 8402, the brackets 8400, 8402 may be made from plastic. However, in other embodiments, the brackets 8400, 8402 may be made from metal or another material.

As shown in the FIGS., some embodiments include a hot/cold divider 8406 to divide the hot section of the water vapor distillation apparatus from the cold section of the water vapor distillation apparatus. This divider 8406, in some embodiments, contributes to the maintenance of the temperature in the hot section, i.e., the hot/cold divider 8406 may, in some embodiments, be a thermal insulator. In some embodiments, the various bracket systems employed within the water vapor distillation apparatus may attach to the hot/cold divider 8406.

In various embodiments of the water vapor distillation apparatus, the apparatus includes a blow down level sensor 8408 and a product level sensor 8410. In some embodiments, the sensors may be identical, but each may be in fluid communication with a different fluid path in the system. In some embodiments, the product level sensor 8410 is located lower in the system as the product is gravity fed from the evaporative/condenser.

In various embodiments of the water vapor distillation apparatus, the apparatus includes a valve manifold 8412. In some embodiments, this may be a hydraulic valve manifold. In some embodiments, the hydraulic valve manifold may be connected to the conductivity cell 8414 (sometimes referred to as a condo cell). Additional views of the manifold 8412 and the valves are shown in FIGS. 85A and 85B.

Referring also to FIGS. 85A and 85B, in some embodiments, the water vapor distillation apparatus includes a base/basin 8416, and a foam bottom base 8418 that sits within the base/basin 8416. The base/basin 8416, in some embodiments, may serve as a central connection point for the various elements/components of the water vapor distillation apparatus. In various embodiments, the water vapor distillation apparatus is a modular system, e.g., one element or component may be removed from the system without dismantling the entire system. For example, the hydraulic manifold 8420 is designed to be easily disconnected from the system, removed, and replaced, without removing other elements/components of the system. The basin 8416 therefore serves as the base for the apparatus/system to connect.

In various embodiments, the foam bottom base 8418 may serve as an insulator and/or thermal insulation element/component. FIG. 85B shows a detail view of section A shown in FIGS. 85A.

Referring now also to FIG. 86, another embodiment of the water vapor distillation apparatus, shown in exploded view, is shown together with the case/shell assembly. Together, the water vapor distillation apparatus and the case/shell form a system 8600.

As shown, the cold case cover assembly 8602 separates from the hot case/cover assembly 8604. The cold/case cover assembly 8602 covers the cold components of the water vapor distillation apparatus, including, but not limited to, the electronics assembly 8606, the scale mitigation assembly 8608, the condo cell 8610 and the hydraulic manifold as well as the electronics plug-ins (not shown, see FIG. 87D as 8612). The hot case/cover assembly 8604 covers the hot components of the water vapor distillation apparatus, including, but not limited to, the sump (with heater), the evaporator/condenser 8614, the steam chest 8616, the compressor/regenerative blower 8618 and the tube-in-tube heat exchanger 8620. In some embodiments, a tool, e.g., a Phillips head screwdriver, may be used to remove the hot section 8604 of the case/cover assembly. In some embodiments, no tool may be required. In some embodiments, a tool may be required to remove the hot section 8604 of the case/cover assembly, but not the cold section 8602 of the case/cover assembly. Referring now also to FIG. 87A, an embodiment of the bracket assembly 8622 is shown. These embodiments of the bracket assembly include an E/C bracket 8624 which is a ring bracket that clamps around the outside of the evaporator/condenser 8614 and attaches to the bracket assembly 8622. Together, the bracket assembly 8622 and E/C bracket 8624 maintain the stability of the position of the components within the case/shell.

As discussed above, the water vapor distillation apparatus, in various embodiments, is a modular apparatus. The various components may each be easily removed without disassembling the entire apparatus. For example, the heat exchanger 8620 may be unclamped and lifted out of the apparatus, to then easily remove the other components of the system. FIG. 87C shows the apparatus with the heat exchanger having been removed. Referring also to FIG. 88, the hydraulic manifold 8626 includes a steam/water mixing chamber 8628, and a condo (or conductivity) cell which includes a conductivity probe 8630 a condo cell casing 8632 a condensate tubing assembly 8634, o-rings/seals 8636, 8638, 8642, 8644, a hydraulic valve manifold mounting plate 8640, a hydraulic valve manifold 8646, which includes valves 8648, including check valves 8650. The hydraulic manifold, in various embodiments, also may include a mixing chamber 8628 support ring 8652.

Referring also to FIG. 87A, some embodiments of the water vapor distillation apparatus include a scale mitigator 8654. Various embodiments of the scale mitigator 8654 may be used, which includes, but are not limited to, the SCALESTICK manufactured by

Southeastern Filtration & Equipment Solutions of Canton, Georgia, U.S.A. However, in various other embodiments, various methods, processes, systems and/or apparatus for scale mitigation may be used.

Referring also to FIG. 87B, in various embodiments, the basin 8656 may include a drain 1 port 8658 and drain 2 port 8660 (or a first drain port 8658 and a second drain port 8660) for the product drain and the blow down drain. An electrical cord input 8662 may also be included. In various embodiments, the system may include an electrical cord with various connectors for use in various areas of the world.

Referring now also to FIG. 87D, the water vapor distillation apparatus electronics assembly 8606, in some embodiments, may be a closed assembly, i.e., may be designed such that a user or service technician may not easily gain entry. However, the water vapor distillation apparatus may include electronics plug-ins such that devices may be easily plugged into the water vapor distillation apparatus and be in communication with the electronics assembly without having to open the electronics assembly. For example, the water vapor distillation apparatus may include electronics plug-ins for one or more device, including, but not limited to, an external product level sensor and/or an external pump. Additionally, in various embodiments, the water vapor distillation apparatus system may include a port/button cover 8664, which, in some embodiments, may be located in the filter/strainer compartment, which includes a cover 8664, which, in some embodiments, may be a protective cover, covering one or more of, but not limited to, the following: a reset button, a state change button, an Ethernet port and/or an Secure Digital Memory Card ("SD card") port. In some embodiments, where the water vapor distillation apparatus may not be connected to the Internet and/or have wireless service, e.g., in locations in the world where Internet / wireless service is not available and/or reliably available, updates to the software of the system may be performed using an SD card. In various embodiments, the water vapor distillation apparatus may include a filter/strainer assembly 8666, which, in some embodiments, may include an input nozzle assembly 8668.

In various embodiments, the water vapor distillation system may include a divider 8670 which divides the cold portion from the hot portion of the apparatus and system. Various embodiments of the water vapor distillation system may include a user interface 8672, which may include one or more of the features described with respect to various embodiments of the water vapor distillation system, and may include an overlay 8674.

In various embodiments, the mist eliminator may include one or more of the embodiments shown in FIGS. 90A-98B.

Referring now also to FIGS. 90A-90E, various views of one embodiment of a mist eliminator 9000 are shown. In this embodiment, the mist eliminator 9000 may include three sections, a top section 9002, a middle section 9004, and a bottom section 9006. In some embodiments, legs 9008, 9010, 9012 are attached to the bottom section 9006. In various embodiments, the top section 9002, a middle section 9004, and a bottom section 9006 are connected with a connecting mechanism, which may include, but is not limited to, screws. In some embodiments, the mist eliminator 9000 is made stainless steel, aluminum and/or plastic, and in various embodiments, may be made from any material including any type of metal and/or any type of plastic.

The mist eliminator 9000 in various embodiments may be sized to fit within the steam chest (described above) and the legs 9008, 9010, 9012 may attach to holes in the evaporator condenser (described above) wherein the evaporator condenser in various embodiments may include holes to accommodate receipt of the legs 9008, 9010, 9012.

In various embodiments, the bottom section 9006 may be sized such that the edge of the bottom section 9006 rests against the inside wall of the steam chest. In various embodiments, the bottom section 9006 may include one or more cut openings 9014, 9016, 9018, 9020, 9022. Steam from the evaporator condenser may travel past the bottom section 9006 and water may travel past the bottom section 9006.

The middle section 9004 includes an edge that may rest against the inside wall of the steam chest. In various embodiments, the middle section 9004 includes edge openings 9024, 9026, 9028, 9030, 9032, 9034 about the circumference of the middle section 9004. The middle section 9004 also includes an opening 9036.

The top section 9002 in various embodiments is generally cone-shaped and provides a cap to the mist eliminator assembly 9000.

Steam may pass through the opening 9036 and also through the edge openings 9024, 9026, 9028, 9030, 9032, 9034 and cut openings 9014, 9016, 9018, 9020, 9022, as well as around the outside circumferential edge of the bottom section 9006, middle section 9004 and the top section 9002. The shape of the top section 9002 forces the steam to change direction. Water vapor that travels through the opening 9036 will hit the underside of the top section 9002 and drip down and eventually, to the sump. Thus, to the extent water passes through from the evaporator condenser with the steam, when the steam, which changes direction when it reaches the top section 9002, changes direction, the water is incapable of following the same path because the water cannot change direction as it has a higher mass. This results in the water being separated from the steam. The water may reach the underside of the top section

9002 and then, as there is no opening in the top section 9002, falls to the middle section 9004, and may travel through the edge openings 9024, 9026, 9028, 9030, 9032, 9034 and cut openings 9014, 9016, 9018, 9020, 9022 and back to the sump.

In various embodiments, the three sections 9002, 9004, 9006 are generally cone-shaped and therefore, to the extent water reaches a surface of one or more of the three sections 9002, 9004, 9006, the water will tend to drip downwards towards the sump.

Referring now also to FIGS. 91A and 91B, another embodiment of a mist eliminator 9100 is shown. In this embodiment, the mist eliminator 9100 may include two sections, a top section 9102 and a bottom section 9004. In some embodiments, legs 9106, 9108, 9110 are attached to the bottom section 9104. In various embodiments, the top section 9102 and a bottom section 9104 are connected with a connecting mechanism, which may include, but is not limited to, screws. In some embodiments, the mist eliminator 9100 is made stainless steel, aluminum and/or plastic, and in various embodiments, may be made from any material including any type of metal and/or any type of plastic.

The mist eliminator 9100 in various embodiments may be sized to fit within the steam chest (described above) and the legs 9106, 9108, 9110 may attach to holes in the evaporator condenser (described above) wherein the evaporator condenser in various embodiments may include holes to accommodate receipt of the legs 9106, 9108, 9110.

In various embodiments, the bottom section 9104 may be sized such that the edge of the bottom section 9104 rests against the inside wall of the steam chest. In various embodiments, the bottom section 9104 may include one or more edge openings 9114, 9116, 9118, 9120, 9122. Steam from the evaporator condenser may travel past the bottom section 9104 to the top section 9102. The bottom section 9104, in various embodiments, includes an opening 9036.

The top section 9102 in various embodiments is generally cone-shaped and provides a cap to the mist eliminator assembly 9100.

Steam may pass through the opening 9112 and also through the edge openings 9024, 9026, 9028, 9030, 9032, 9034 and edge openings 9114, 9116, 9118, 9120, 9122, as well as around the outside circumferential edge of the bottom section 9104 and the top section 9102. The shape of the top section 9102 forces the steam to change direction. Water vapor that travels through the opening 9112 will hit the underside of the top section 9102 and drip down and eventually, to the sump. Thus, to the extent water passes through from the evaporator condenser with the steam, when the steam, which changes direction when it reaches the top section 9102, changes direction, the water is incapable of following the same path because the

water cannot change direction as it has a higher mass. This results in the water being separated from the steam. The water may reach the underside of the top section 9102 and then, as there is no opening in the top section 9102, falls to the bottom section 9104, and may travel through the edge openings 9114, 9116, 9118, 9120, 9122 and opening 9112 and back to the sump.

In various embodiments, the top section 9102 and bottom section 9104 are generally cone-shaped and therefore, to the extent water reaches a surface of one of the sections 9102, 9104 the water will tend to drip downwards towards the sump.

Referring now to FIGS. 92A -92B, another embodiment of a mist eliminator 9200 assembly 9200 is shown. In this embodiment, a plurality of mist eliminator caps 9202 are attached to a bottom section 9204. In various embodiments, the bottom section 9202 includes a plurality of openings 9212 that may be configured to line up with the openings in the upper tube sheet 1004 (shown in FIG. 10A) of the evaporator condenser.

In some embodiments, legs 9206, 9208, 9210 are attached to the bottom section 9204. In some embodiments, the mist eliminator 9200 is made stainless steel, aluminum and/or plastic, and in various embodiments, may be made from any material including any type of metal and/or any type of plastic.

The mist eliminator 9200 in various embodiments may be sized to fit within the steam chest (described above) and the legs 9206, 9208, 9210 may attach to holes in the evaporator condenser (described above) wherein the evaporator condenser in various embodiments may include holes to accommodate receipt of the legs 9206, 9208, 9210.

In various embodiments, the bottom section 9204 may be sized such that the edge of the bottom section 9204 rests against the inside wall of the steam chest.

Steam may pass through the plurality of openings 9212 and also through the a lower sections 9226 of the plurality of mist eliminator caps 9202 , which are open to the upper section 9228 of the plurality of mist eliminator caps 9202, as well as around the outside circumferential edge of the bottom section 9204. The shape of the upper section 9228 forces the steam to change direction. Water vapor that travels through the plurality of openings 9212 will hit the underside of the upper section 9228 and drip down and eventually, to the sump. Thus, to the extent water passes through from the evaporator condenser with the steam, when the steam, which changes direction when it reaches the upper section 9228, changes direction, the water is incapable of following the same path because the water cannot change direction as it has a higher mass. This results in the water being separated from the steam. The water may reach the underside of the upper section 9228 and then, as there is no opening in the upper

section 9228, falls to the bottom section 9204, and may travel through the edge openings 9214, 9216, 9218, 9220, 9222, 9224 and plurality of openings 9212 and back to the sump.

In various embodiments, the upper sections 9228, and in some embodiments, the bottom section 9204 are generally cone-shaped and therefore, to the extent water reaches a surface of the upper sections 9228 or the bottom section 9204, the water will tend to drip downwards towards the sump.

Referring now also to FIGS. 93A and 93B, another embodiment of a mist eliminator assembly 9300 is shown. In this embodiment, a mist eliminator assembly 9300 is a cap that attaches to each of the plurality of rods (not shown, shown in FIG. 9A as 902) within the tubes in the evaporator condenser assembly. Steam flows past the bottom section 9304, as indicated by the arrow, and then past the top section 9302. The shape of the top section 9302 forces the steam to change direction. Water vapor thus travels past the bottom section 9304 and then hits the underside of the top section 9302 and drips down, back to the sump. Thus, to the extent water passes through from the evaporator condenser with the steam, when the steam, which changes direction when it reaches the top section 9302, changes direction, the water is incapable of following the same path because the water cannot change direction as it has a higher mass. This results in the water being separated from the steam. The water may reach the underside of the top section 9302 and then, as there is no opening in the top section 9302, falls back to the sump.

Referring now also to FIG. 94, in some embodiments, a chevron shaped mist eliminator 9400 may be used. In this embodiment, the steam is subjected to a plurality of tortuous pathways including tortuous pathways 9404, 9406, 9408. The steam changes directions many times. As such, any water that may have entered the mist eliminator will be separated from the steam as the water is unable to change directions with the steam. The water may then drip back to the sump.

In some embodiments, the mist eliminator 9400 is made of stainless steel, aluminum and/or plastic, and in various embodiments, may be made from any material including any type of metal and/or any type of plastic.

The mist eliminator 9400 in various embodiments may be sized to fit within the steam chest (described above) and the leg 9408 may attach to a hole in the evaporator condenser (described above) wherein the evaporator condenser in various embodiments may include holes to accommodate receipt of the leg 9408.

Referring now also to FIGS. 95A and 95B, an embodiment of a baffle port is shown. In various embodiments, the baffle port may be inserted into the steam chest, as shown in

FIGS. 96 and 97. FIGS. 96 and 97 show various embodiments of the mist eliminator (9400, 9200 respectively) inside the steam chest. A partial view of the evaporative condenser is shown.

Referring now to FIGS. 98A and 98B, another embodiment of a mist eliminator 9800 is shown. In this embodiment, three layers of mesh 9802, which, in some embodiments, may be made from stainless steel or steel, are stacked with spacers in between. One or more legs 9804 may be attached to the layers of mesh 9802. The mist eliminator 9800 in various embodiments may be sized to fit within the steam chest (described above) and the one or more legs 9804 may attach to a hole in the evaporator condenser (described above) wherein the evaporator condenser in various embodiments may include holes to accommodate receipt of the leg 9404 (or one or more legs).

In some embodiments, the mist eliminator 9400 is made of stainless steel, aluminum, PTFE and/or plastic, and in various embodiments, may be made from any material including any type of metal and/or any type of plastic.

In various embodiments, each layer of the mesh may include edge openings 9806, 9808, 9810, 9812, 9814, 9816. In some embodiments, the layers of mesh 9802 may be sized such that the edge touches the inside wall of the steam chest. Water may drip through the openings 9806, 9808, 9810, 9812, 9814, 9816 and to the sump.

In various embodiments, the three layers of mesh are staggered with respect to one another. This creates a tortuous path for the steam and therefore, the steam changes directions when flowing through the mesh. Thus, the location of the mesh openings with respect to each layer of the three layers of mesh 9802 forces the steam to change direction. To the extent water passes through from the evaporator condenser with the steam, when the steam changes direction, the water is incapable of following the same path because the water cannot change direction as it has a higher mass. This results in the water being separated from the steam. The water may falls back to the sump.

In various embodiments, the water vapor distillation apparatus and/or the various embodiments of the mist eliminator assembly may include a splash guard above the mist eliminator. In various embodiments, the splash guard may be constructed of a hydrophobic material.

In some embodiments, the splash guard may be constructed of one or more layers of mesh. In some embodiments, where two or more layers of mesh are used, the two or more layers of mesh may be rotated ninety-degrees from each other.

In various embodiments, the splash guard may be made of stainless steel, aluminum, PTFE and/or plastic, and in various embodiments, may be made from any material including any type of metal and/or any type of plastic.

Referring now also to FIGS. 99A-99C, various views of one embodiment of a mist eliminator 10000 are shown. In this embodiment, the mist eliminator 10000 may include six sections, a ring frame 10002, a screen section 10004, a cone frame section 10006, a top section 10008, a middle section 10010, and a bottom section 10012. In some embodiments, legs 10014, 10016, 10018 are attached to the bottom section 10012. In various embodiments, the various sections may be molded and heat staked together. In various embodiments, the cone frame section 10006 receives the screen section 10004, which, in various embodiments, may be cone shaped. In various embodiments, the screen section 10004 may be made from a mesh filter, which, in some embodiments, may be made of PTFE, or polytetrafluorethylene. In some embodiments, the PTFE mesh section 10004 may include mesh openings of 0.025 inches and maybe 0.010 inches thick. In some embodiments, the ring frame 10002, cone frame section 10006, top section 10008, middle section 10010, bottom section 10012 are made from RYTON® thermoplastic, however, in various other embodiments, these sections may be made from stainless steel, aluminum and/or plastic, and in various embodiments, may be made from any material including any type of metal and/or any type of plastic.

The mist eliminator 10000 in various embodiments may be sized to fit within the steam chest (various embodiments of which are described above and below) and the legs 10014, 10016 may attach to holes in the evaporator condenser (various embodiments of which are described above and below) wherein the evaporator condenser in various embodiments may include holes to accommodate receipt of the legs 10014, 10016.

In various embodiments, the bottom section 10012 may be sized such that the edge of the bottom section 10012 rests against the inside wall of the steam chest. In various embodiments, the bottom section 10016 may include one or more cut openings 10020, 10022, 10024, 10026, 10028. Steam from the evaporator condenser may travel past the bottom section 10012 and water may travel past the bottom section 10012.

The middle section 10010 includes an edge that may rest against the inside wall of the steam chest. In various embodiments, the middle section 10010 includes edge openings 10030, 10032, 10034, 10036, 10038 about the circumference of the middle section 10010. The middle section 10010 also includes an opening 10040.

The top section 10008 in various embodiments is generally cone-shaped. Steam may pass through the opening 10040 and also through the edge openings 10030, 10032, 10034,

10036, 10038 and cut openings 10020, 10022, 10024, 10026, 10028, as well as around the outside circumferential edge of the bottom section 10012, middle section 10010 and the top section 10008. The shape of the top section 10008 forces the steam to change direction. Water vapor that travels through the opening 10040 will hit the underside of the top section 10008 and drip down and eventually, to the sump. Thus, to the extent water passes through from the evaporator condenser with the steam, when the steam, which changes direction when it reaches the top section 10008, changes direction, the water is incapable of following the same path because the water cannot change direction as it has a higher mass. This results in the water being separated from the steam. The water may reach the underside of the top section 10008 and then, as there is no opening in the top section 10008, falls to the middle section 10010, and may travel through the edge openings 10030, 10032, 10034, 10036, 10038 and cut openings 10020, 10022, 10024, 10026, 10028 and back to the sump.

In various embodiments, the sections 10004, 10006, 10008, 10010, 10012, are generally cone-shaped and therefore, to the extent water reaches a surface of one or more of the three sections 1004, 1006, 1008, 10010, 10012, the water will tend to drip downwards towards the sump.

In various embodiments, the top section 10008 may include a tab portion 10042. This section of the mist eliminator 10000 is configured to be located underneath the low pressure steam outlet port. Thus, the tab portion 10042 may be beneficial for many reasons, including, but not limited to, preventing / minimizing / reducing water droplets from being pulled to the compressor/ regenerative blower, which, in some instances, may contaminate the compressor/regenerative blower.

In various embodiments, the water vapor distillation apparatus and/or the various embodiments of the mist eliminator assembly may include a splash guard above the mist eliminator. In various embodiments, the splash guard may be constructed of a hydrophobic material.

In some embodiments, the splash guard may be constructed of one or more layers of mesh. In some embodiments, where two or more layers of mesh are used, the two or more layers of mesh may be rotated ninety-degrees from each other.

In various embodiments, the splash guard may be made of stainless steel, aluminum, PTFE and/or plastic, and in various embodiments, may be made from any material including any type of metal and/or any type of plastic.

Referring now also to FIGS. 100A-100C, another embodiment of the case/shell 10100 is shown. In various embodiments, the case/shell 10100 may include one or more of the

following a level switch plug in 10102 and an IEC power plug 10104. In various other embodiments, other power plugs may be used, in some embodiments, these may be regulatory compliant power plugs, but in other embodiment, may not be regulatory compliant power plugs. Below these plugs, in various embodiments, outlet ports may be located for product water 10106, divert water 10108, and blowdown water 10110. At the bottom of the various ports, a source water inlet 10112 may be located. In various embodiments, locating the ports and inlets in this configuration may be beneficial/desirable for many reasons, including, but not limited to, the product water port 10106 is located on the top, therefore, if there's any leakage from the connection, the product water does not get contaminated. However, if there is any leakage from the divert water 10108, blowdown water 10110, or source water 10112 ports, they will not contaminate the product water outlet 10106. Additionally, if there is any mud or dirt that is splashed onto the case/shell 10100, the product water port 10106, being located at a higher location from the bottom, will be less likely to be contaminated.

In various embodiments, the case/shell 10100 may be water tight and in some embodiments, may include an IPX3 leak seal rating. In some embodiments, the case/shell 10100 may be sprayed with water without any ingress inside.

Referring now also to FIG. 101, in various embodiments, the case/shell 10100 may include at least two covers, a hot cover 10114 and a cold cover 10116, which are separated by a divider 10118. The hot cover 10114 covers the "hot" components of the water vapor distillation apparatus, and the cold cover 10116 covers the "cold" components of the water vapor distillation apparatus. In various embodiments, the case/shell 10100 may include hand-holds 10124, 10126 for ease of removal of the hot cover 10114. In various embodiments, the cold cover 10116 may be locked with a mechanism requiring tools to unlock. Once the cold cover door is open, in various embodiments, the hot cover 10114 may only be removed by first undoing another mechanism that attached the hot cover 10114 to the divider 10118. In some embodiments, the hot cover 10114 is attached to the divider 10118 using screws. However, in various other embodiments, any attachment mechanism may be used. Thus, in various embodiments, cold cover 10116 must be unlocked before the hot cover 10114 may be opened. This is beneficial for many reasons, including, but not limited to, preventing access to the hot area, which may be dangerous, to anyone except someone with the tools to open the cold cover 10116 and open the hot cover 10114, which may be, e.g., a service technician.

Referring also to FIG. 104, in various embodiments, the case/shell 10100 may include one or more hand holds. In some embodiments, there may be two hand holds located each in the front 10126, 10128 and back 10130, 10132 of the case/shell 10100.

Referring now also to FIG. 105, a first drain port 10134 and a second drain port 10136 may be, in some embodiments, located in the front of the case/shell 10100 within a hand hold 10128. The first drain port 10134 may be for draining the sump and the second drain port 10136 may be for draining blowdown water. The first drain port 10134 and the second drain port 10136 may include drain valves, which, in various embodiments, may be as shown in as 10138. In various embodiments, the drain valve 10138 may be a manual ball valve. In various embodiments, the drain ports 10134, 10136 may be located in the front of the case/shell, and therefore accessible through opening the cold cover 10116. This may be beneficial/desirable for many reasons, including, but not limited to, accessing the drain ports without having to access the hot components of the water vapor distillation apparatus.

Referring now also to FIG. 106, in various embodiments, mechanisms for securing the system during shipments, for example, and or for securing the system to lifting straps for transporting the system may be located on the chassis 10144. In some embodiments, the mechanisms may be "D-rings 10140, 10142, and in various embodiments, one or more D-rings may be located on each side of the chassis 10144. In various embodiments, other mechanisms may be used and /or the mechanisms may be located in various locations and in various quantities on the chassis 10144 or elsewhere on the case/shell 10100. In various embodiments, the D-rings 10140, 10142, or other mechanisms, may be attached to the molded chassis 10144 at manufacture.

In various embodiments, the case/shell 10100 may include one or more drain ports on the bottom of the chassis 10144. In various embodiments, there may be a drain port for draining the cold side and the hot side. In some embodiments, there may be more than one drain port on the hot side and/or on the cold side. In some embodiments, the various drain ports may include a screen or other feature to allow moisture/fluid to drain out of the system but to protect the inside of the system from any foreign matter access, for example, prevention of insects and other foreign matter from entering the system.

In various embodiments, the case/shell 10100 may include at least one user interface feature 10146 which in some embodiments may include, but is not limited to, one or more of the following: one or more LEDs, one or more buttons, one or more screens, including, but not limited to, a touch screen which may include, but is not limited to, a 3D, or 3-dimmensional, touch screen. In some embodiments, the user interface 10146 may also include an overlay or other to protect the one or more features of the user interface. In some embodiments, the overlay or other may provide protection from water and/or temperatures, e.g., hot or cold. The user interface in this embodiment may have one or more of the

characteristics and/or features described herein with respect to the user interface. In various embodiments, the user interface may include one or more LEDs (light-emitting diodes) and a 7-segment display. In various embodiments, the LEDs may indicate one or more of the following: power is connected to the system; error; apparatus in start-up state; apparatus in production state; and/or wireless cell connectivity and connection.

In some embodiments, the LEDs may be solid. In some embodiments, one or more LEDs may flash. For example, in some embodiments, the wireless connectivity and connection LED may remain solid to indicate that the apparatus is connected and flash to indicate that the apparatus is receiving and sending data.

In various embodiments, the at least one seven-segment displays may display error codes, system status and/or service status. The at least one seven-segment display displays text. In some embodiments, the system may include at least one button which, in some embodiments, may be a run/ idle button to allow the user/service technician to clear errors and toggle the apparatus in and out of the run state. In some embodiments, the system may include a maintenance button that may allow a user/service technician to select safety override, descale, and disinfect.

Referring now also to FIG. 107, an embodiment of a fluid diagram is shown.

In various embodiments, the cold side includes an electronics control module 10146. In various embodiments, the electronics control module 10146 is cooled by source water. Therefore, raw source water coming into the water vapor distillation apparatus is flushed passed the electronics control module 10146 to keep the electronics control module 10146 cooled. In various embodiments, the electronics control module 10146 may be configured to receive 85 – 265 volts of AC power.

In various embodiments, the system may receive source water from anything, including, but not limited to, a municipal water supply, which is pressurized, or a non-municipal water supply, which is non-pressurized. Therefore, in some embodiments, the system includes a regulator 10150 and a source pump 10152. The regulator 10150 is used when the system is connected to a municipal water supply and the source pump 10152 is used when the system is not. In various embodiments, a level switch may be used (not shown) in the non-municipal source water supply. In various embodiments, when the level switch is plugged into the system, the system recognizes this and therefore recognizes that the source pump 10152 will be used. In some embodiments, when the source pump 10152 is plugged in, the system looks for the level switch to be plugged in as well. In various embodiments, if the regulator is plugged in, then the system does not look for a level switch

to be plugged into the system. In various embodiments, the level switch may be a 5 volt level switch.

Referring now also to FIG. 108, in various embodiments, a valve manifold 10154 is included in the water vapor distillation apparatus. In various embodiments, the valve manifold 10154 includes a steam/water mixing chamber 10156 (which may also be referred to as a mixing can), which is permanently mounted onto the base and chassis of the case/shell, a manifold interconnect cold side 10158 and a manifold interconnect hot side 10160. The manifold interconnect cold side 10158 and a manifold interconnect hot side 10160 are welded together, in some embodiments, using vibration welding, and then connected to the steam/water mixing chamber 10156. In some embodiments, the manifold interconnect cold side 10158 may be molded onto the steam/water mixing chamber 10156, and then the manifold interconnect hot side 10160 is welded to the manifold interconnect cold side 10158, which, in this embodiment, is actually part of the steam/water mixing chamber 10156.

In various embodiments, the steam/water mixing chamber 10156 includes a cover 10162 that attached to the steam/water mixing chamber 10156 to seal the chamber. In various embodiments, the valve manifold 10154 includes valves 10164 controlling the source water, blowdown in and steam vent fluid paths. In various embodiments, the valve manifold may control more or less fluid lines and in some embodiments, may control one or more of the above-mentioned, but may control others as well or instead place of the fluid lines.

A clip 10168 attaches over the valves 10164. The valves 10164 are each a separate unit and are together clamped onto the steam/water mixing chamber 10156 using a lock clamp 10166. The lock clamp 10166, in some embodiments, is rotatable mounted to the steam/water mixing chamber 10156 and rotation in a first direction allows the valves 10164 to be unlocked and removed, and rotation in a second direction allows the valves 10164 to be locked onto the steam/water mixing chamber 10156. This configuration may be beneficial/desirable for many reasons, including, but not limited to, the ability to remove individual valves from the valve manifold 10154 and replace individual valves when desired. Thus, each valve is individually serviceable.

In various embodiments, the manifold interconnect cold side 10158 and the manifold interconnect hot side 10160 may be plastic, welded pieces, and in some embodiments, may be vibration welded together. The manifold interconnect cold side 10158 and the manifold interconnect hot side 10160 includes molded fluid paths 10170 that accommodate fluid from the hot side, which are connected via hot side fluid inlets 10172, such that fluid from the hot side may flow through the hot side fluid inlets 10172 and then into the fluid lines formed by

the manifold interconnect cold side 10158 and the manifold interconnect hot side 10160. This configuration may be beneficial for many reasons, including, but not limited to, not having tubing connecting from the hot side to the cold side, which may reduce the incidence of occlusions and or steam egress. Rather, the tubing connects directly to the hot side fluid inlets 10172, which allow for the fluid to flow to the cold side.

In various embodiments, the valve manifold 10164 is made from molded plastic. However, in other embodiment, the valve manifold 10164 may be made from other materials, including, but not limited to, metal.

In some embodiments, the manifold interconnect hot side 10160 may be located such that it is partially on the hot side of the system. In some embodiments, an opening in the divider 10118 to accommodate a portion of the manifold interconnect hot side 10160. In various embodiments, the mixing can or steam/water mixing chamber 10156 may include a copper tube for steam to flow through. This may be beneficial/desirable for many reasons, including, but not limited to, that the system is quieter with the use of the copper tube for the steam.

In various embodiments, the valve manifold10154 may also include at least one check valve 10172. In various embodiments, the check valve 10172 acts as a vacuum relief valve. In various embodiments, to overcome a vacuum that may be formed due to cooling within the system, e.g., cooling forming pressure excess of 0.5 PSI, the check valve 10172 allows that vacuum to be equalized.

Referring now also to FIG. 109, in various embodiments, a conductivity manifold 10174 may be included. The conductivity manifold 10174 is located adjacent to the valve manifold 10154, and serves as the product water manifold. In this way, the two valve manifolds 10154, 10174 are completely separate, fluidicly, therefore, the product water and source water, blowdown, etc., are not intermingled in the same manifold, maintaining the integrity of the product water. This may be beneficial for many reasons, including, but not limited to, prevention of contamination of the product water in the event of a leak. In some embodiments, the two manifolds 10154, 10174 may be made from the same parts but there may be an air gap maintained between them. In various embodiments, the two manifolds 10154, 10174 do not have shared fluid lines.

Similar to the valve manifold 10154, the conductivity manifold 10174 includes condo valves 10176 that are held onto the fluid line manifold 10178 using a mechanism, which, in the embodiment shown, is a condo clip 10180. The conductivity probes 10182, 10184 are located, in this embodiment, on opposite sides of the fluid line manifold 10178. As discussed above,

the condo valves10176 are separately removable and replaceable. By removing the condo clip 10180, the condo valves 10176 may be removed and replacement. In various embodiments, the condo clip 10180 may be replaced by another mechanism that allows for the removal and replacement of the valves. In some embodiments, the valves may not be replaceable.

Referring now also to FIGS. 110-113, another embodiment of the level sensor assembly 10186 is shown. In various embodiments of the water vapor distillation apparatus, the apparatus includes at least two level sensor assemblies, 10186, 10188, as shown in FIG. 102, one for each the blowdown water and product water.

In various embodiments, the level sensor assembly 10186 includes a top cover 10190 mated to a bottom cover 10192. In various embodiments, the top cover 10190 includes a vent 10194 which, in various embodiments, allows for air displacement by the incoming water/fluid. The level sensor 10196 is pivotably connected to a sensor stand 10198 which is located between the top cover 10190 and the bottom cover 10192. The level sensor 10196 includes at least one magnet 10200. The level sensor 10196 is molded of plastic in various embodiments, however, in other embodiments; the level sensor 10196 may be made of another material, for example, metal.

The level sensor assembly 10186 includes a printed circuit board 10202 which in some embodiments is heat staked onto the top cover 10190. Hall Sensors determine the position of the magnets 10200.

The level sensor assembly 10186 is attached to a liquid manifold, and in the embodiments shown herein, the water vapor distillation apparatus and system includes two manifolds, a product water manifold 10204 and a blowdown water manifold 10206. The liquid manifolds 10204, 10206 are mounted onto the chassis 10144. Fluid from the manifold 10204, 10206 enters the level sensor assembly 10186 through a bottom cover opening 10208. The fluid rising in the housing causes the level sensor 10196 to rise and pivot, and in doing so, the distance the level sensor 10196 moves is detected by the Hall Sensors using the magnets 10200 in the level sensor 10196. The fluid leaving through the bottom cover opening 10208 causes the level sensor 10196 to fall and pivot, and in doing so, the distance the level sensor 10196 moves is detected by the Hall Sensors using the magnets 10200 in the level sensor 10196.

In various embodiments, the magnets 10200 are K&J Magnetics part no. D44SH, made by K&J Magnetics, Inc., Plumsteadville, PA, U.S.A.

The level sensor assembly 10186 is attached to the manifolds 10204, 10206 using posts on the manifolds 10204, 10206 that connect through the post holes 10210, 10212 on the

bottom cover opening 10208 of the level sensor assembly 10186, and are spring clipped. In some embodiments, the spring clips are McMaster-Carr part no. 86795T28, made by McMaster-Carr of Robbinsville, New Jersey, U.S.A. However, in various other embodiments, different clips may be used. Thus, the level sensor assembly 10186 is easily removable and replaceable by unclipping the level sensor assembly 10186 from the respective manifold 10204, 10206.

Referring now also to FIGS. 114-115B, an embodiment of the heat exchanger 10214 is shown. The heat exchanger 10214 may include many of the features described above with respect to the various embodiments of the heat exchanger. In the embodiment shown, the heat exchanger 10214 includes another embodiment of the terminations. The terminations include a source water termination 10218 and a tube termination 10216. The source water termination 20218 seals the source water from the ends of the tubes within the heat exchanger 10214. The tube termination 10216 slides over the tubes in the heat exchanger 10214 and seals each tube from each other. One exit includes the two tubes carrying clean water, the other exit includes the two tubes carrying dirty water. In various embodiments, the source water termination 10218 and the tube termination 10216 are made from overmolded EPTM RYTON®.

The tube termination 10216 attaches to the source water termination 10218 and is held together by a wire bale 10220. In various embodiments, the wire bale 10220 is made from steel wire and is in tension to hold. In various embodiments, the wire bale 10220 may be made from other materials, including, but not limited to, plastic and other types of metals.

The tube termination 10216 includes barbs 10222, 10224 which attach to silicone hoses in the water vapor distillation apparatus.

Referring now also to FIGS. 116-121, another embodiment of the regenerative blower/ compressor 10300. In this embodiment, the shaft 10302 includes a cavity 10304 that allows the water to flow to lubricate the bearings 10306, 10308. The water flows through the cavity 10304 and then enters the space where the bearings 10306, 10308 are located through a bearing feed opening 10310. Thus, the bearings 10306, 10308 are hydrodynamic bearings. In various embodiments, the bearings 10306, 10308 may be graphite bearings. In various embodiments, the shaft 10302 includes ceramic sleeves 10312, 10314, which are ceramic coated metal. The ceramic sleeves 10312, 10314 contact the bearings 10306, 10308.

The compressor 10300 includes a top compressor housing 13316 and a bottom compressor housing 10318. The top compressor housing 10316 and the bottom compressor housing 10318 are, in various embodiments, made from RYTON® plastic, however, in various other embodiments, may be made from any type of metal or plastic or a hybrid of metal and

plastic. The impeller 10320 is located between the top compressor housing 10316 and the bottom compressor housing 10318. In various embodiments, the impeller 10320 is made from RYTON® plastic, however, in various other embodiments, may be made from any type of metal or plastic or a hybrid of metal and plastic. The bearing feed water provides the lubrication for the bearings 10306, 10308 which provides a liquid disc for the impeller 10320 to rotate upon.

The compressor 10300 includes a can motor including a stator assembly 10328 and a magnet rotor 10324. The magnet rotor 10324 is integrated into the shaft of the impeller 10320. The compressor 10300 includes an impeller magnet seal assembly 10326 that encapsulates the magnet rotor 10324. Thus, the stator assembly 10328 drives the magnetic shaft or magnetic rotor 10324 of the impeller 10320. In various embodiments, the bearing water may cool the stator assembly 10328.

In various embodiments, at least one Hall Effect Sensor is used as an encoder to determine the speed of the can motor based on the variability of the magnetic field. In some embodiments, there are three Hall Effect Sensors used. In various other embodiments, one or more Hall Effect Sensors may be used. Still also referring to FIG. 121, the stator assembly 10328 is shown with two Hall Effect Sensors 10330, 10332 which are located on stator printed circuit board assemblies 10334, 10336. The stator assembly 10328 also includes a stator pack 10338 which terminates with three wires 10340, a positive, a negative and a ground. The three wires 10324 are connected to the electronics control module 10148. In some embodiments, the connection to the electronics control module 10148 may be via an IP54 rated connector.

Referring now also to FIGS. 122-127B, an embodiment of the evaporator/condenser assembly 10350 is shown. The evaporator/condenser assembly 10350 includes a sump assembly 10352. The sump assembly 10352 includes a sump nozzle 10358. This sump nozzle 10358 connects to the valve for the sump first drain port 10134. This configuration allows for a user/technician to drain the sediment and other buildup out of the sump assembly 10352. The sump assembly 10352, in some embodiments, includes press concealed heat studs 10360 to hold a thermal switch and thermistor (not shown) to the sump. The thermistor may be used to determine the temperature within the sump 10352 and the thermal switch may turn the heating element 10356 off if the temperature within the sump assembly 10352 exceeds a pre-determined threshold. In some embodiments, the heating element 10356 may be a 1200 Watt heating elements. In some embodiments, the thermistor may be an OMEGA IN 04004, made by OMEGA Engineering, Inc., of Stamford, Connecticut, U.S.A. In some embodiments, the sump housing 10352 is made from 316 Stainless Steel, which may be beneficial/desirable for

many reasons, including, but not limited to, its resistance to corrosion from in the source water. However, in various embodiments, the sump housing 10354 may be made from other metals and/or from plastic.

The sump assembly 10352 is connected to the bottom tubesheet assembly 10362. In various embodiments, the bottom tubesheet assembly 10362 includes a lower over molded sealing element 10364 which in some embodiments, is over molded with EPDM rubber. The over molded sealing element 10364 provides individual sealing for each of the tube assemblies. Thus, the tube assemblies 10366 fit individually through the openings 10368 in the over molded plastic sealing element 10364. The bottom tubesheet assembly housing 10370, which in various embodiments is made from plastic, includes, in some embodiments, mounting feet 10372, 10374, 10376, for mounting the evaporator/condenser assembly 10350 onto the chassis 10144 using, in some embodiments, wire bales (not shown). The wire bales fit over receiver channels 10378, 10380, 10382 on the upper portion of the mounting feet 10372, 10374, 10376.

In various embodiments, the bottom tubesheet assembly 10362 includes a pin locating feature (not shown) that accommodates pins that are located on the chassis 10144. Once one of the pins is located, then the evaporator/condenser assembly 10350 is in the correct location and may be clamped to the chassis 10144. In various embodiments, marman clamps may be used to secure the evaporator/condenser assembly 10350 onto the chassis 10144 and within the water vapor distillation apparatus.

In various embodiments, a top tubesheet assembly 10384 includes a housing 10386, which, in various embodiments, may be made from plastic or any other material. The top tubesheet assembly 10384 may include an upper over molded sealing element 10388 which in some embodiments, is over molded with EPDM rubber. The upper over molded sealing element 10388 provides individual sealing for each of the tube assemblies. Thus, the tube assemblies 10366 fit individually through the openings 10390 in the upper over molded plastic sealing element 10388. In various embodiments, the wall height of the housing 10386 of the top tubesheet assembly 10384 is higher than that of the bottom tubesheet assembly 10362. This may be beneficial for many reasons, including, but not limited to, prevention/reduction of water carryover and therefore, water contamination.

In various embodiments, the top tubesheet assembly 10384 may include a weir 10392 which, in various embodiments, is angled such that the weir 10392 assists the water in going down the weir port 10394. The weir 10392 is configured to allow for sufficiently fast draining of water at boiling temperature. The weir 10392, in various embodiments, includes a weir cap

10396, which, in various embodiments, may include rib features or other features to increase the strength of the weir cap 10396. The weir port 10394 is connected to the blowdown water fluid path.

In various embodiments, the upper tubesheet assembly 10384 includes a condenser vent port 10398 that is connected to the condenser space of the evaporator/condenser assembly 10350, and a tube connecting to the condenser vent port 10398 connects also to the product water manifold 10204. In various embodiments, the upper tubesheet assembly 10384 includes a condenser vent port 10400 that is connected to the condenser space of the evaporator/condenser assembly 10350, and a tube connecting to the condenser vent port 10398 connects also to the steam vent that goes to the steam valve.

In various embodiments, the evaporator/condenser assembly 10350 may include an evaporator/condenser 10402 which, in various embodiments, may contain one or more of the elements and/or characteristics as described above with respect to various embodiments of the evaporator/condenser. However, in the embodiments shown, the evaporator/condenser 10402 includes a tube retainer 10404 which, in various embodiments, may be made of RYTON, however, in various embodiments, may be made of metal, which may include, but is not limited to, Stainless Steel. However, in various embodiments, the tube retainer 10404 holds the tubes 10366, which in various embodiments may be made from metal or plastic, but in some embodiments, may be made from copper or stainless steel, or any other material, including any metal or plastic. In various embodiments, the tube retainer 10404 retains the tubes in the evaporator/condenser 10402 when servicing the filler rods 10406, e.g., when removing the filler rods 10406.

In various embodiments, the evaporator side of the evaporator/condenser 10402 includes a temperature sensor.

Some embodiments of the filler rods 10406, which may also be called packing rods, may include nubs 10408 distributed about the outer surface of the filler rod 10406. In various embodiments, the nubs 10408 near the top of the filler rods 10406 may be larger than those at the bottom. In various embodiments, the nubs 10408 near the ends of the filler rods 10406 may be larger than those in the middle. In various embodiments, the filler rods 10406 may be made from RYTON®, but in other embodiments, may be made from any material, including, but not limited to, metal or plastic. In various embodiments, the filler rods 10406 may be sized such that they have a diameter that is about 0.25 inches smaller than the tubes 10366. In some embodiments, the ends of the filler rods 10406 may include a hollowed out portion 10410. This may be desirable/beneficial for many reasons, including, but not limited to, the filler rods

10406 require less plastic to manufacture, therefore may be less expensive, and/or the filler rods 10406 may weigh less.

In various embodiments, the steam chest 10412 may be clamped onto the evaporator/condenser assembly 10350 using marman clamps. However, in various embodiments, the steam chest 10412 may be attached using bolts or other mechanisms of attachment.

In various embodiments, the shell of the evaporator/condenser 10402 is made from RYTON® or another plastic, however, in various embodiments, the evaporator/condenser 10402 shell may be made from Stainless Steel or another metal, or may be made from a different plastic. In various embodiments, the evaporator/condenser 10402 may include one or more wings 10414 for attaching the evaporator/condenser assembly 10350 to the chassis 10144. In some embodiments, the wings 10414 attach to struts in the chassis 10144 for stability.

Referring now also to FIGS. 129-133, in various embodiments, a first conductivity sensor 10500 may be used to determine quantify the quality of the product water before the product water leaves the system. In various embodiments, the product water enters the conductivity cell, where the conductivity probe or sensor is housed, various embodiments of which have been described herein, and if the first conductivity sensor 10500 returns a value to the controller that is outside a pre-determined threshold value or a range of value, then a divert valve 10504 is opened and the product water is disposed of and not released through the product water path, rather, the water flows to the divert output 10512. However, if the first conductivity sensor 10500 returns a value to the controller that is within a pre-determined threshold value or a range of value, then a first product valve 10502 is opened and the product water is released from the system through the product water output port 10510.

In some embodiments, a second conductivity sensor 10506 and a second conductivity cell may be included in the system. In these embodiments, once the first product valve 10502 is opened, the product water flows through a second product valve 10508 and then into the second conductivity sensor 10506. If the second conductivity sensor 10506 returns a value to the controller that is outside a pre-determined threshold value or a range of value, then the second product valve 10508 is closed and the system is placed into a fault condition. However, if the second conductivity sensor 10506 returns a value to the controller that is within a pre-determined threshold value or a range of value, then the system may continue to product water.

In some embodiments, the second conductivity sensor 10506 and second product valve 10508 may be located within the water vapor distillation apparatus, as shown in FIGS. 107 and 131, for example. However, in some embodiments, the second conductivity sensor 10506 and second product valve 10508 may be located outside the water vapor distillation apparatus as a modular system that may be connected to the product output, for example, as shown in FIG. 130.

In various embodiments, the first conductivity sensor 10500 and the second conductivity sensor 10506 may be any conductivity sensor, which may include one from made by OMEGA Engineering, Inc., of Stamford, Connecticut, U.S.A. However, in various embodiments, the first conductivity sensor 10500 and the second conductivity sensor 10506 may be one as shown in FIG. 132. Referring now also to FIG. 132, in some embodiments, another embodiment of a conductivity sensor 10514 may be used. In this embodiment, the conductivity sensor 10514 includes three probes 10516, 10518, 10520 that are connected by cable. The impedance between the three probes 10516, 10518, 10520 is measured. If any one of the resistances is below a threshold, this indicates that the conductivity is too high and registers a fault condition. As described above, in various embodiments, the fault condition in the first conductivity sensor 10500 would open the divert valve 10504. The fault condition in the second conductivity sensor 10506 would register as a system fault condition, in some embodiments, and shut-down the production of product water in the system.

In various embodiments of this embodiment of the conductivity sensor 10514, the resistance between the probes 10516, 10518, 10520 is fixed at 500 k Ohms. Thus, in various embodiments, the conductivity sensor 10514 includes three Stainless Steel conductivity probes 10516, 10518, 10520 (which, in various other embodiments, may be made from another material), at least one probe thermistor, and in some embodiments, a probe thermistor for each probe 10516, 10518, 10520, and 500 k Ohm resistors between each probe 10516, 10518, 10520 (external to the water). The resistance between the probes 10516, 10518, 10520 is measured by an impedance measurement circuit, which, in some embodiments, may be an Analog Devices AD5934, however in other embodiments; another impedance measurement circuit may be used. Analog switches are used to multiplex between pairs of probes 10516, 10518, 10520. The at least one thermistor is embedded in at least one probe to measure the temperature of the water. In some embodiments, each probe 10516, 10518, 10520 includes an embedded thermistor.

Conductivity (in uS/cm normalized to 25 deg Celsius temperature) = cell calibration constant (eg 400000 uS/cm per Ohm) / resistance (in Ohms) / (1+0.02*(temperature (in deg C)

– 25)), where "temperature" is measured by the at least one thermistor, the cell calibration constant is related to the probe 10516, 10518, 10520 geometry and spacing and "0.02" is the percent change (i.e., 2%) per degree Celsius in conductivity, where 2% per degree Celsius is an approximation that varies depending on the specific dissolved solids within the water.

Thus, in various embodiments, under regular operations of the system, if the product water is acceptable, or if there's air in the product line, 500 k Ohms resistance will be measured between the probes 10516, 10518, 10520. However, if a cable/lead brakes or fails, the measured impendance jumps drastically to a mega impedance and the cable failure will be detected by the system immediately. Thus, there is a clear and certain delineation between a broken probe and any other condition. If the conductivity sensor 10514 encounters air, the impedance is infinite between the probes 10516, 10518, 10520. With the 500 k Ohms resistance between the probes 10516, 10518, 10520, the conductivity sensor 10514 distinguishes between air and a broken probe.

The 500 k Ohm resistors, in various embodiments, are used to provide an upper bound on the observed resistance. Without these resistors, the measured resistance may be >> 1MegaOhm when ultrapure water with conductivity << 1uS/cm is present. With high resistances, it may be difficult to accurately measure resistances over many orders of magnitude and such high resistances would be indistinguishable from open-circuit cables. In the system, cable / lead faults are easily detected.

In various embodiments of this embodiments of the conductivity sensor 10514, the probes 10516, 10518, 10520 may include temperature sensors / thermistors. In various embodiments, during disinfection using steam (discussed below), the temperature sensors may feed temperature information to the controller to confirm that the temperature in the product output fluid lines reached the appropriate temperature to successfully disinfect. In various embodiments, because these are redundant temperature sensors in each of the probes 10516, 10518, 10520, if one fails for any reasons, it is likely one of the other two will provide temperature readings. Additionally, using these redundant temperature sensors, in various embodiments, the controls may perform an integrity check on the temperature sensors by comparing the readings and determining if any one appears to be outside a threshold range from the other temperature sensor's readings.

In some embodiments, a dedicated processor may be included in the system that communicates with both conductivity sensors 10500, 10506. In some embodiments, the various valves may be configured to fail safe, e.g., if the valve brakes or malfunctions, the

valve closes. In various embodiments, when the system registers a fault condition, the system shuts down.

The conductivity control system described herein may be used to detect various conditions of the system and also serves to be a redundant system. Therefore, if a valve malfunctions, for example, if the first product water valve 10502 malfunctions and is left open, then the second product valve 10508 serves to maintain the product water in the system.

In various embodiments of the system, a flow meter may be installed in the product water line between the first product valve 10502 and the second product valve 10508. The flow meter would communicate with the controller and indicate whether there is flow between the two valves 10502, 10508. If there is flow and the control system indicates that both the valves 10502, 10508 are closed, this would indicate a fault condition of one or both of the valves.

In some embodiments, the control system may run periodic tests at pre-programmed times or at regular intervals or on demand that compares the readings of the first conductivity sensor 10500 with the second conductivity sensor 10506. In some embodiments, if the readings differ greater than a pre-determined threshold amount, then the system indicates a fault condition.

In some embodiments, during the course of the system running and producing product water, when the conductivity determined by the first the first conductivity sensor 10500 and the second conductivity sensor 10506 differ greater than a pre-determined threshold amount, then the system indicates a fault condition.

Referring now also to FIG. 133, in various embodiments, a method and system for determining conductivity of water includes using a first conductivity sensor and the system receiving a first conductivity sensor reading 10524. Next, the system determines whether the reading from the first conductivity sensor is within an acceptable range 10526. If it is, then the first product valve is opened 10530 and the second product valve is opened 10532 and then, using a second conductivity sensor, the system receives a second conductivity sensor reading 10534. Next, the system determines whether the reading from the second conductivity sensor is within an acceptable range 10526. If it is, then the system may, in some embodiments, determine whether the first conductivity sensor reading differs more than a threshold amount from the second conductivity reading 10538. However, in some embodiments, step 10538 may not be included each time the method is used, but in some embodiments, may be included every other time, and/or at an interval, and /or on demand, and/or at pre-determined and/or pre-programmed times. If the system determines that the first conductivity sensor reading differs

more than a threshold amount from the second conductivity reading 10538, then a fault condition is indicated 10528. If not, then the product water goes to the output and no fault is indicated.

If it is determined that either the first conductivity sensor reading 10526 or the second conductivity sensor reading 10536 is not within the acceptable range, or threshold range for acceptability, then a fault condition is indicated 10528.

In various embodiments, when the divert valve 10504 is open, the second conductivity sensor 10506 may be shut down or the control system does not expect to receive a reading. Thus, if the control system receives a reading from the second conductivity sensor 10506, then the system indicates a fault condition as this indicates a leak or a valve malfunction.

In various embodiments, the system may include an override button 10522. This override button may be used by a user/technician to clear a fault condition. In various embodiments, the override button may be behind a mechanical guard or within a locked area or door and therefore, the system may only be overridden by a user/technician with a key. In various embodiments, to override a fault condition, the system may require the button be held down for a pre-determined time. In some embodiments, overriding includes the system /water vapor distillation apparatus purges product water from the system.

In some embodiments, if the conductivity readings for either the first conductivity sensor 10500 or the second conductivity sensor 10506, or both, are not within a pre-determined/pre-programmed acceptable range, then, in some embodiments, the system may continue running and making product water, but the second product valve 10508 and/or the first product valve 10502 are closed. The system may then determine an occlusion condition and then the system will automatically go to a fault condition.

In some embodiments, the threshold amount may be different for the first conductivity sensor 10500 and the second conductivity sensor 10506. In some embodiments, for example, the threshold for the first conductivity sensor 10500 may be about 10 microsiemens per centimeter at 25 degrees Celsius. In some embodiments, for example, the threshold for the second conductivity sensor 10506 may be about 40 microsiemens per centimeter at 25 degrees Celsius. Thus, in some embodiments, the first conductivity sensor 10500 may be more robust and divert product water that may have met the threshold of the second conductivity sensor 10506. This configuration may be beneficial for many reasons, including, but not limited to, ensuring that the criteria for allowing product water to proceed to the output is more robust where diverting the product water is still an option. Once the product water passes the first product valve 10502, divert is not available.

In various embodiments, the user interface LEDs may indicate different colors and/or flashing or steady, depending on the state the system / water vapor distillation apparatus is in. In some embodiments, the LEDs may indicate, using color, or lighting one or another LED, whether the product water is being run (which may mean dispensed or past the first product valve 10502) or diverted. In some embodiments, the 7-segment display may indicate the state. IN some embodiments, either the LEDs or the 7-segment display, or both, may indicate the state, including, but not limited to, if the system is in a fault condition.

In some embodiments, the system may use the following method to determine whether the system/water vapor distillation apparatus has water flowing through using the product Level Sensor Assembly (as described above), the first product valve 10502 and the second product valve 10508. The system closes both the first product valve 10502 and the second product valve 10508, and then the system watches the readings from the product Level Sensor Assembly. If the level in the product Level Sensor Assembly changes, then this indicates that at least one of the first product valve 10502 or the second product valve 10508 is working. This may be beneficial for many reasons, including, but not limited to, ensuring that at least one of the first product valve 10502 or the second product valve 10508 is functioning to prevent unintentional output of product water.

In some embodiments, the system includes a method for disinfection. In some embodiments, the water vapor distillation apparatus, using the evaporator/condenser assembly, introduces steam in excess of 100 degrees Celsius through the product water 10544 and divert 10542 fluid lines. In various embodiments, this method disinfects the various components and fluid lines in the system. In various embodiments, this method may begin by a user/technician connecting a particular hose to the outputs which may be diverted to a bucket of water to quench the steam. In some embodiments, the system may be placed into the disinfect state by toggling using either the button 10522 and or using another component of the user interface, and/or being connected to a computer and the computer instructing the system to enter into the disinfect state. Once in the disinfect state, in various embodiments, the sump heater 10356 is turned on and the system runs to bring the water to a higher temperature than during regular distillation for a pre-programmed or pre-determined period of time. In some embodiments, the disinfect may be a pre-set program in the system and using the user interface, the user/technician may toggle through various programs until placing the system into the disinfect state.

In various embodiments, the disinfection method may include closing the first and / or the second product valves 10502, 10508. Heat transfer may raise the temperature in the fluid

lines and valves beyond the first product valve 10502 to an appropriate temperature to successfully disinfect, without actually applying the steam to those areas. In this way, steam would be prevented from leaving the product outlet 10510 which may be beneficial for many reasons, including, but not limited to, preventing the possibility of steam emerging from the system which may be hazardous. In this embodiment, any user may run the disinfection state, rather than limiting the running of the disinfection state to a technician. This embodiment also would not require a hose be applied to the product outlet 10510 for the disinfection, or water to quench the steam.

In various embodiments, the product water fluid lines and specific components keep the product water at a higher pressure than the blowdown water/specific components for the blowdown water. In this way, blowdown water is less likely and/or unlikely to flow to and comingle with the product water.

In various embodiments, the system may include multiple printed circuit boards (PCB). In some embodiments, the system may include a first PCB, a machine control processor, which includes the controls for producing water and controlling the system for producing water, a second PCB, a host control processor, which communicates with the machine control processor, and includes the user interface controls and controls for the remote agent subsystem (described in more detail below), including the logging system, amongst other controls. A third PCB, the power PCB, may also be included which includes all of the controls for the power for the system. The power PCB also communicates with the machine control board. A forth PCB, a personal computer PCB, includes the controls for the personal computer and also communicates with the machine control board and the host control board. This electronics configuration may be beneficial/desirable for many reasons, including, but not limited to, where changes in the memory are desired because of, e.g., software for the user interface, only the host control board is affected and therefore, only one board, the host control board, need be modified and / or replaced. Additionally, this configuration creates a modularized electronics system where systems may be custom fitted to particular locations. For example, various locations may require a more robust user interface, and/or various modes of connectivity, and various locations may require a very simple user interface. For example, some locations may require Wi-Fi, while others do not. Thus, the components for Wi-Fi may be customized onto some host controls boards and not others, to lower the expense where the function is not desired. Various versions of the host control board may be used depending on the systems ultimate location and therefore, the other three PCBs would be identical and only the host control board would differ. Switching out one PCB to customize a system provides versatility

and modularity to the system. Additionally, the microprocessor on the machine control board may be smaller than the one used on the host control board. Thus, by separating the two boards, the expense for the machine control board may be less than the host control board because the machine control board may not require a large microprocessor. Additionally, all of the heat dissipating devices may be placed on the power PCB. Thus, this makes the system more efficient for managing heat in the PCBs. In some embodiments, the power PCB may be mounted to a heat sink 10546, which in some embodiments, may be an aluminum plate (or other heat dissipating metal) pressed onto the back of the electronics assembly, which, in some embodiments, together with the electronics assembly, sandwich the copper tube that feeds source water to the electronics control assembly to provide cooling to the electronics. This cooling fluid line also provides cooling to the power PCB. In some embodiments, a heat sink 10546 temperature controller may be included in the system.

In various embodiments, the system includes a heat sink valve 10548. Thus, as source water comes into the system, the source water flows by the heat sink 10546 and in some instances, when the mixing can valve 10550 is open, and the heat sink valve 10548 is closed, will flow to the mixing can 10156. This provides a cooling loop for the system even when product water is not being made (i.e., the water vapor distillation apparatus is not heating or running). However, when the water vapor distillation apparatus is heating or running, the source water comes into the system, the source water flows by the heat sink 10546 and in some instances, when the mixing can valve 10550 is closed, and the heat sink valve 10548 is open, will flow to the sump 10354. Thus, whether or not the system is in run or heat mode, the electronics control module and the heat sink 10546 will be cooled by incoming source water.

In some embodiments, the user interface may be a smart phone, for example, a QUALCOM-based phone. In some embodiments, the user interface may be a SAMSUNG Galaxy S4, however, in various embodiments; the smart phone may be any smart phone. The smart phone may be customizably programmed and attached to the system.

In various embodiments, the system may include a tilt sensor, which in some embodiments, may be a 3-axis accelerometer. In some embodiments, the tilt sensor may be positioned on the machine control processor. In some embodiments, the system controls may not allow the water vapor distillation apparatus to run if the system does not meet a threshold level, which the controls system receives from the tilt sensor.

Some embodiments of the system may include a GPS, which, in some embodiments, may be located on the host control processor. This may be desirable for many reasons, including, but not limited to, remotely tracking the location of the system and therefore, in

some embodiments, changing thresholds and other controls based on the location of the system thereby responding to potentially different needs in response to different water and/or climate conditions.

Referring now also to FIG. 134, in various embodiments, the can motor may be controlled based on the motor temperature. In various embodiments, a controller receives the motor temperature 10552 and the output is the desired motor speed 10554 and then this runs through a controller limiter/saturation max and min speed 10556, which yields the commanded motor speed 10558. This is fed into the motor controller 10560, which drives the motor 10562, and then heat comes off the motor which is plugged onto the motor temperature 10564. In various embodiments, the controller may target 160 degrees Celsius as the motor temperature.

In some embodiments, the temperature may remain constant but over time, the motor speed may decrease due to decreased efficiency which may be present from time to time due to various conditions, for example, scaling. This controls method is beneficial/desirable for many reasons, including, but not limited to, if the motor speed were constant, than the temperature would rise. This could create negative conditions for the system. Thus, by maintaining a constant temperature, the temperature does not reach a negative level but the motor speed decreases.

Referring now also to FIG. 135, in various embodiments, the system includes controls for the low pressure ("LP") water temperature, which refers to the water under low pressure, i.e., the source water, which is in the evaporator side of the evaporator/condenser 10402. The LP desired temperature 10566 is fed into the heater controller 10568. Also, an enable signal if fed into the heater controller 10568. The output of the heater controller 10568 is heater duty cycle/ heater drive signal (0 to 100) 10570 and then this is limited (heater limit 10572), which then controls the actual heater electronics 10574. The LP temperature is reduced 10576 and it this is fed into the vent controller 10578. The vent controller 10578 is enabled and a desired temperature is output as a vent valve command 10580. The command is fed to the vent electronics 10582 which is fed back to the LP temperature desired temperature 10566. The control of the heater and the vent is mutually exclusive. When the system is heating, the vent is open to control the pressure within the system.

Referring now also to FIG. 136, in various embodiments, the system includes a product controller. The desired product water level 10584 is fed into the product level controller 10586. The output is the product valve duty cycle 10588. The product valve duty cycle 10588 is then fed into the valve electronics 10590. The fluid flows to the desired level (determined using the product level sensor assembly 10592)

Referring now also to FIGS. 137 - 140 in various embodiments, the system, and in some embodiments, there may be multiple systems/devices 10594 included in a network (this disclosure is not limited to single or multiple devices, rather, this method/system/network may be used with at least one system/device), communicates 10596 by way of a cell phone network, Wi-Fi, Ethernet, Modem, 4G, Iridium Satellite Modem or other satellite model, and/or any other mechanism to connect to the internet, for example, with at least one external manager 10600 through a cloud 10598. However, in some embodiments, a single system/device 10602 may communicate 10604, for example, using a USB-based communications link/connection, with one external manager 10606. The at least one external managers 10600 may connect to the cloud 10598 using any communication mechanism, including, but not limited to, web pages, web-based API and/or SQL. In various embodiments, the at least one external manager 10600 may include server pages, analytic devices and or WaterView. In various embodiments, the cloud 10598 may include at least one database and at least one cloud server.

As the data in the system/device (whether a single system 10602 or multiple systems/devices 10594 on a network) changes, the data is written to a persistent file or log. In embodiments where the device/systems are communicating through the internet, at a pre-determined time, for example, at 11:59 p.m., or at pre-determined / pre-programmed intervals, the communications 10596 connect to the internet and the system connects to the cloud 10598. The data is uploaded/moved to the cloud. The one or more external managers 10600 may download the data to a server and/or a computer device, and the data is therefore backed up both by the cloud 10598 and the one or more external managers 10600.

Each time the data is updated, the most up-to-date data and/or state is uploaded into the live/most recent state and the old state is moved to a history. At the end of an interval, for example, 24 hours, of device/system run, the at least one external manager 10600 may review the data and determine if changes are needed, etc. In various embodiments, only changes in state/data are logged. However, in some embodiments, for sensors, valves, etc., that may be constantly changing; the system may log the data at a pre-determined/pre-programmed interval, e.g., every 5 minutes. Logging only the changes or logging data in intervals may be beneficial for many reasons, including, but not limited to, transferring and/or logging less data overall which is more efficient.

In various embodiments, the at least one external manager, either 10606 or 10600, may set the state for the systems/devices.

In various embodiments, for example, the embodiment shown in FIG. 137, the at least one systems/devices 10594 may connect/communicate 10596 with the cloud 10598 at pre-programmed intervals, e.g., every 2 hours. This is beneficial for many reasons, including, but not limited to, the systems/devices 10594 at all times which may decrease the opportunity for hacking into the systems/devices 10594, and/or compromising the systems/devices 10594. If one or more of the at least one external managers 10600 desires to connect to one or more systems/device 10594 at a given time that is outside when the at least one systems/device 10594 are connected to the cloud 10598, the at least one external manager 10600 may shoulder tap the cloud 10598 and communicate to the cloud 10598 that the at least one external manager 10600 wants to communicate with one or more systems/devices 10594. The cloud 10598 may send a text message to the at least one or more systems/device 10594 that tells the at least one or more systems/devices 10594 to connect to the cloud 10598. This configuration may be beneficial for many reasons, including, but not limited to, conserving bandwidth as the at least one external managers 10600 do not have ot stay connected to the cloud 10598 or the at least one systems/devices 10594 all the time, rather, only when it is necessary.

This network communications configuration may be used for remotely controlling and/or remotely monitoring the one or more systems/devices 10594. Additionally, This network communications configuration may be used for downloading, remotely, software updates and/or reconfiguring one or more systems/devices 10594.

While the principles of the invention have been described herein, it is to be understood by those skilled in the art that this description is made only by way of example and not as a limitation as to the scope of the invention. Other embodiments are contemplated within the scope of the present invention in addition to the exemplary embodiments shown and described herein. Modifications and substitutions by one of ordinary skill in the art are considered to be within the scope of the present invention.

# CLAIMS

What is claimed is:

1. A system for product water output comprising:

a controller;

a first conductivity sensor in communication with the controller;

a first product valve downstream from the first conductivity sensor and in communication with the controller;

a second product valve downstream from the first product valve and in communication with the controller;

a second conductivity sensor downstream from the second product valve and in communication with the controller; and

a divert valve downstream from the first conductivity sensor and upstream from the first product valve and in communication with the controller.

2. The system according to any one or more of claims 1-10, wherein the controller opens the divert valve and maintains the first product valve and second product valve in a closed position when the first conductivity sensor determines that the conductivity of product water is not within a first acceptable range.

3. The system according to any one or more of claims 1-10, wherein the controller opens the first product valve and the second product valve when the first conductivity sensor determines that the conductivity of product water is within an acceptable range.

4. The system according to any one or more of claims 1-10,wherein the second conductivity sensor determines the conductivity of the product water and the controller indicates a fault condition when the second conductivity sensor determines that the conductivity of product water is not within a second acceptable range.

5. The system according to any one or more of claims 1-10, wherein the first acceptable range is lower than the second acceptable range.

6. The system according to any one or more of claims 1-10, wherein the controller compares the conductivity from the first conductivity sensor and the second conductivity sensor and if the conductivity from the first conductivity sensor differs more than a threshold amount from the conductivity of the second conductivity sensor, a fault condition is indicated.

7. The system according to any one or more of claims 1-10, wherein if it is determined that either the first conductivity sensor reading or the second conductivity sensor reading is not within the acceptable range, or threshold range for acceptability, then a fault condition is indicated.

8. The system according to any one or more of claims 1-10,wherein the first conductivity sensor and the second conductivity sensor comprising:

three probes connected by a cable, at least one of the three probes comprising a temperature sensor and wherein the resistance between each of the three probes is 500 k Ohms.

9. The system according to any one or more of claims 1-10,wherein when the divert valve is open, if the controller receives a reading from the second conductivity sensor, a fault condition is indicated.

10. The system according to any one or more of claims 1-10, further comprising a flow meter downstream from the first product valve and upstream from the second product valve.

11. A method for determining the quality of product water output comprising:

providing a controller;

providing a first conductivity sensor in communication with the controller;

providing a first product valve downstream from the first conductivity sensor and in communication with the controller;

providing a second product valve downstream from the first product valve and in communication with the controller;

providing a second conductivity sensor downstream from the second product valve and in communication with the controller; and

providing a divert valve downstream from the first conductivity sensor and upstream from the first product valve and in communication with the controller.

12. The method according to any one or more of claims 11-20, further comprising the first conductivity sensor determining that the conductivity of product water is not within a first acceptable range and opening the divert valve and maintaining the first product valve and second product valve in a closed position.

13. The method according to any one or more of claims 11-20, further comprising the first conductivity sensor determining that the conductivity of product water is within an acceptable range and opening the first product valve and the second product valve.

14. The method according to any one or more of claims 11-20, further comprising the second conductivity sensor determining the conductivity of the product water and the controller indicating a fault condition when the second conductivity sensor determining that the conductivity of product water is not within a second acceptable range.

15. The method according to any one or more of claims 11-20, further comprising wherein the first acceptable range is lower than the second acceptable range.

16. The method according to any one or more of claims 11-20, further comprising comparing the conductivity from the first conductivity sensor and the second conductivity sensor, and if the conductivity from the first conductivity sensor differs more than a threshold amount from the conductivity of the second conductivity sensor, indicating a fault condition.

17. The method according to any one or more of claims 11-20, further comprising:

determining that either the first conductivity sensor reading or the second conductivity sensor reading is not within the acceptable range, or threshold range for acceptability; and

indicating a fault condition.

18. The method according to any one or more of claims 11-20, further comprising wherein the first conductivity sensor and the second conductivity sensor comprising:

three probes connected by a cable, at least one of the three probes comprising a temperature sensor and wherein the resistance between each of the three probes is 500 k Ohms.

19. The method according to any one or more of claims 11-20,further comprising:

opening a divert valve;

receiving a reading from the second conductivity sensor; and\

indicating a fault condition.

20. The method according to any one or more of claims 11-20, further comprising a flow meter downstream from the first product valve and upstream from the second product valve.

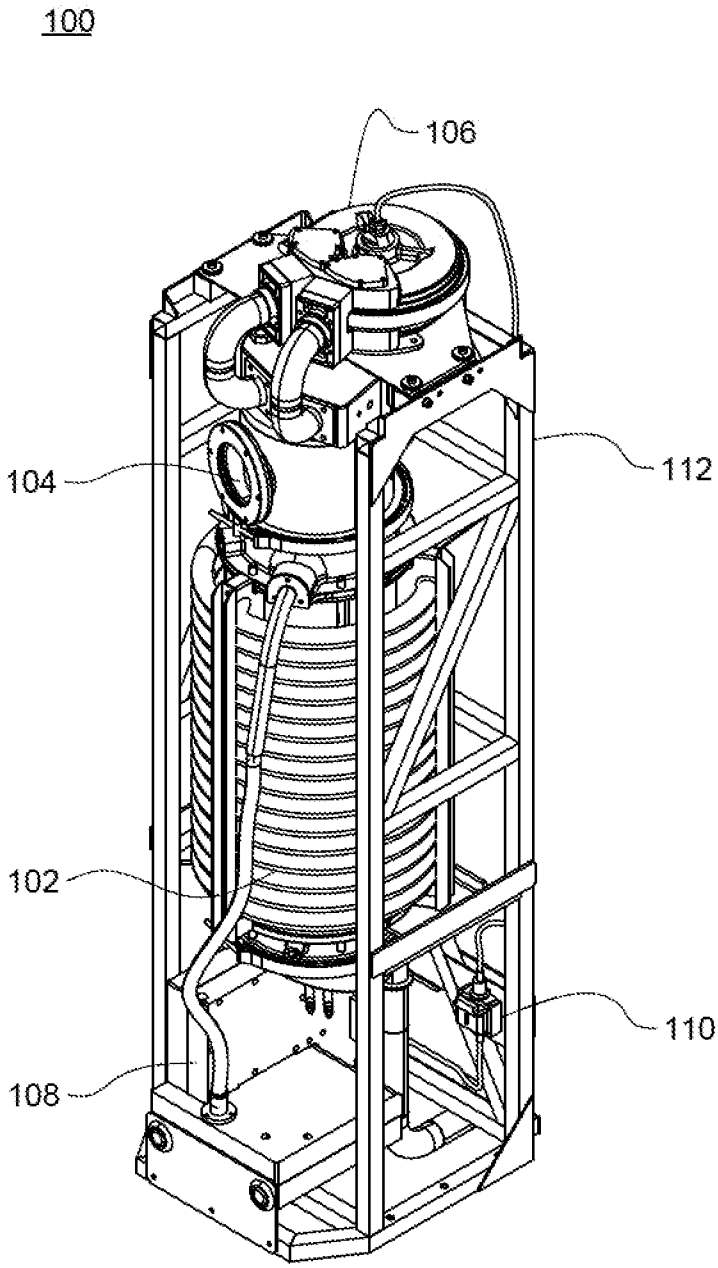



FIG.1

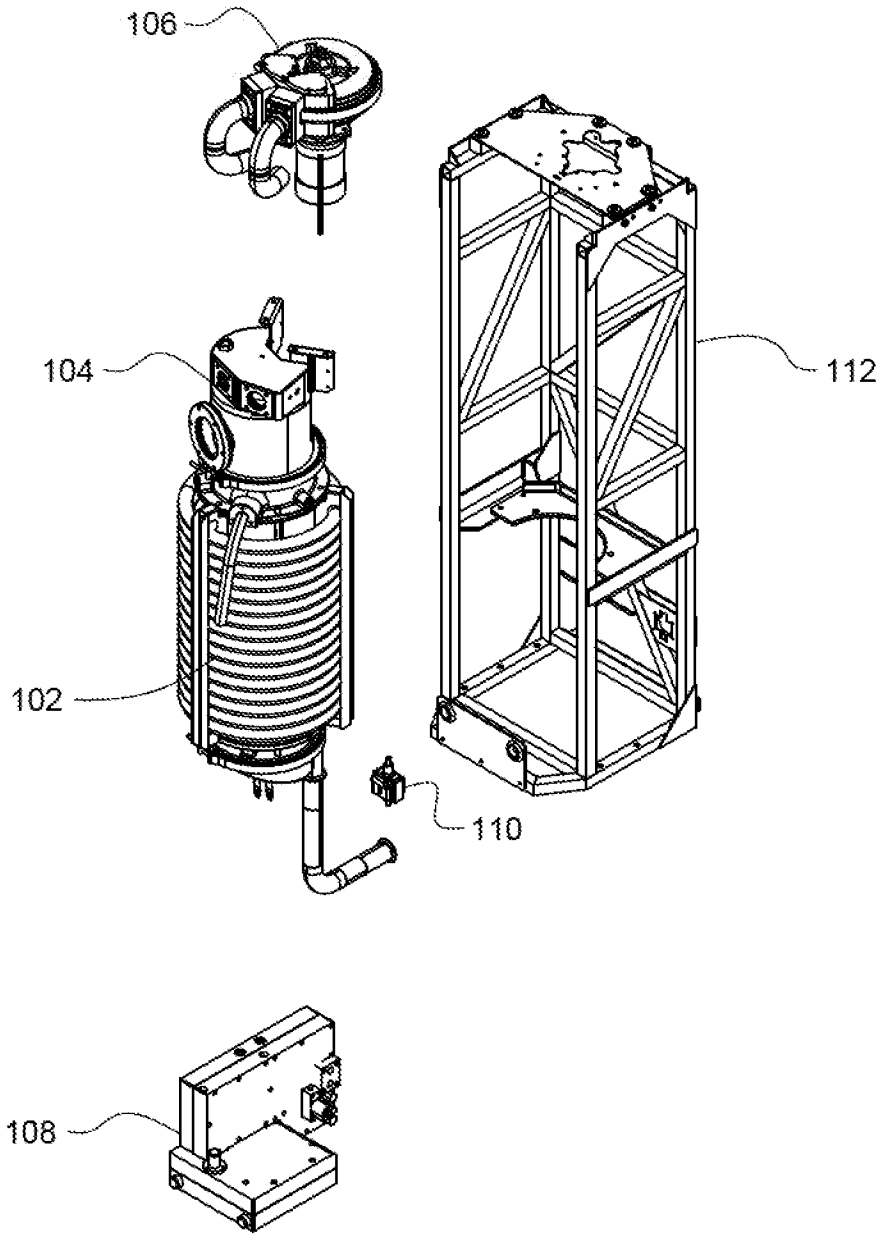



FIG.1A

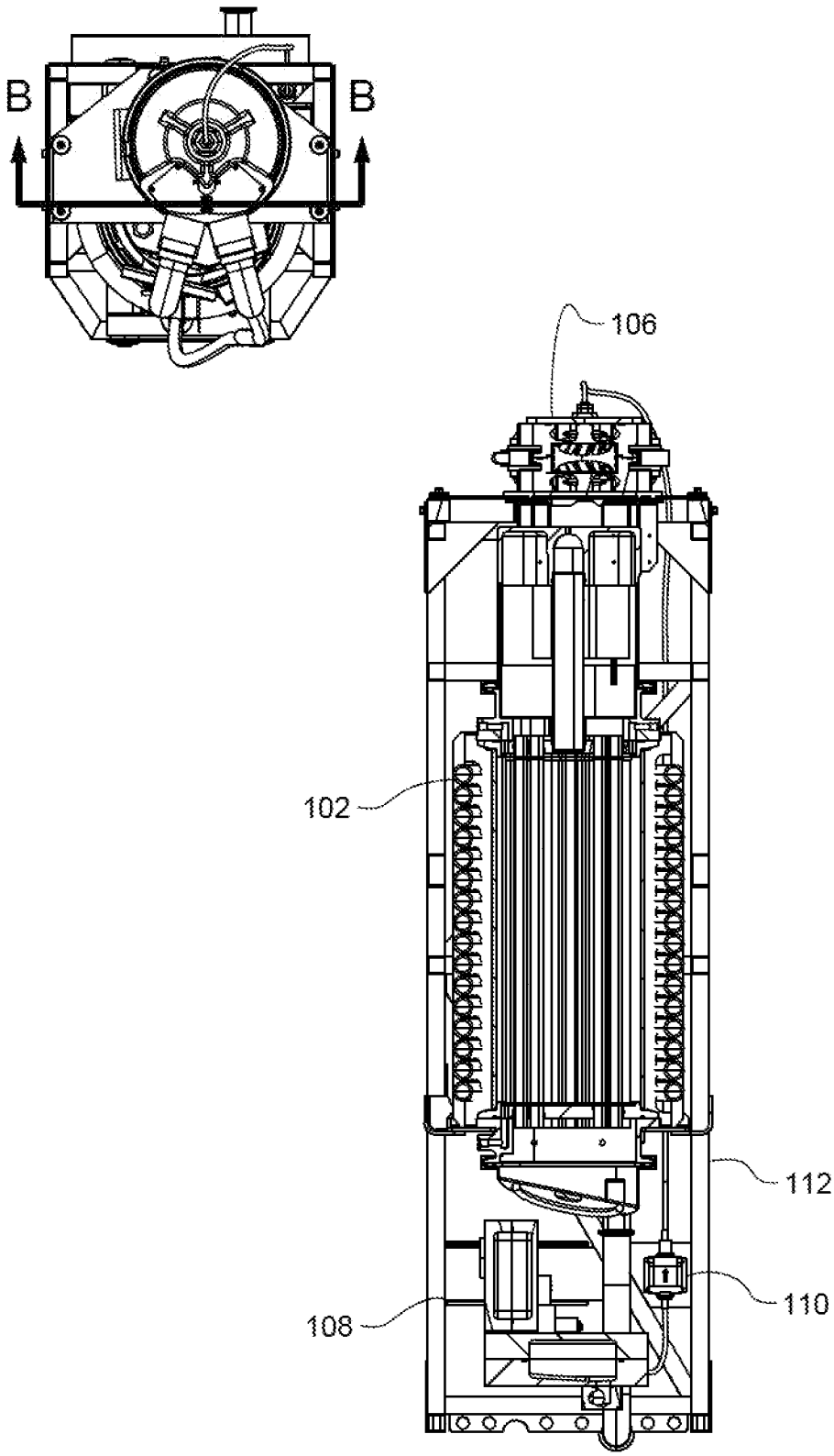



FIG.1B

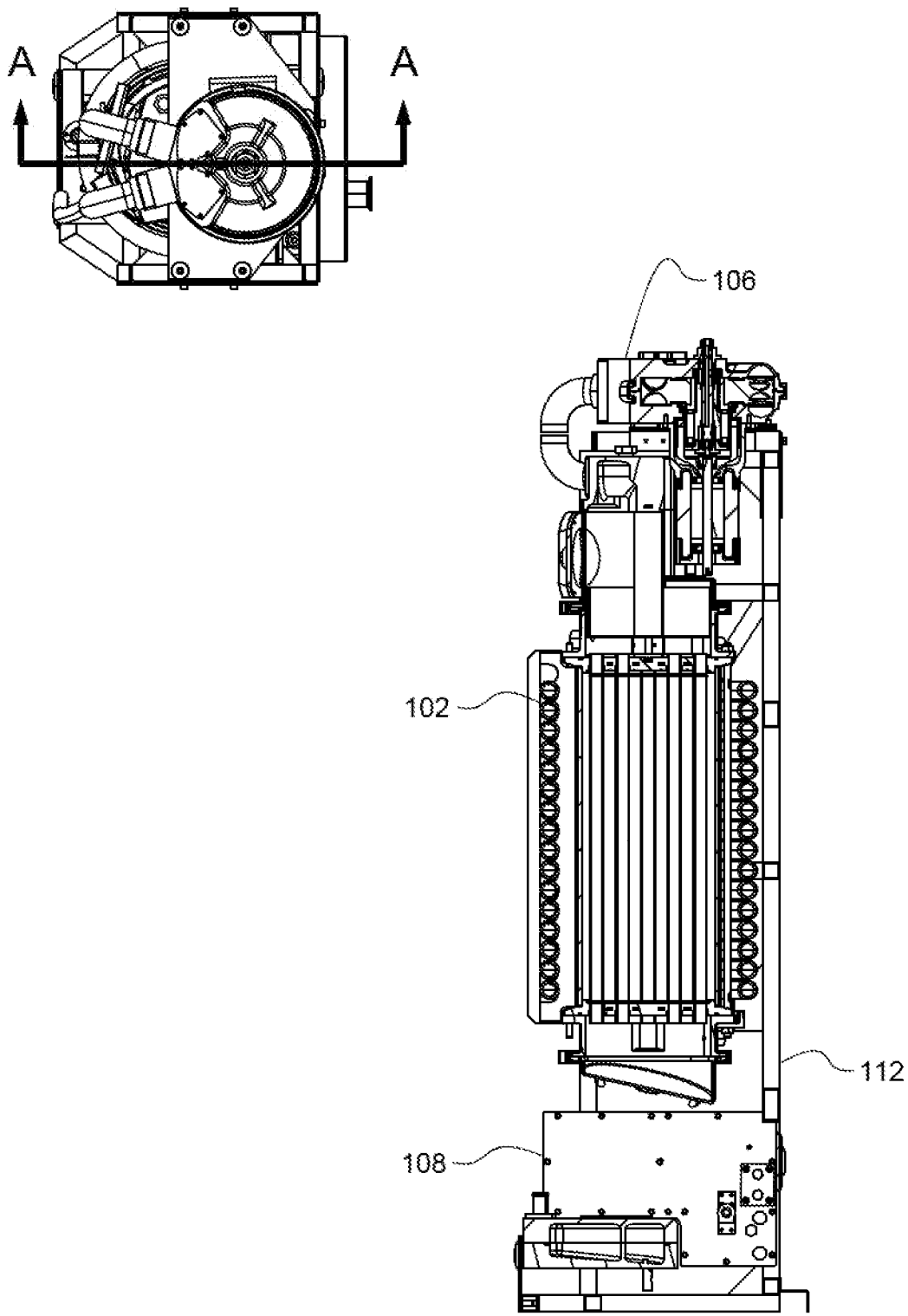



FIG.1C

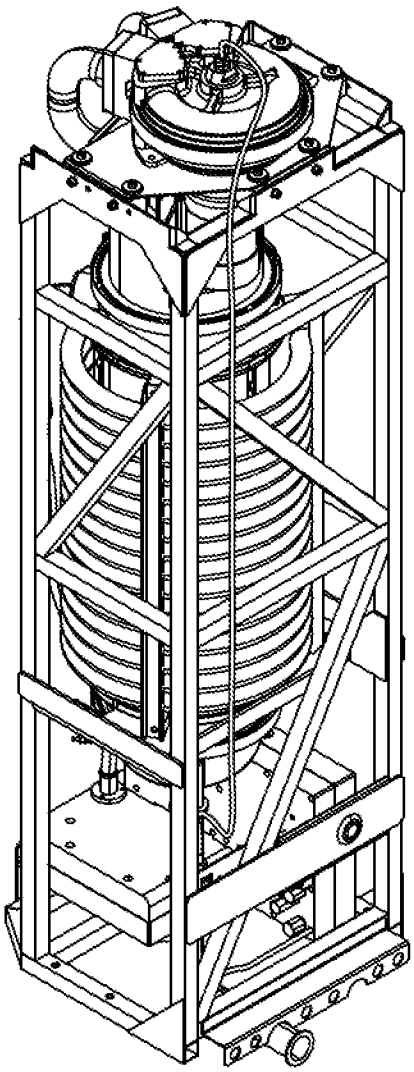


FIG.1D

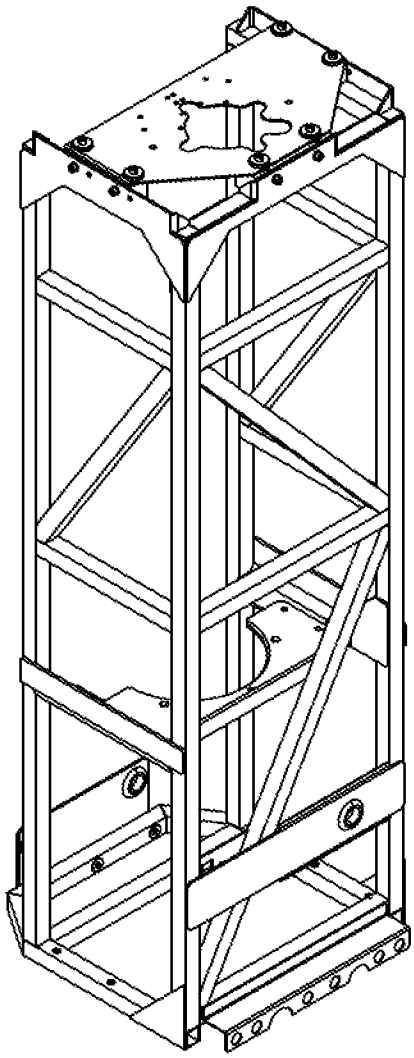


FIG.1E

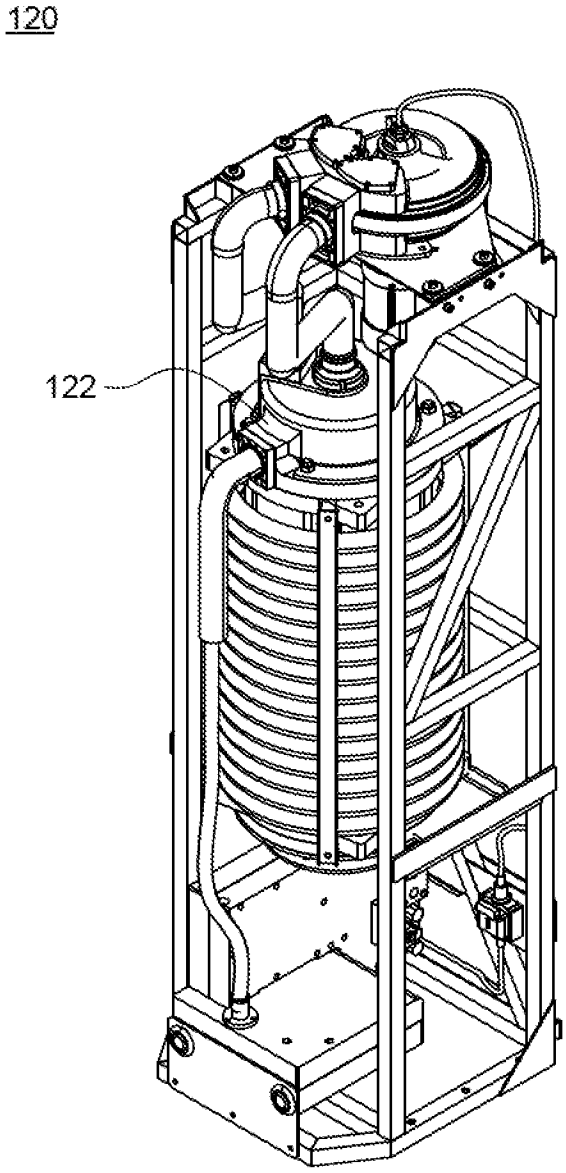



FIG.1F

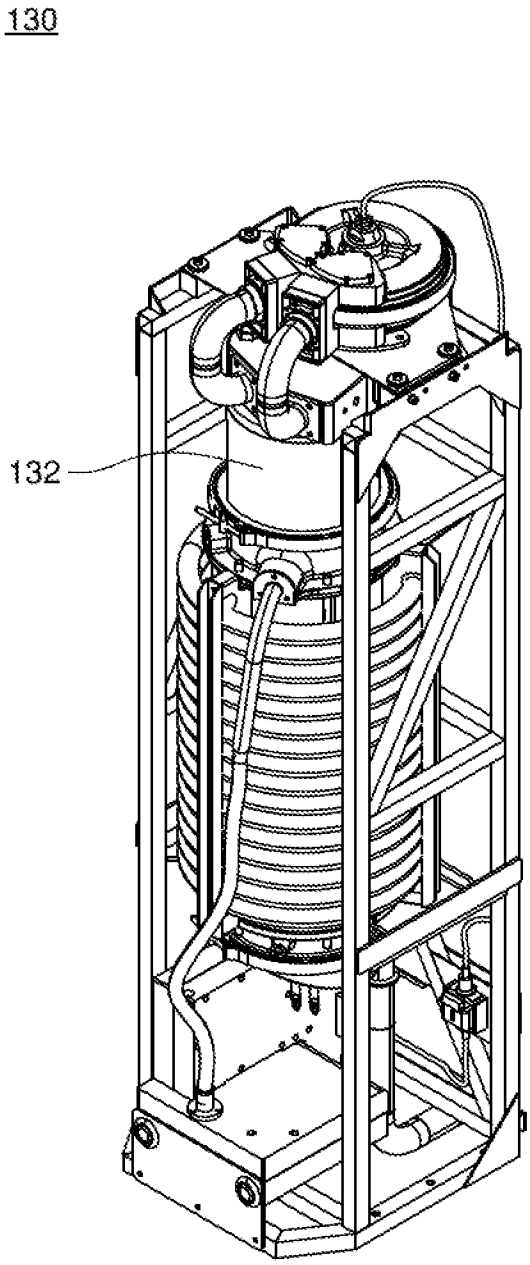



FIG.1G

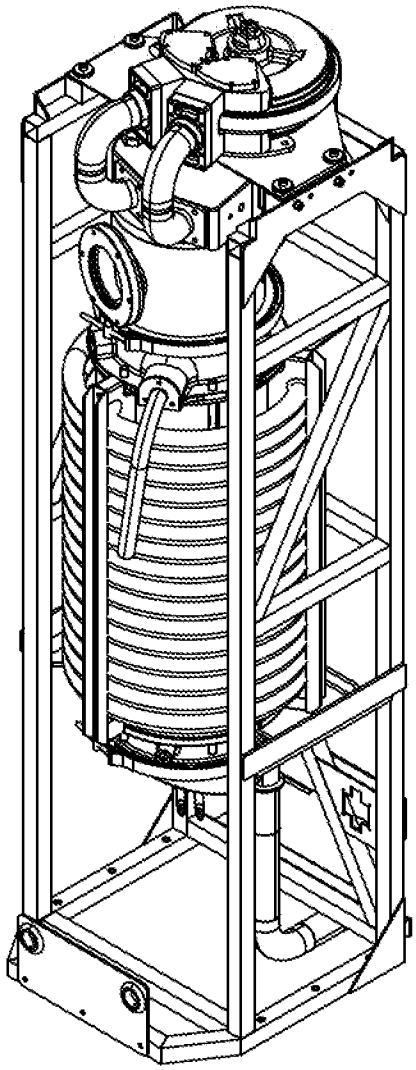


FIG.1H

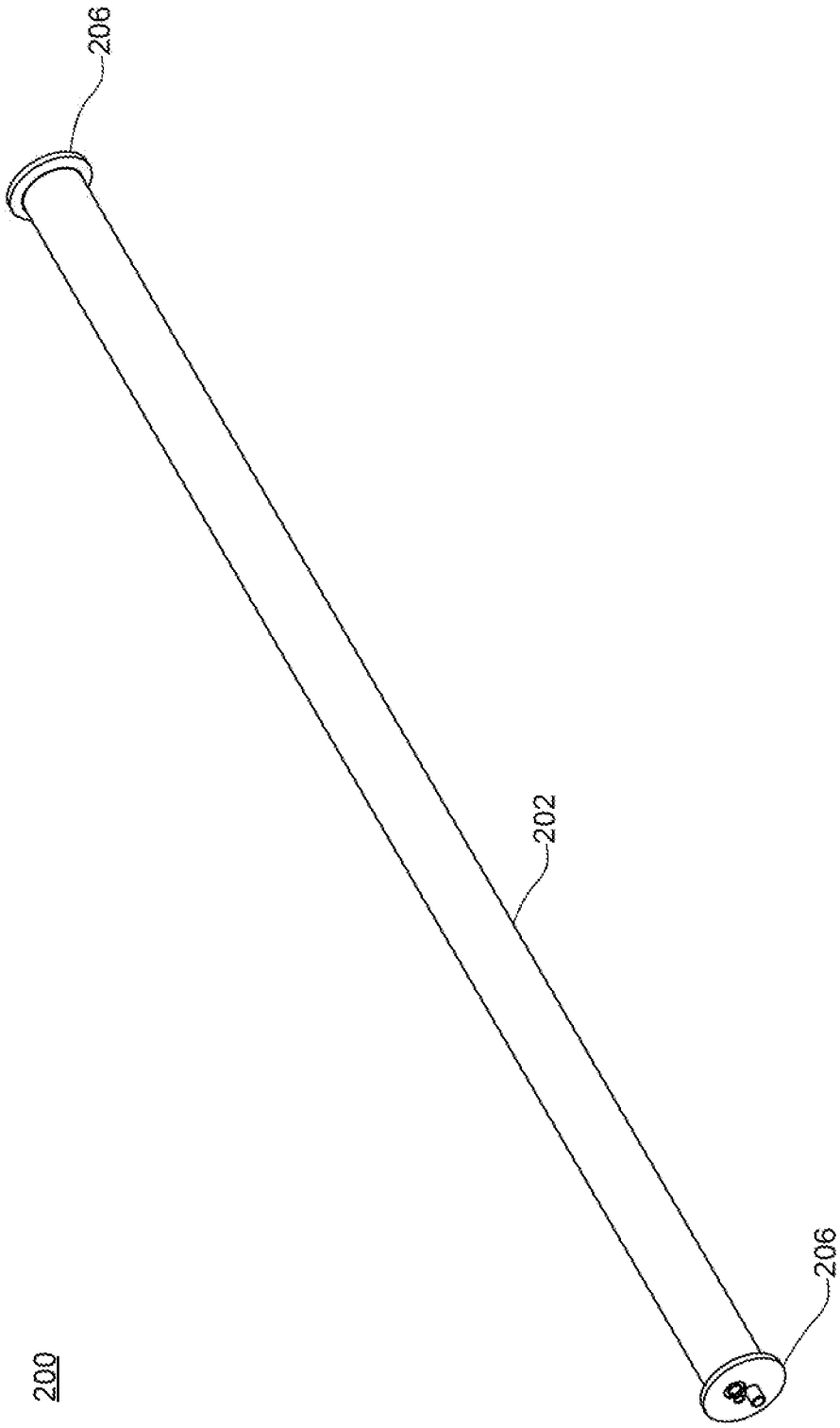



FIG.2

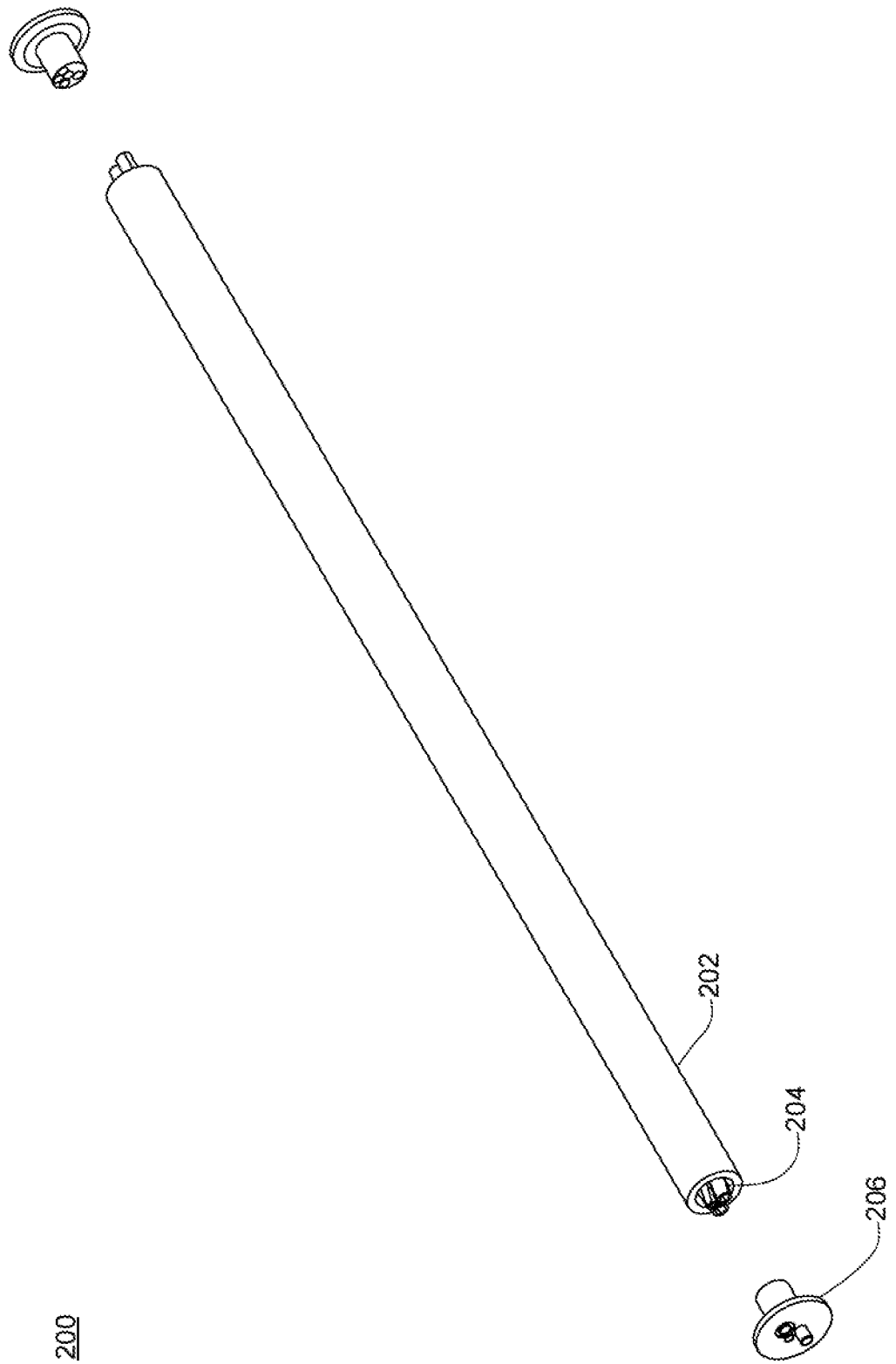



FIG.2A

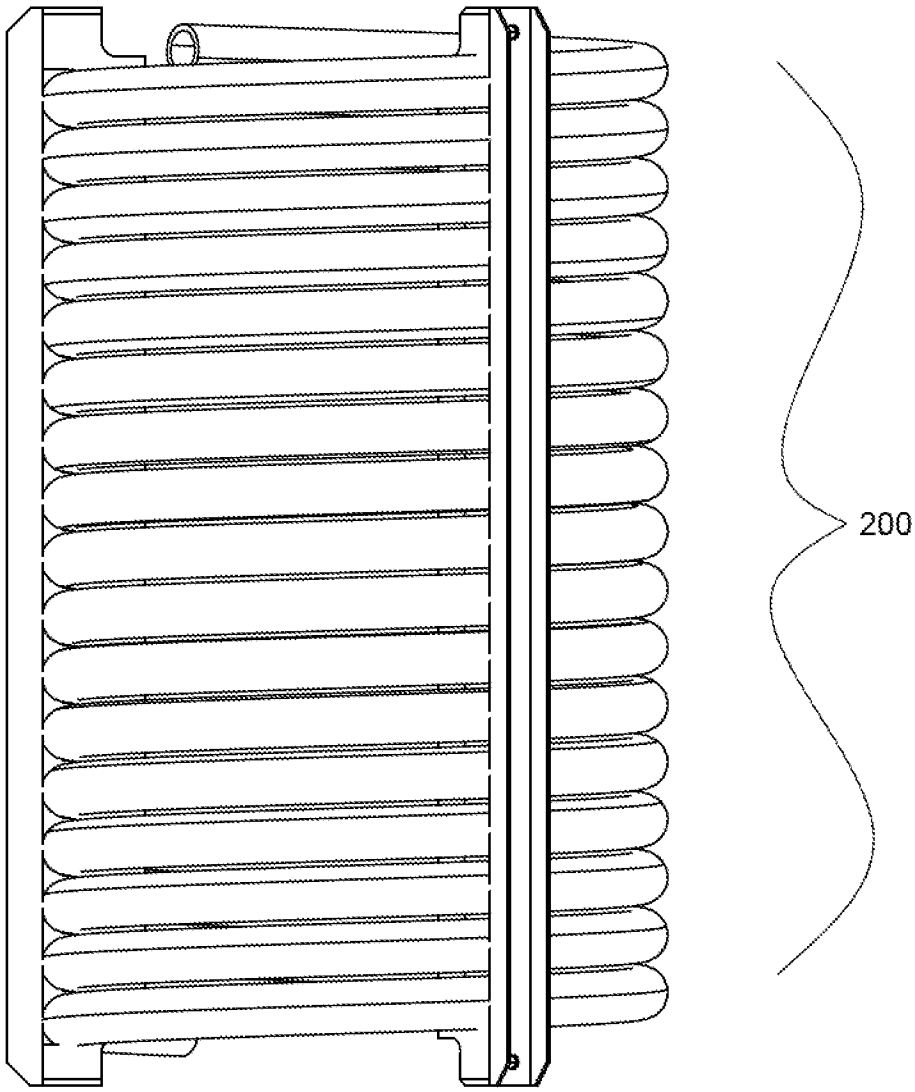



FIG.2B

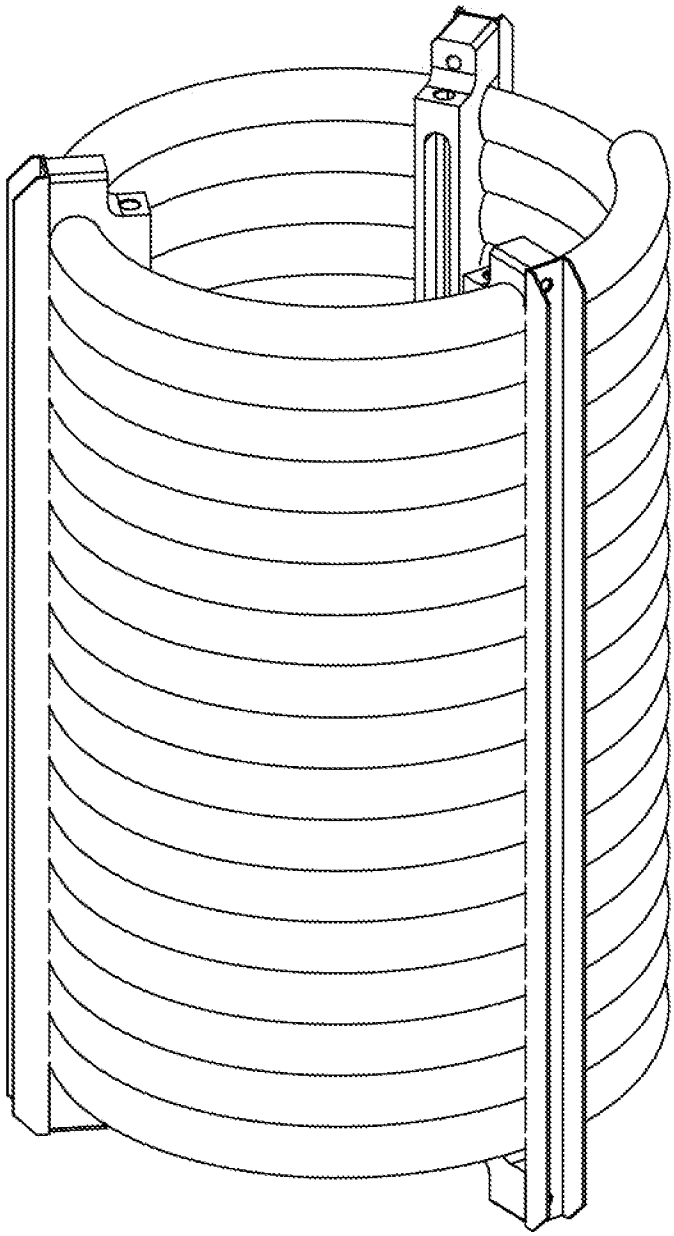
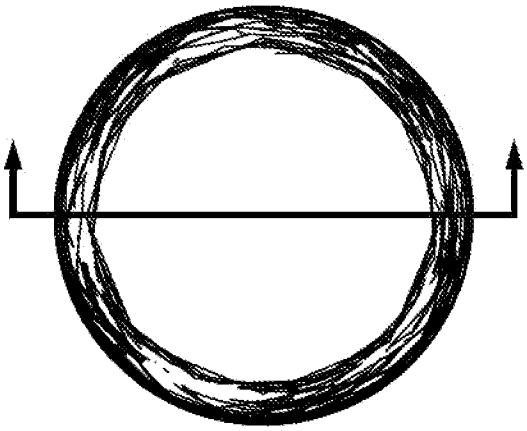


FIG.2C



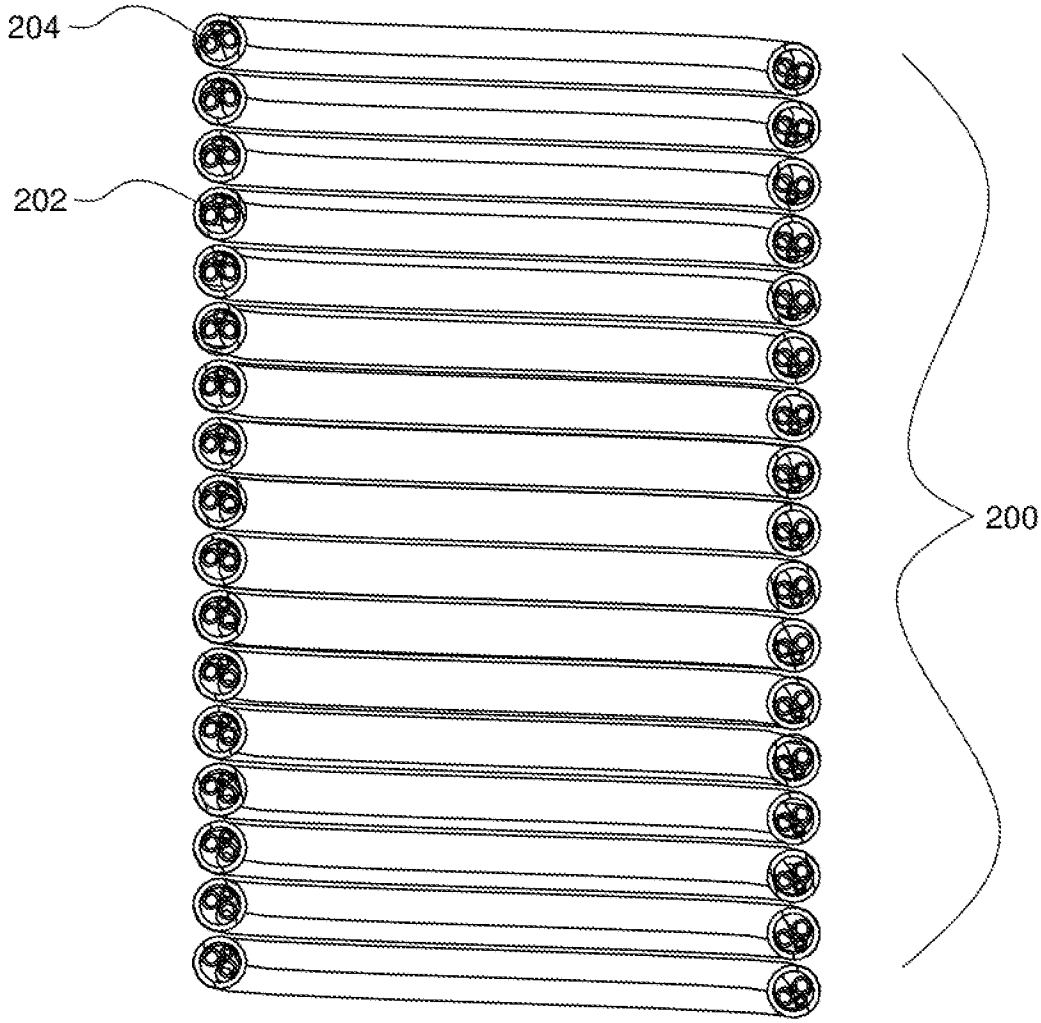



FIG.2D

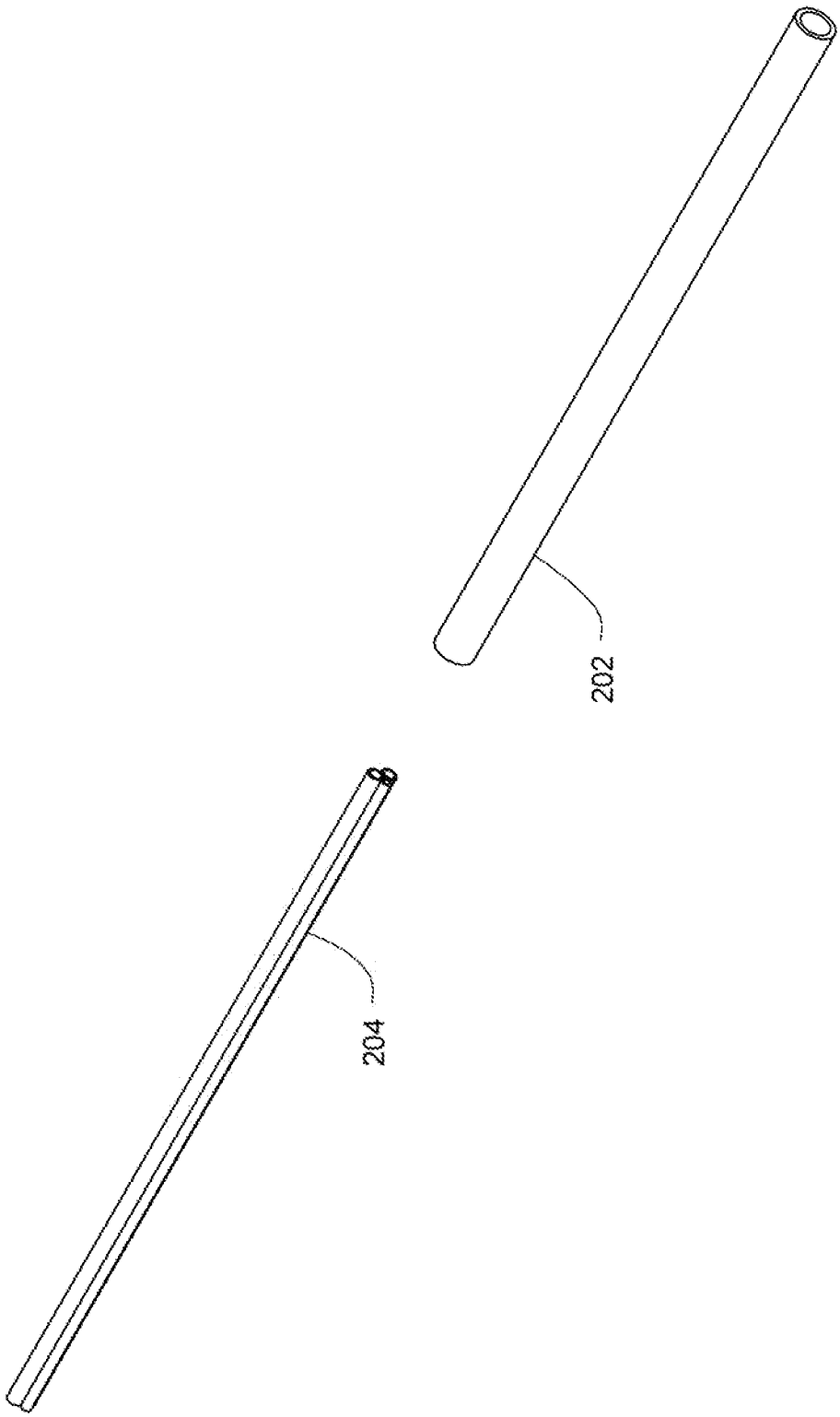



FIG.2E

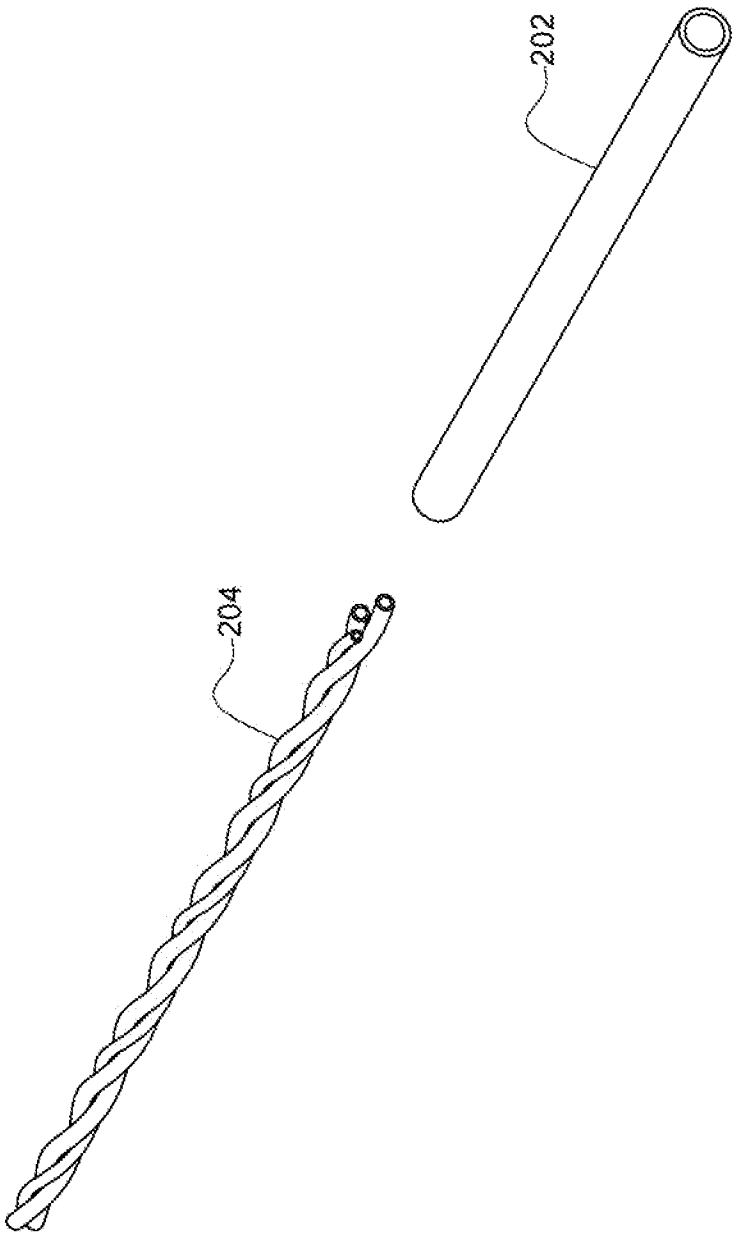



FIG.2F

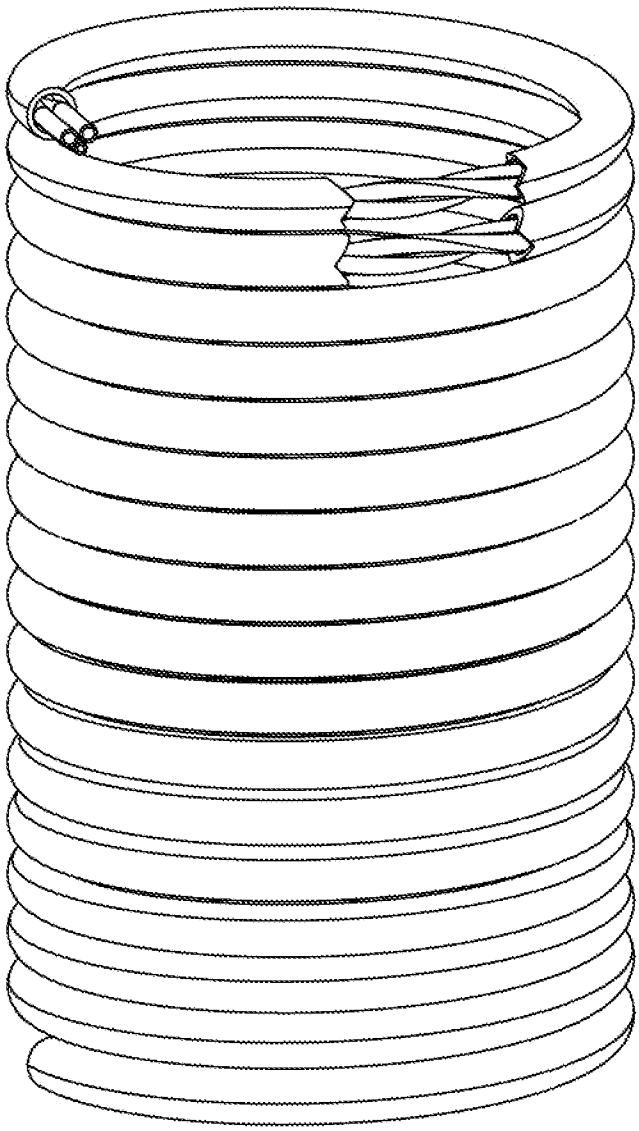


FIG.2G

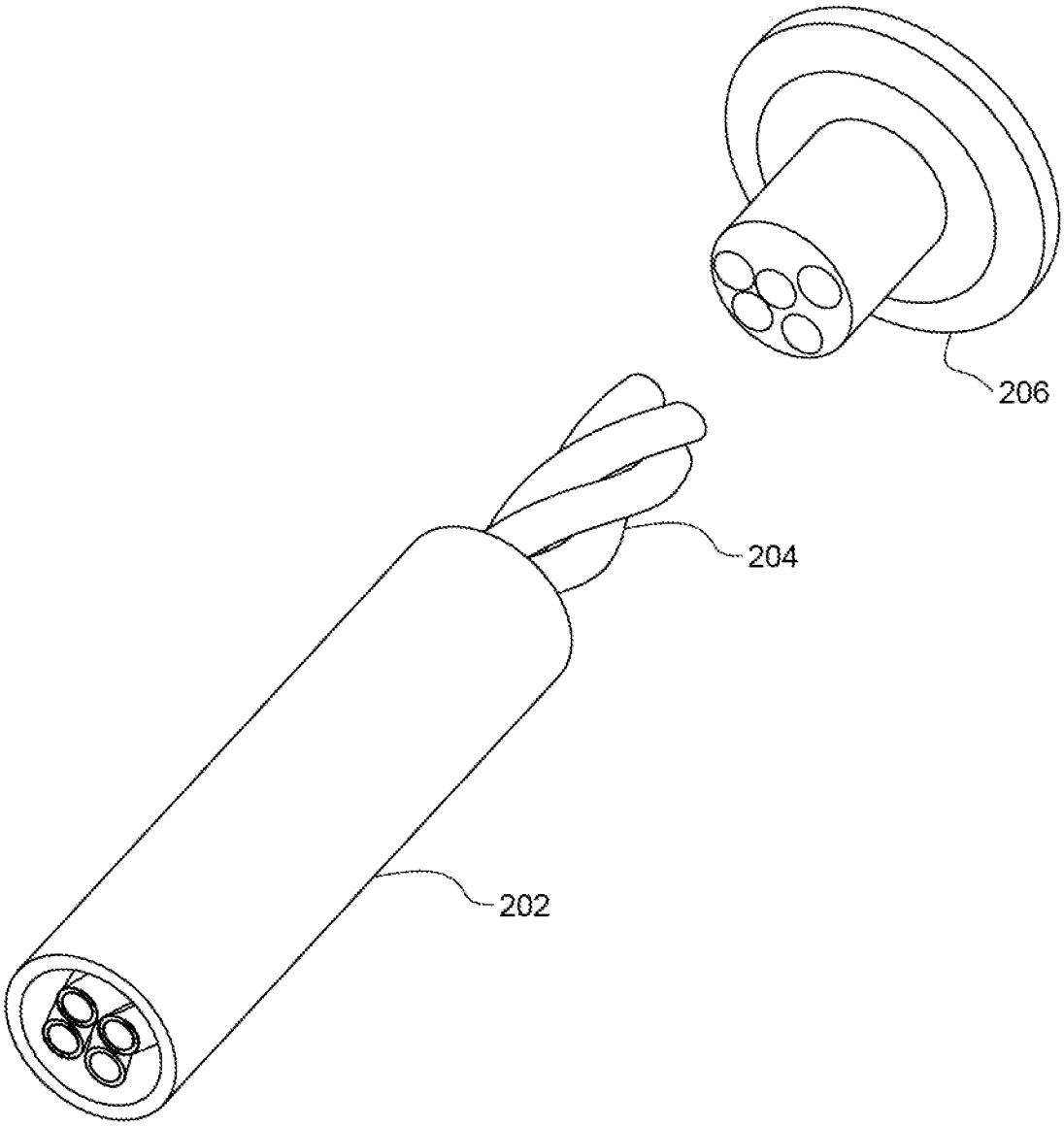



FIG.2H

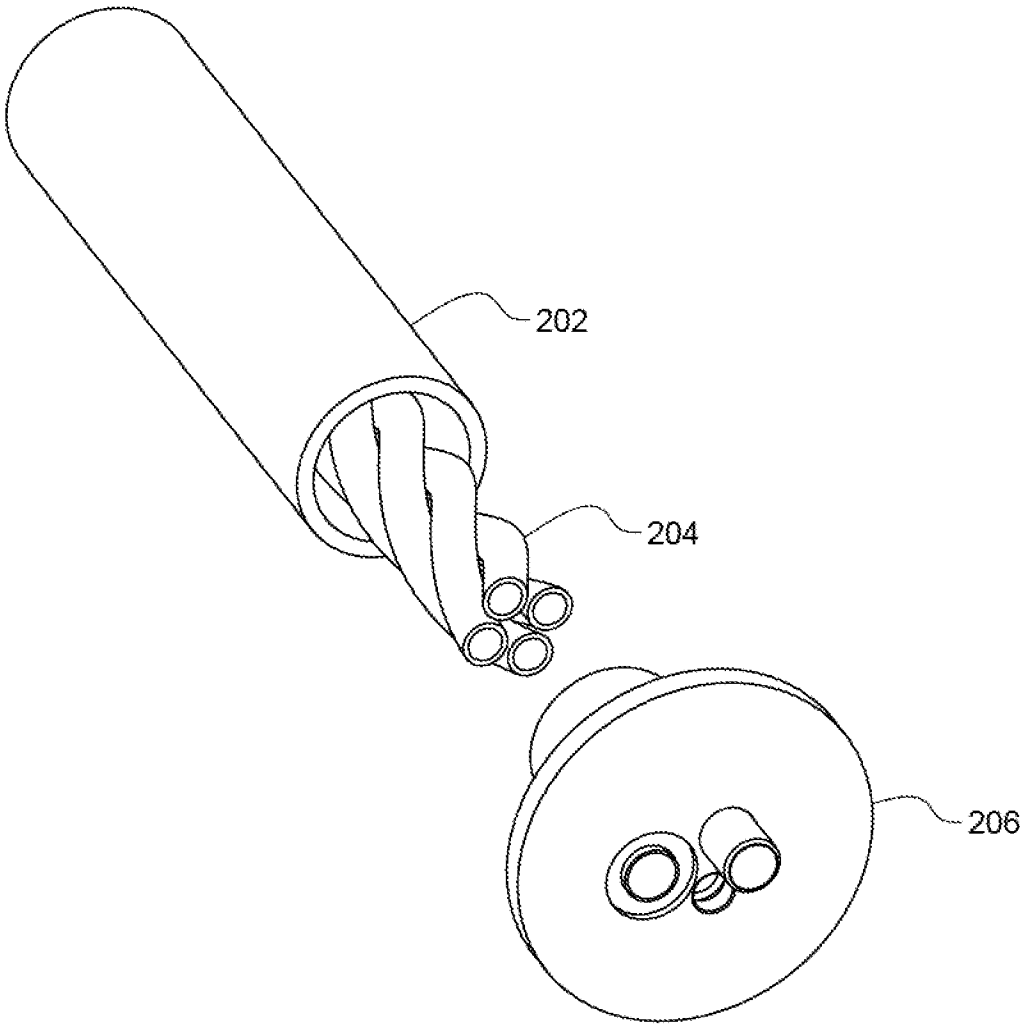



FIG.2I

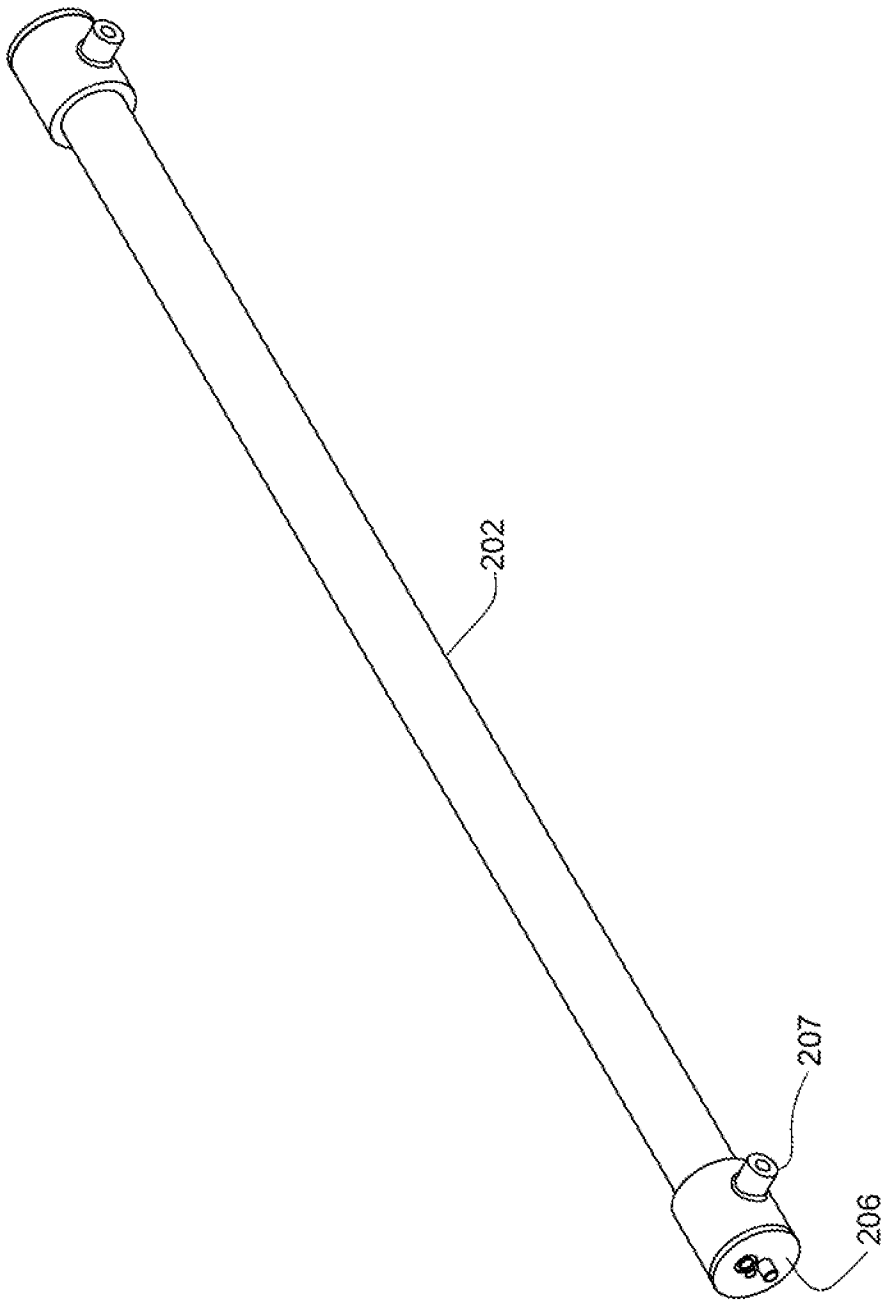



FIG. 2J

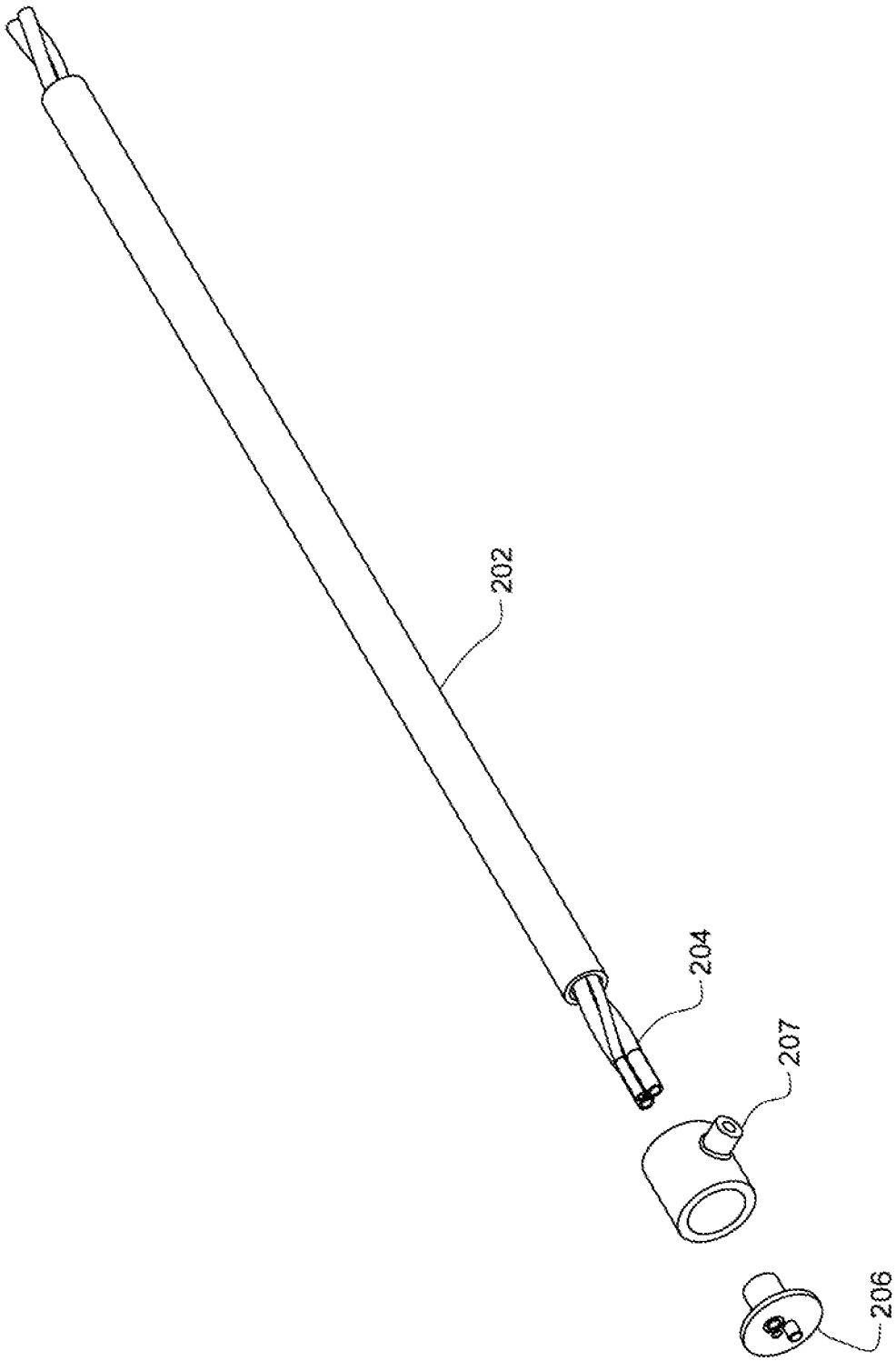



FIG. 2K

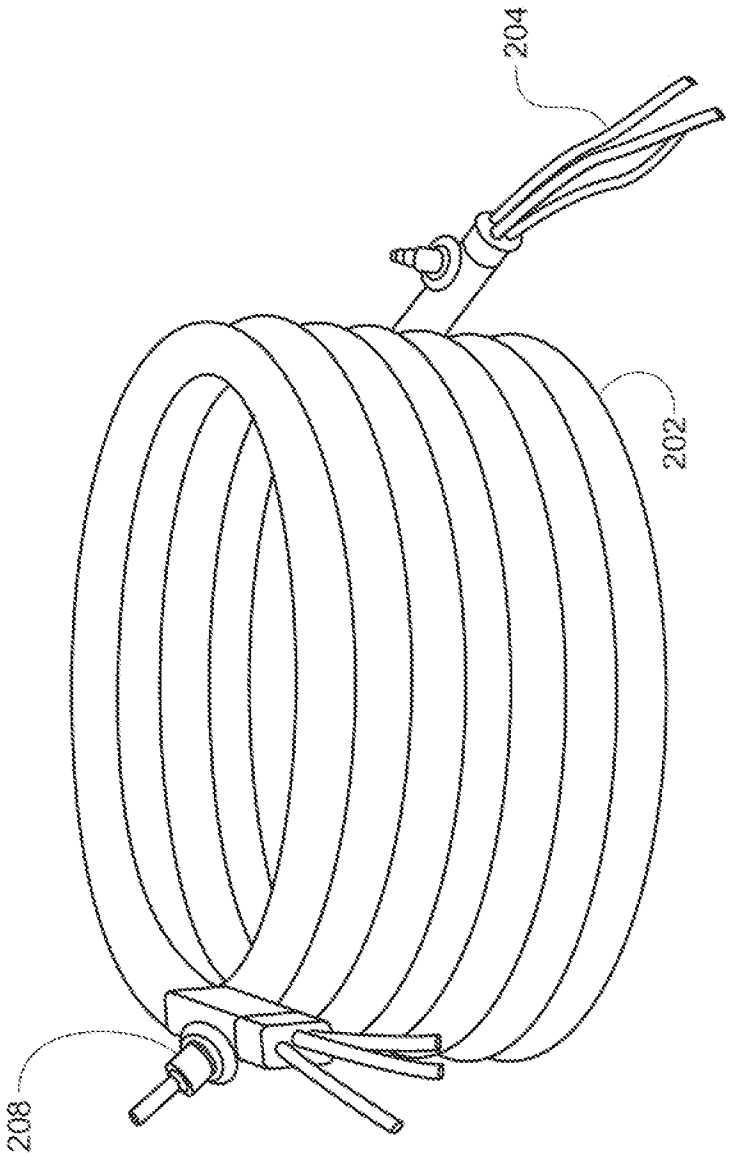



FIG. 2L

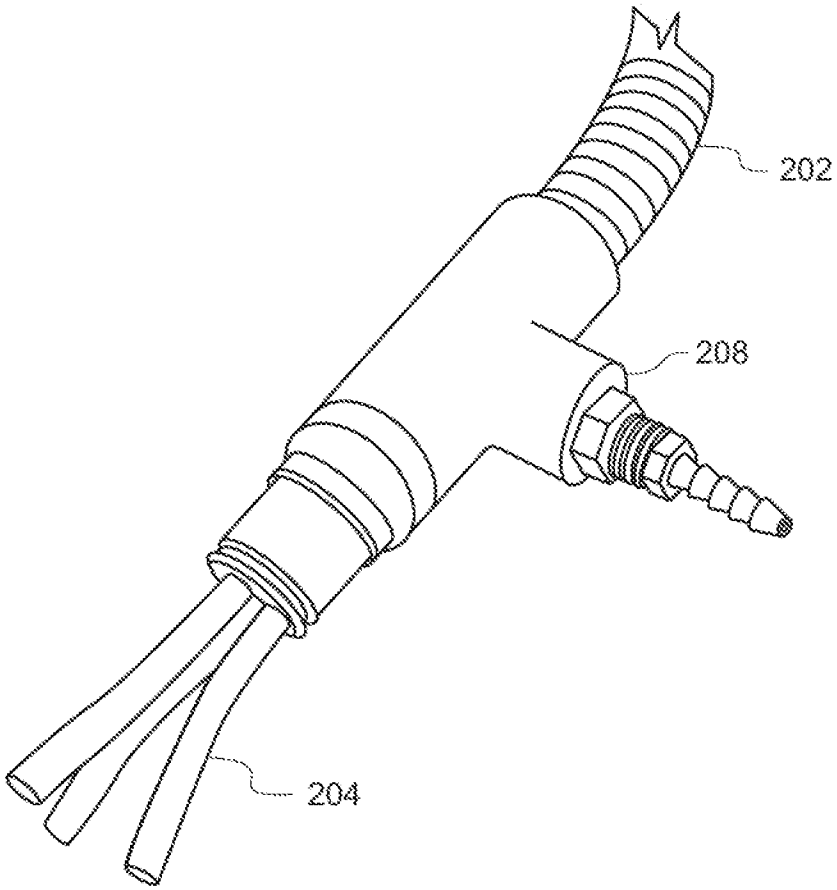



FIG. 2M

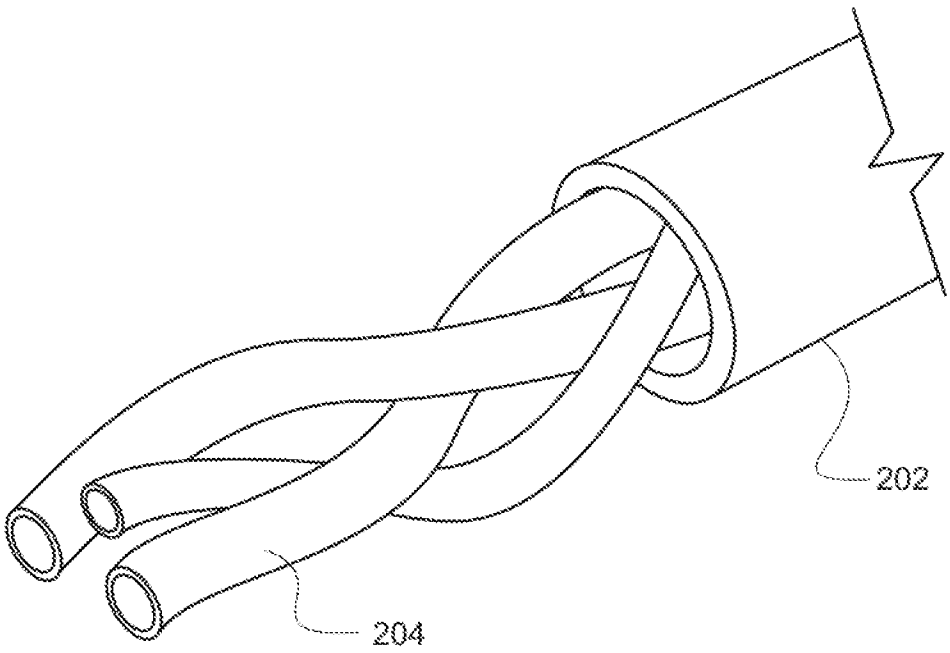
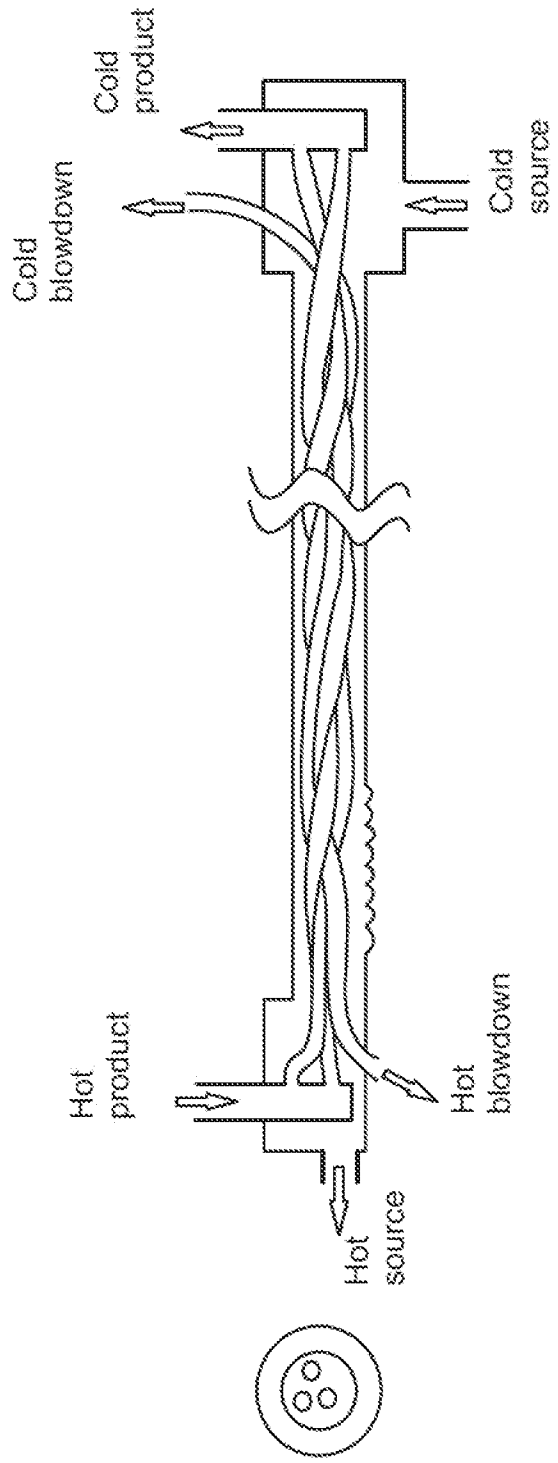



FIG. 2N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Cold blowdown
Cold source
Hot product
Hot blowdown
Hot source

FIG.2O

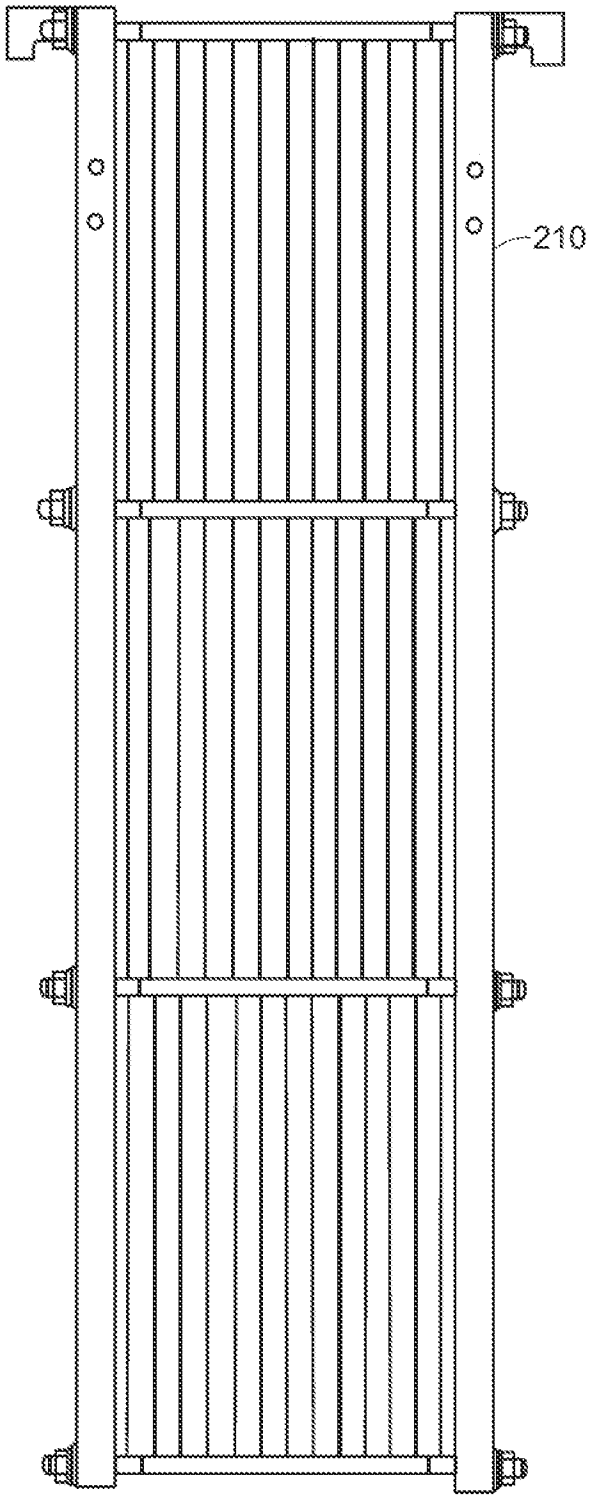



FIG. 2P

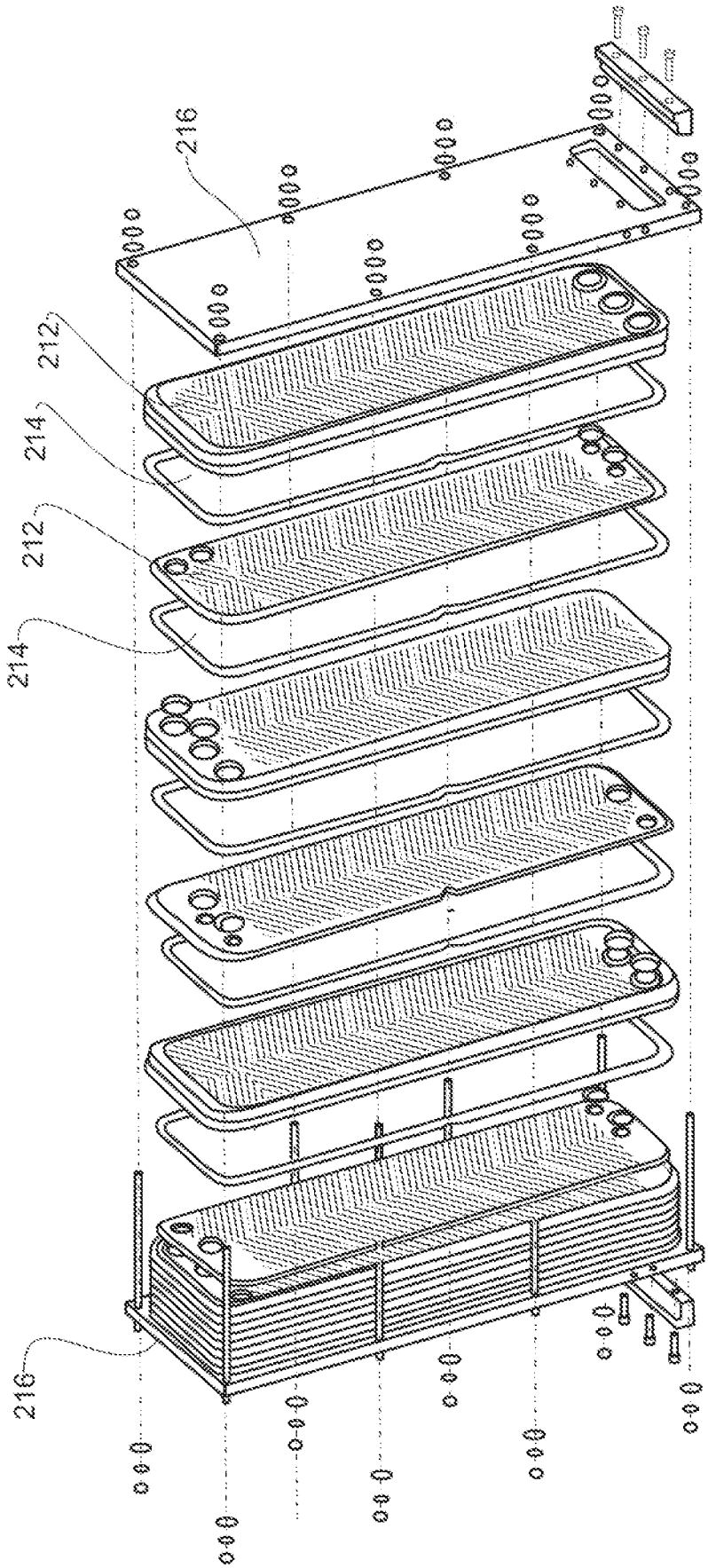



FIG. 2Q

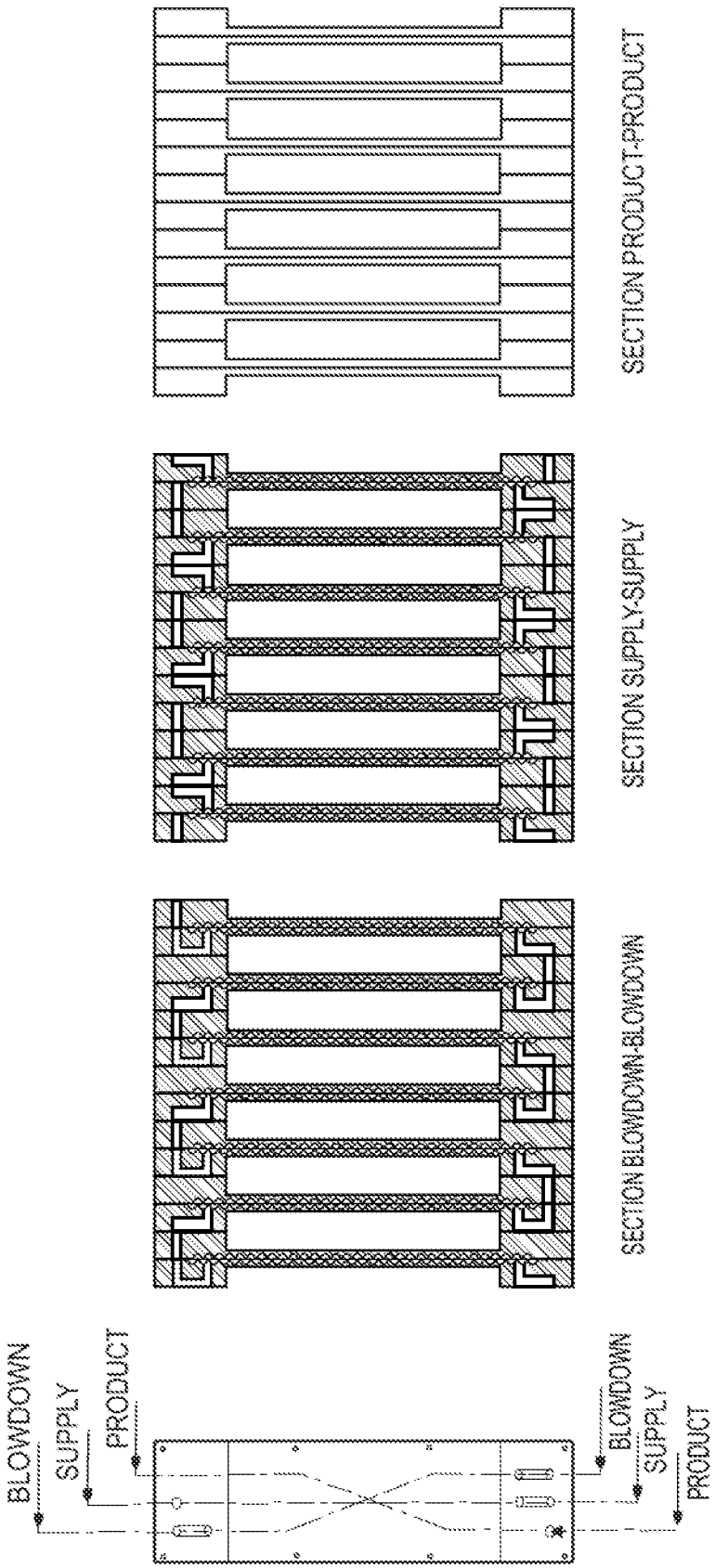

SECTION PRODUCT-PRODUCT
SECTION SUPPLY-SUPPLY
SECTION BLOWDOWN-BLOWDOWN
BLOWDOWN
SUPPLY
PRODUCT
BLOWDOWN
SUPPLY
PRODUCT

FIG. 2R

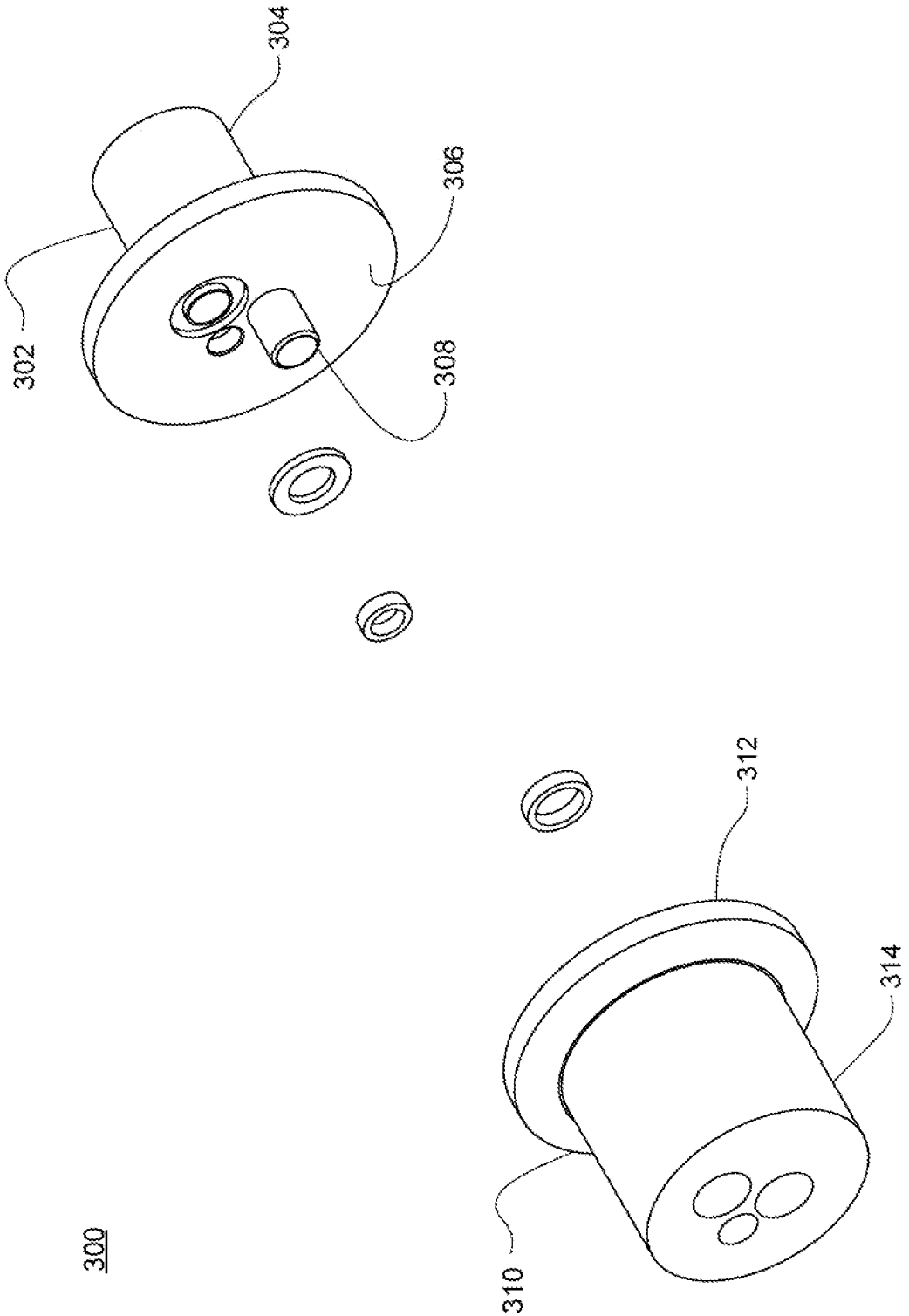



FIG.3

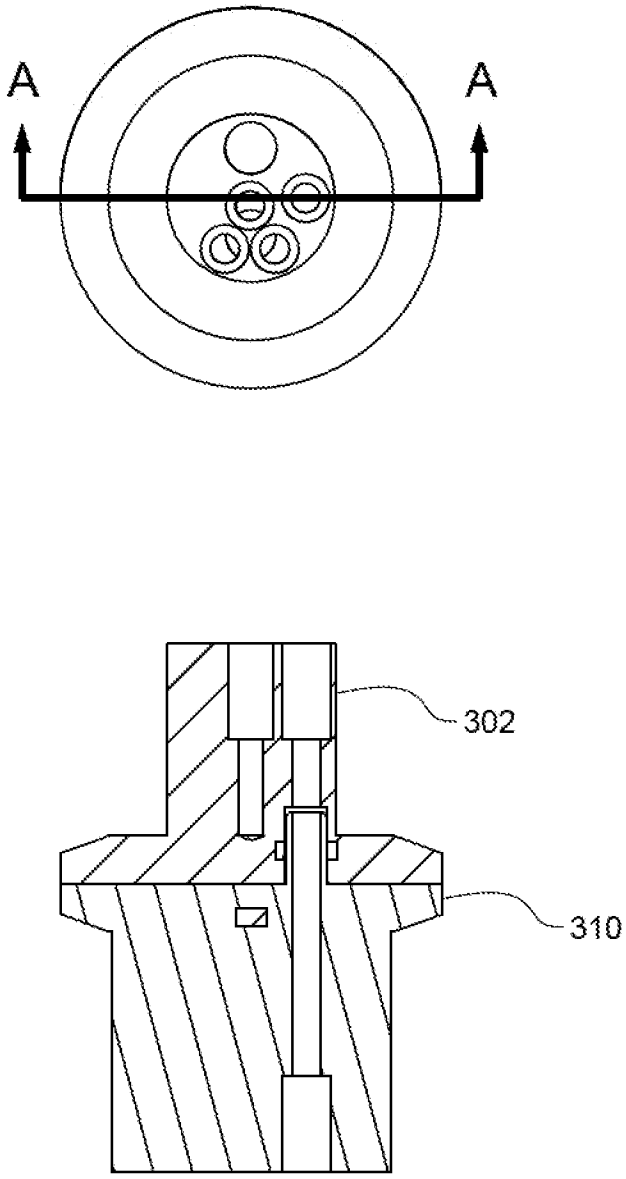



FIG.3A

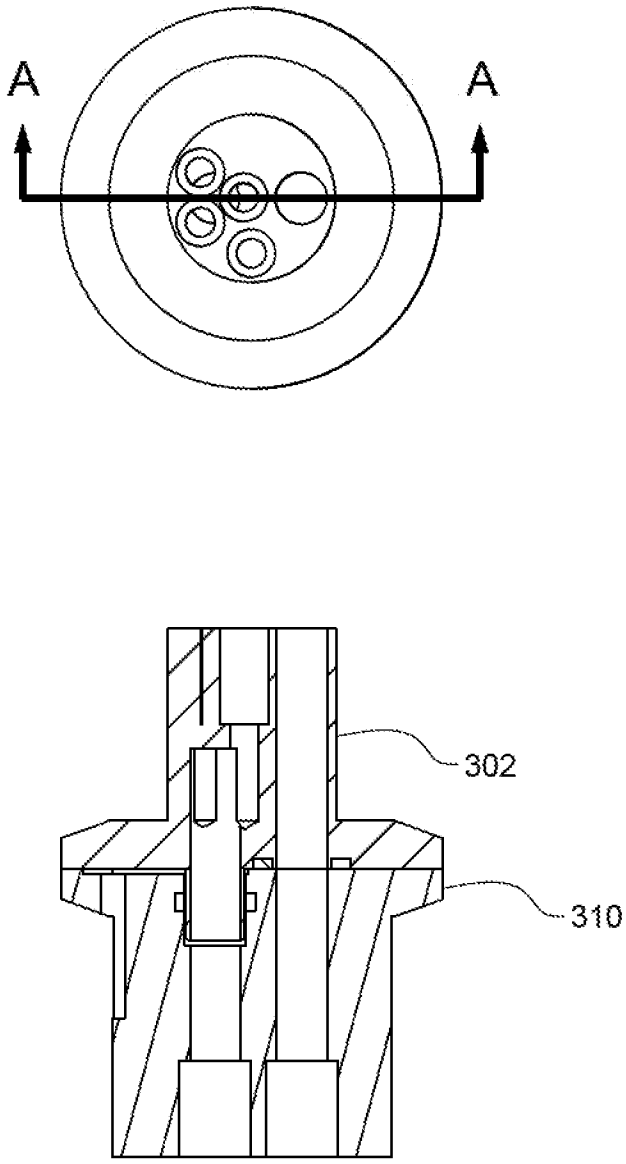



FIG.3B

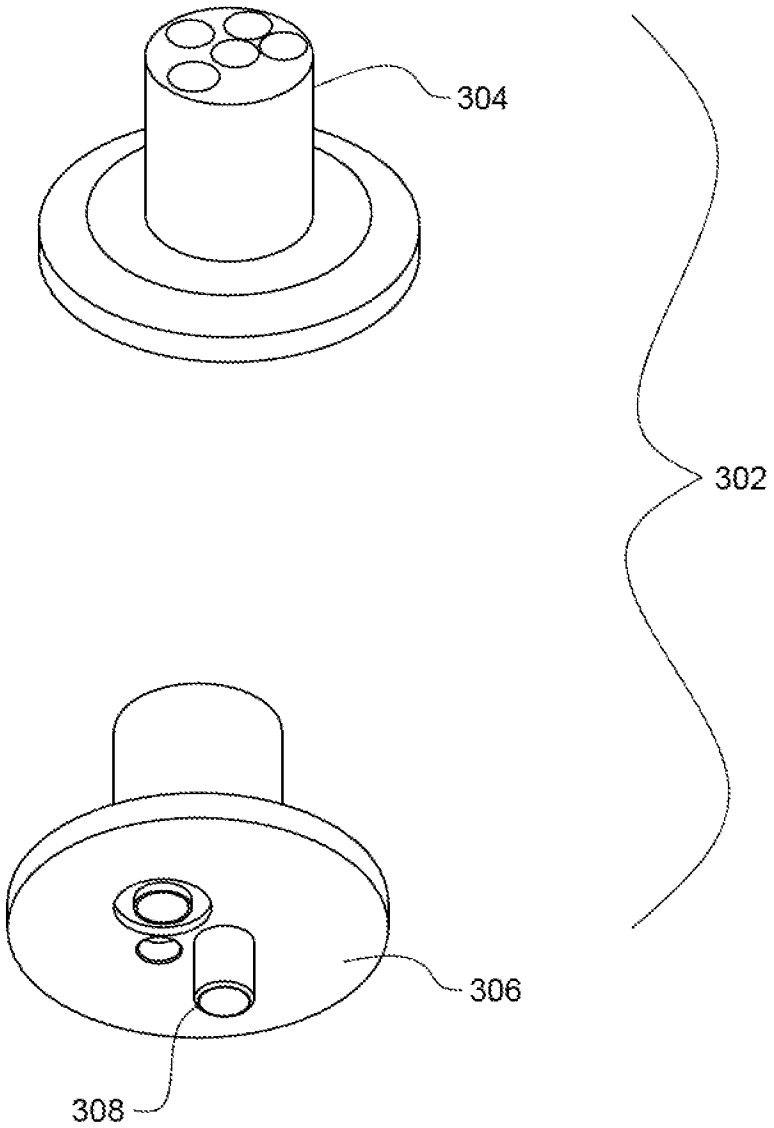



FIG.3C

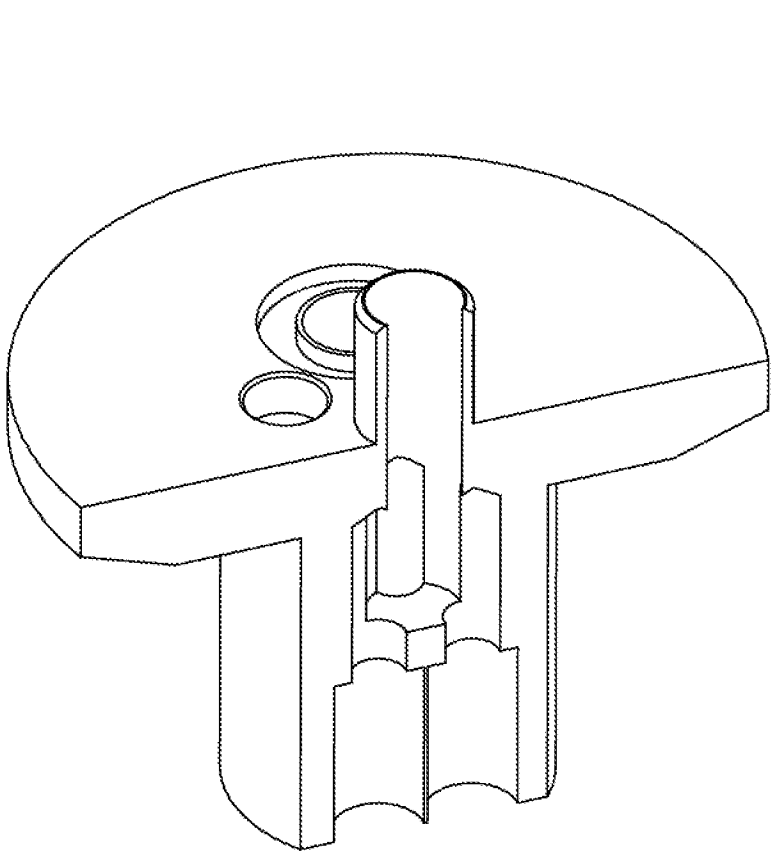
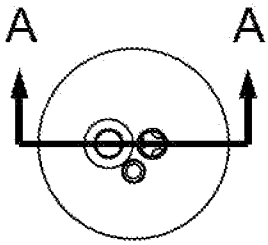



FIG.3D



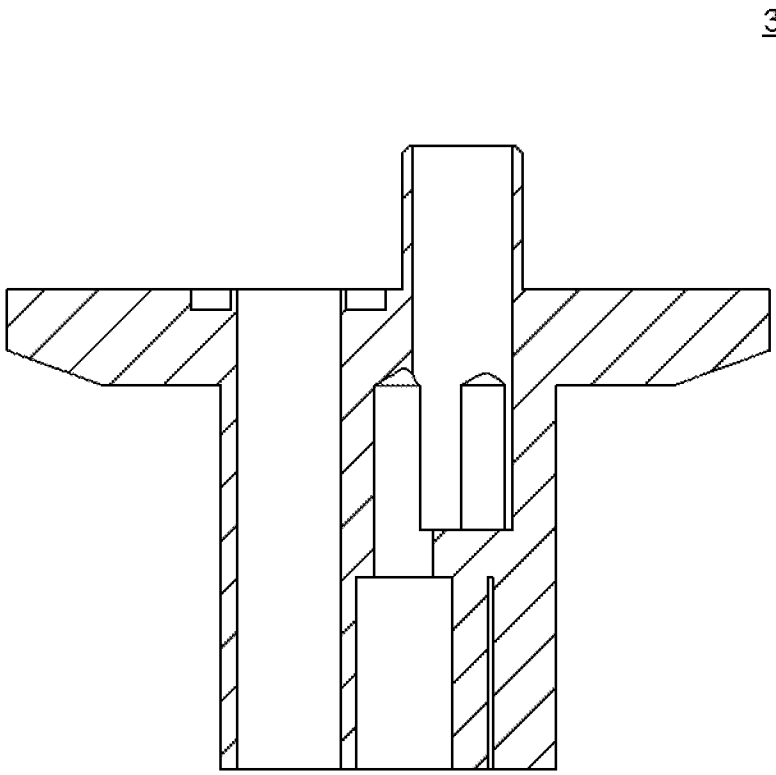
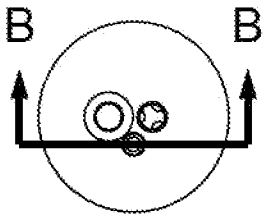




FIG.3E



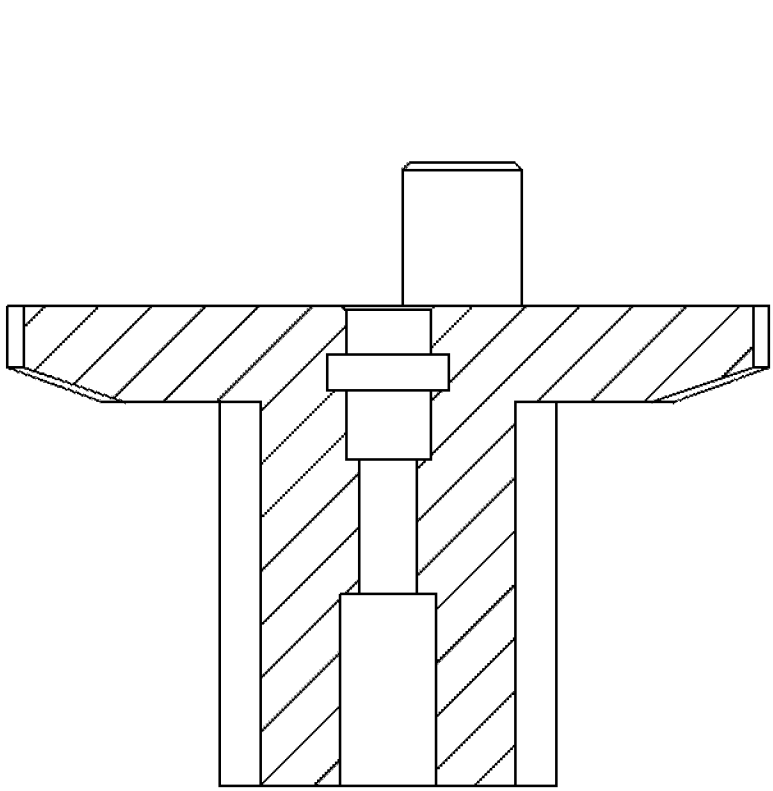




FIG.3F

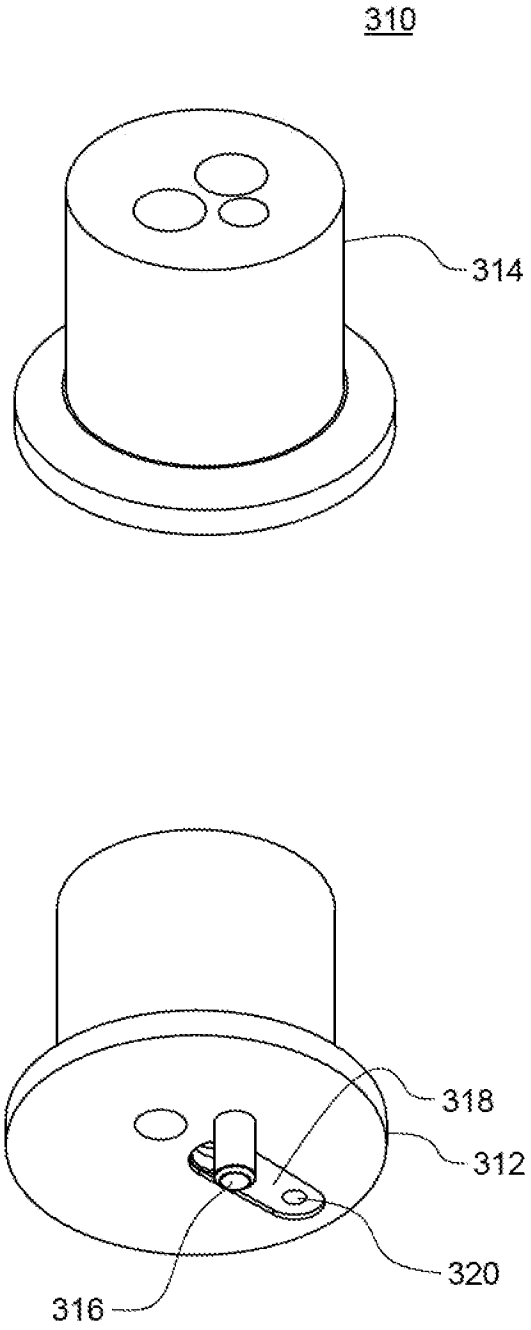



FIG.3G

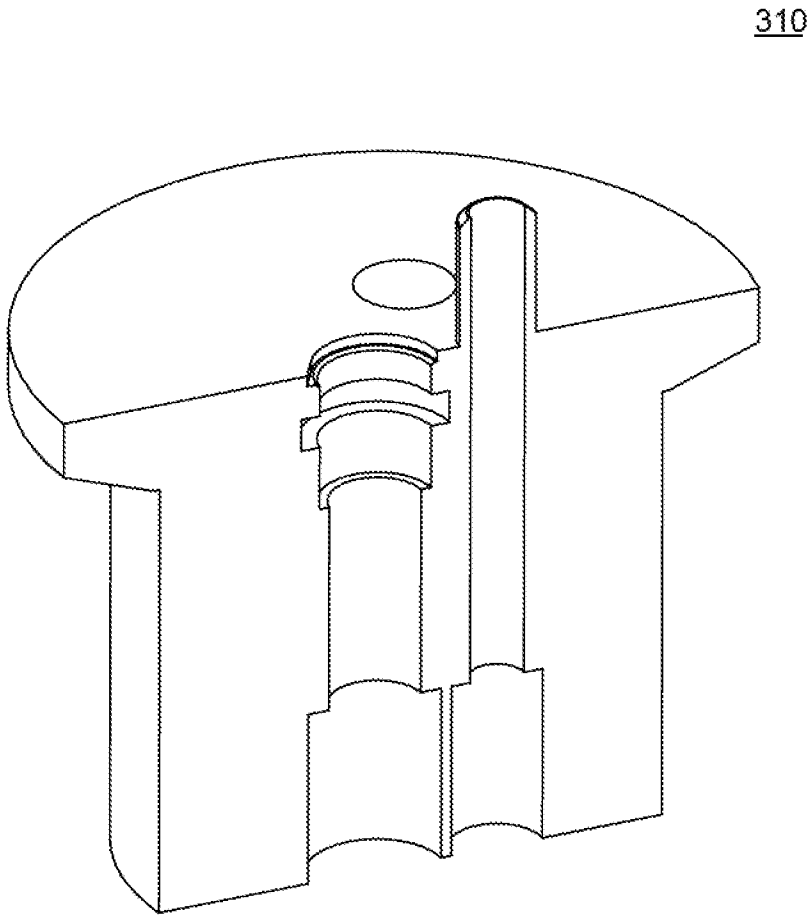
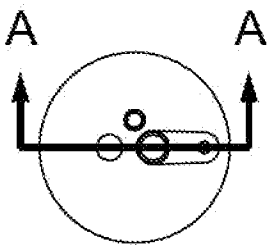



FIG.3H



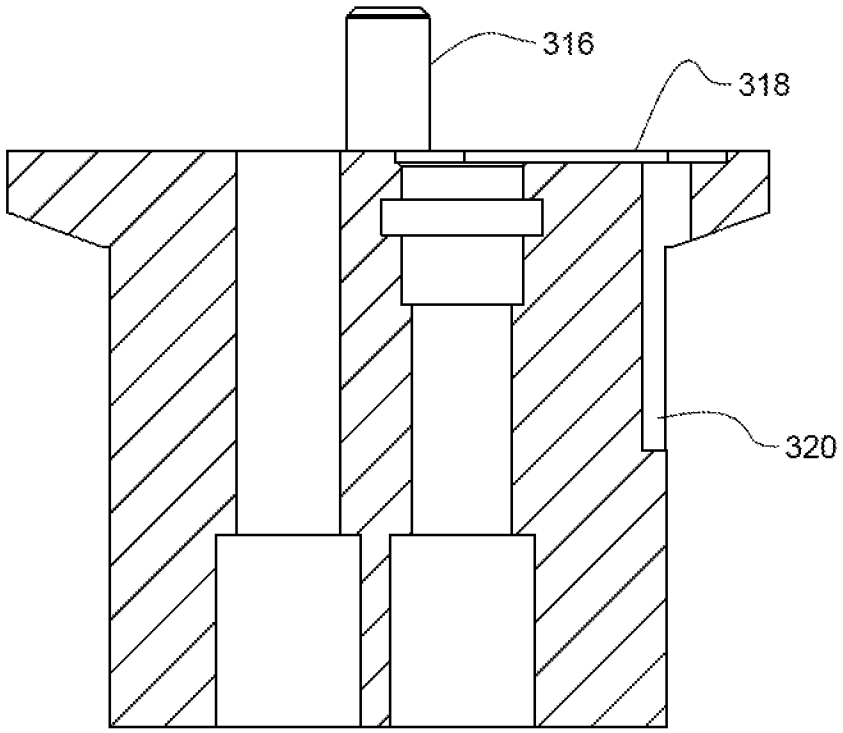
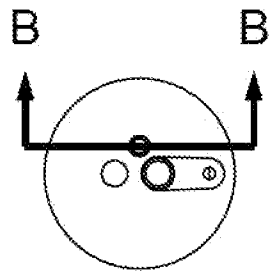




FIG.3I




310

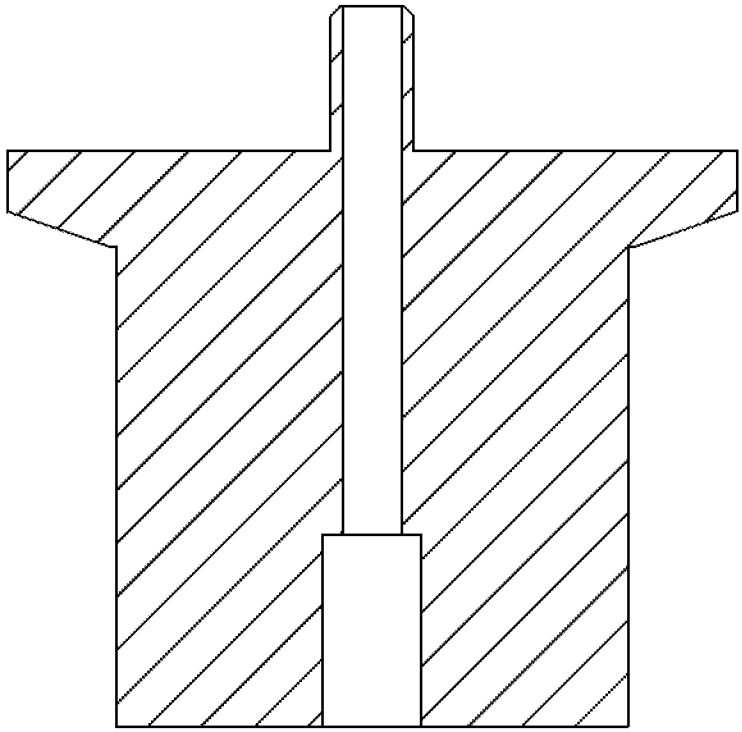


FIG.3J

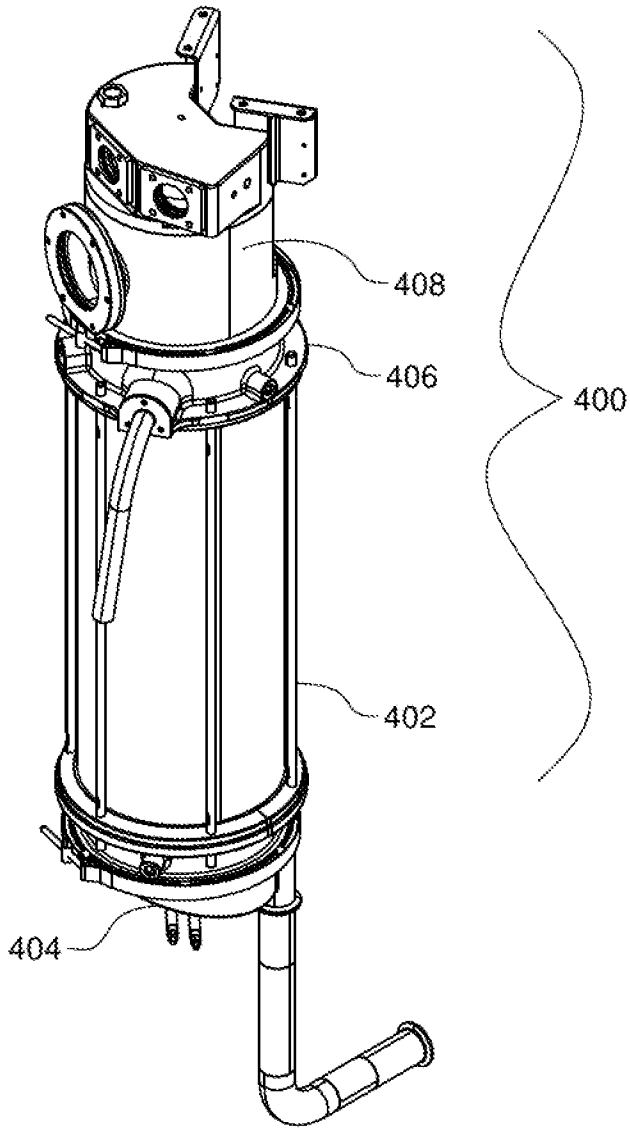



FIG.4

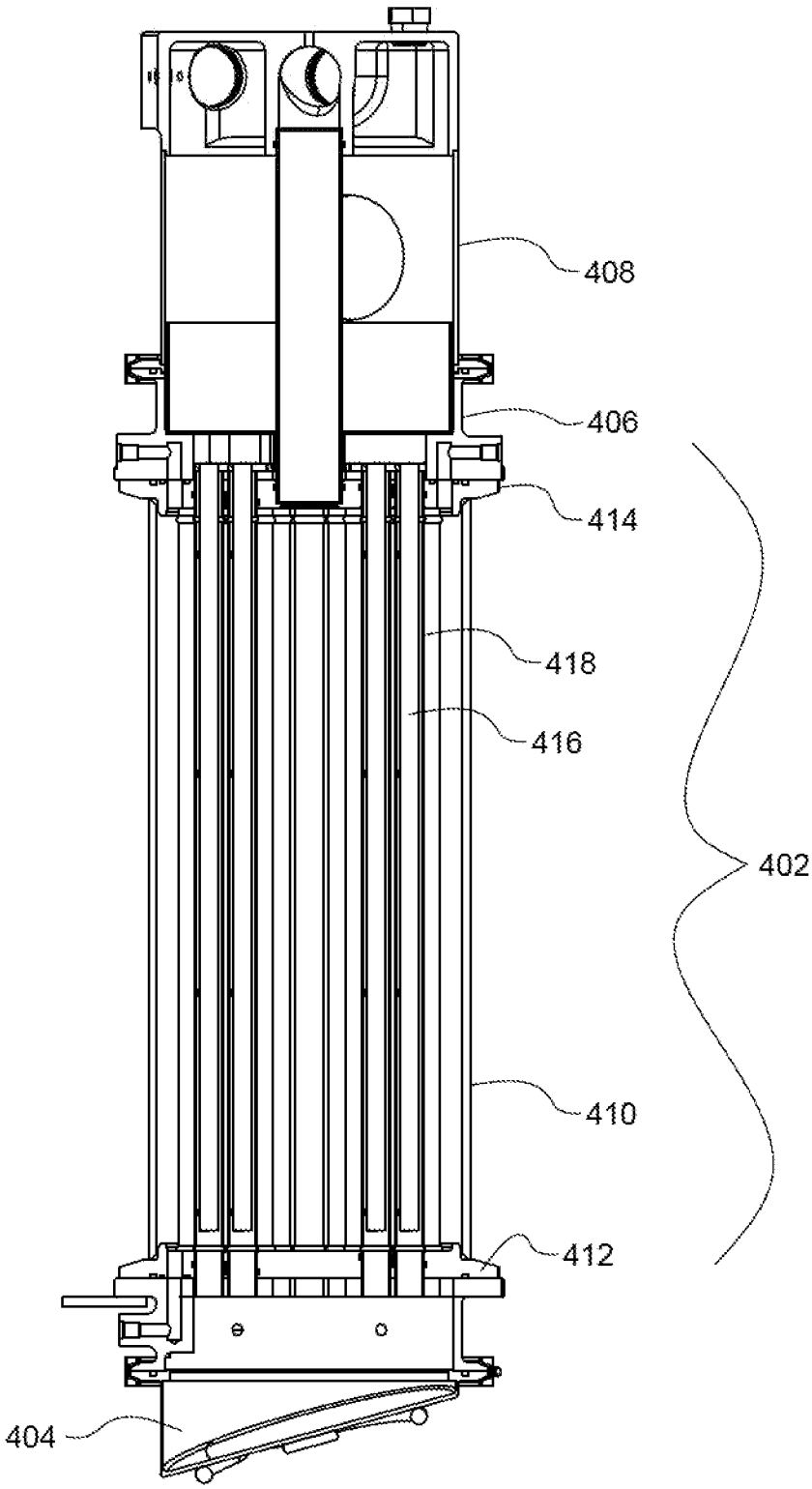



FIG.4A

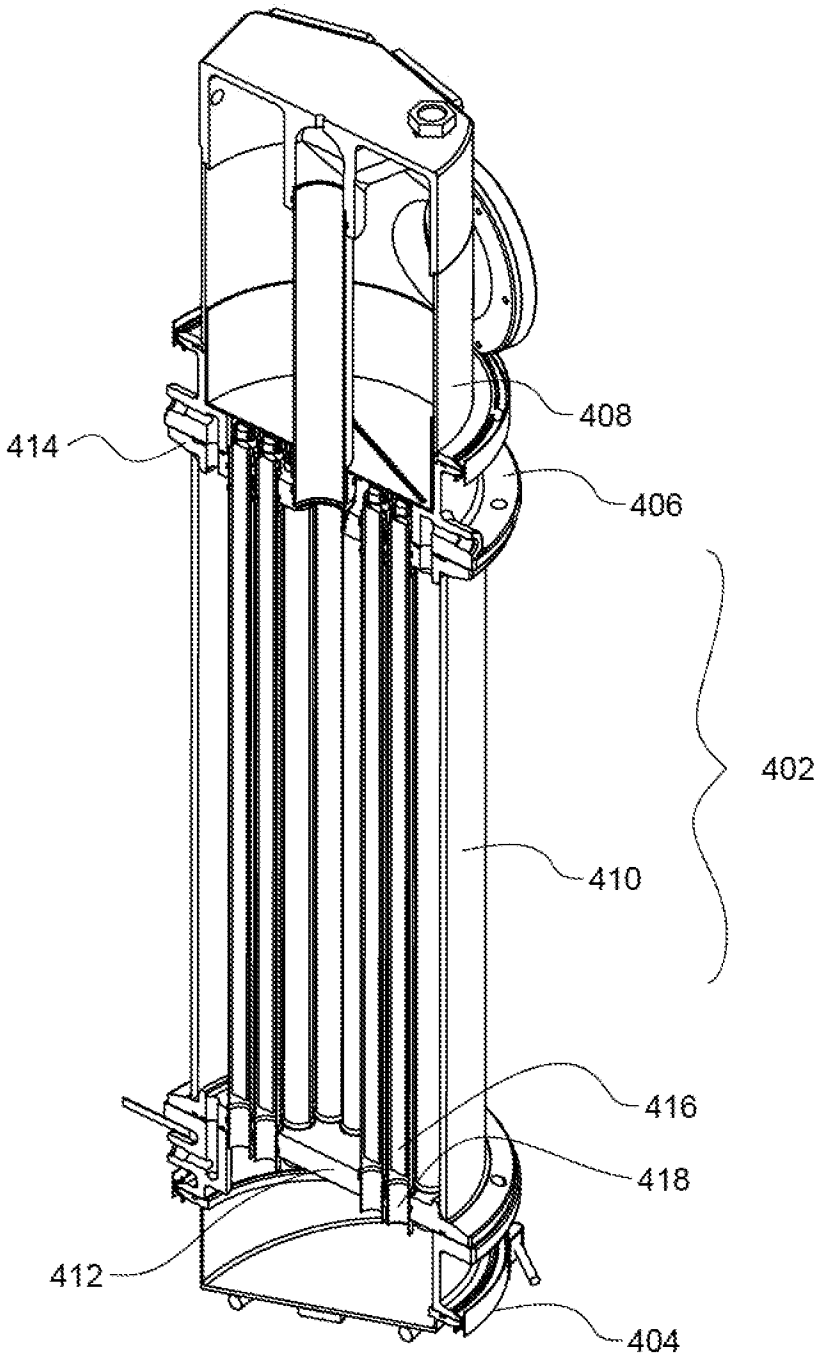



FIG.4B

420

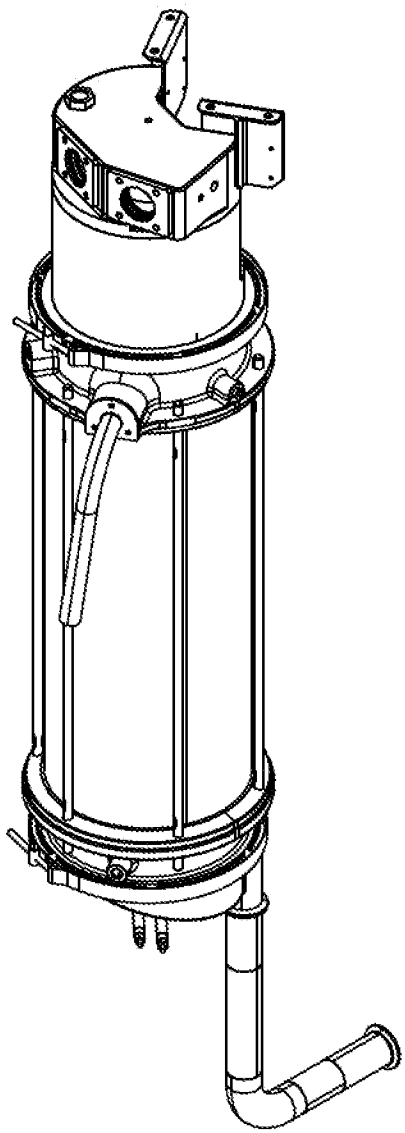


FIG.4C

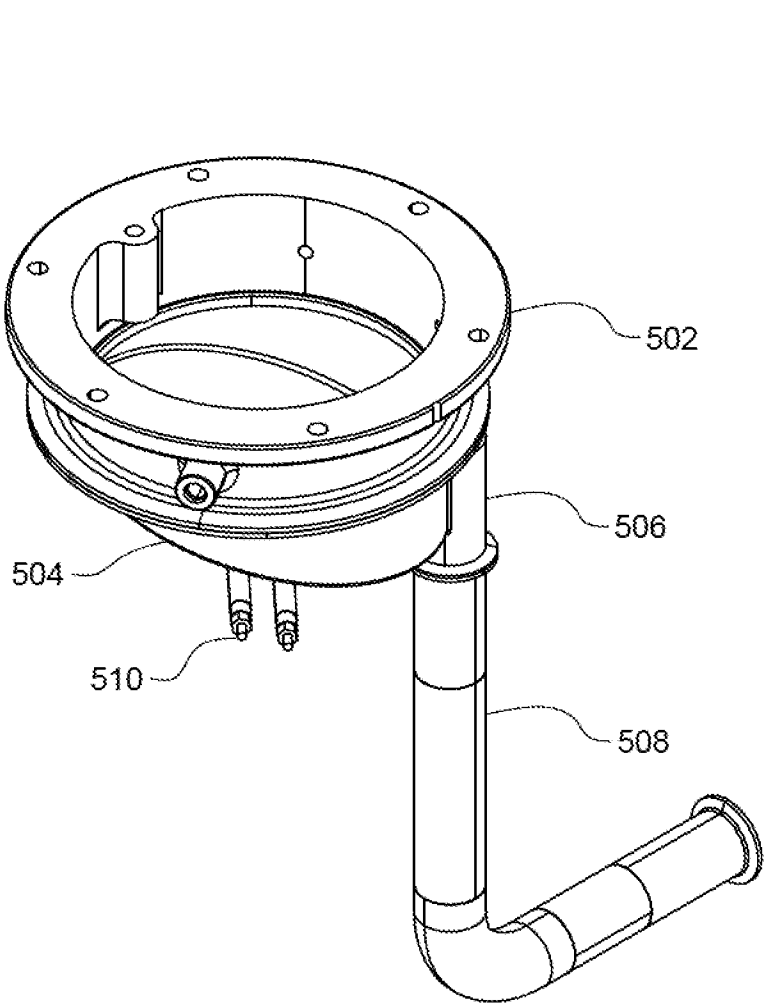



FIG.5

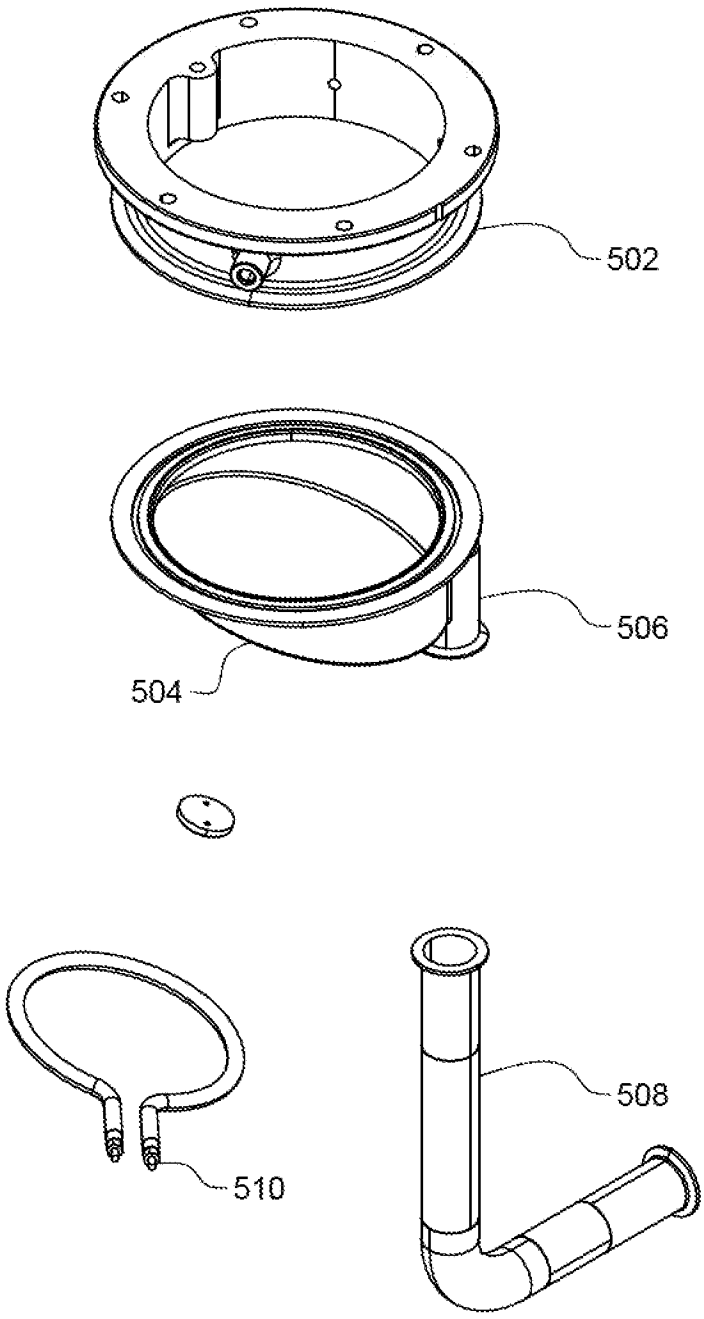



FIG.5A

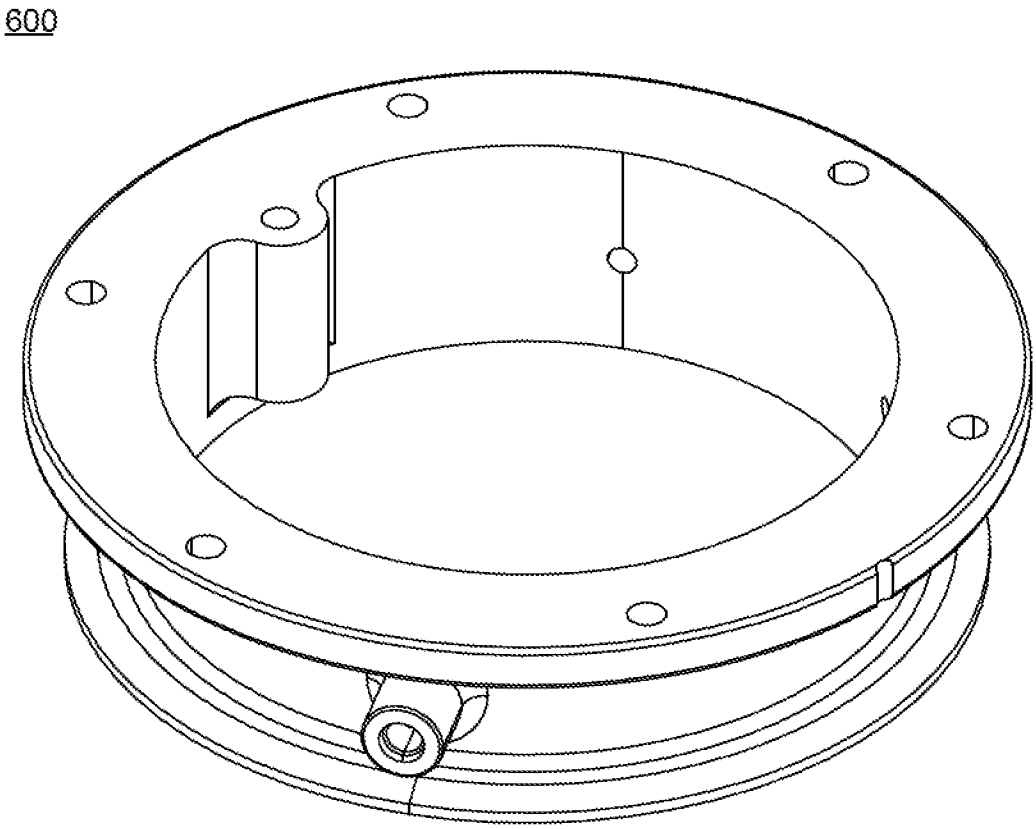



FIG.6

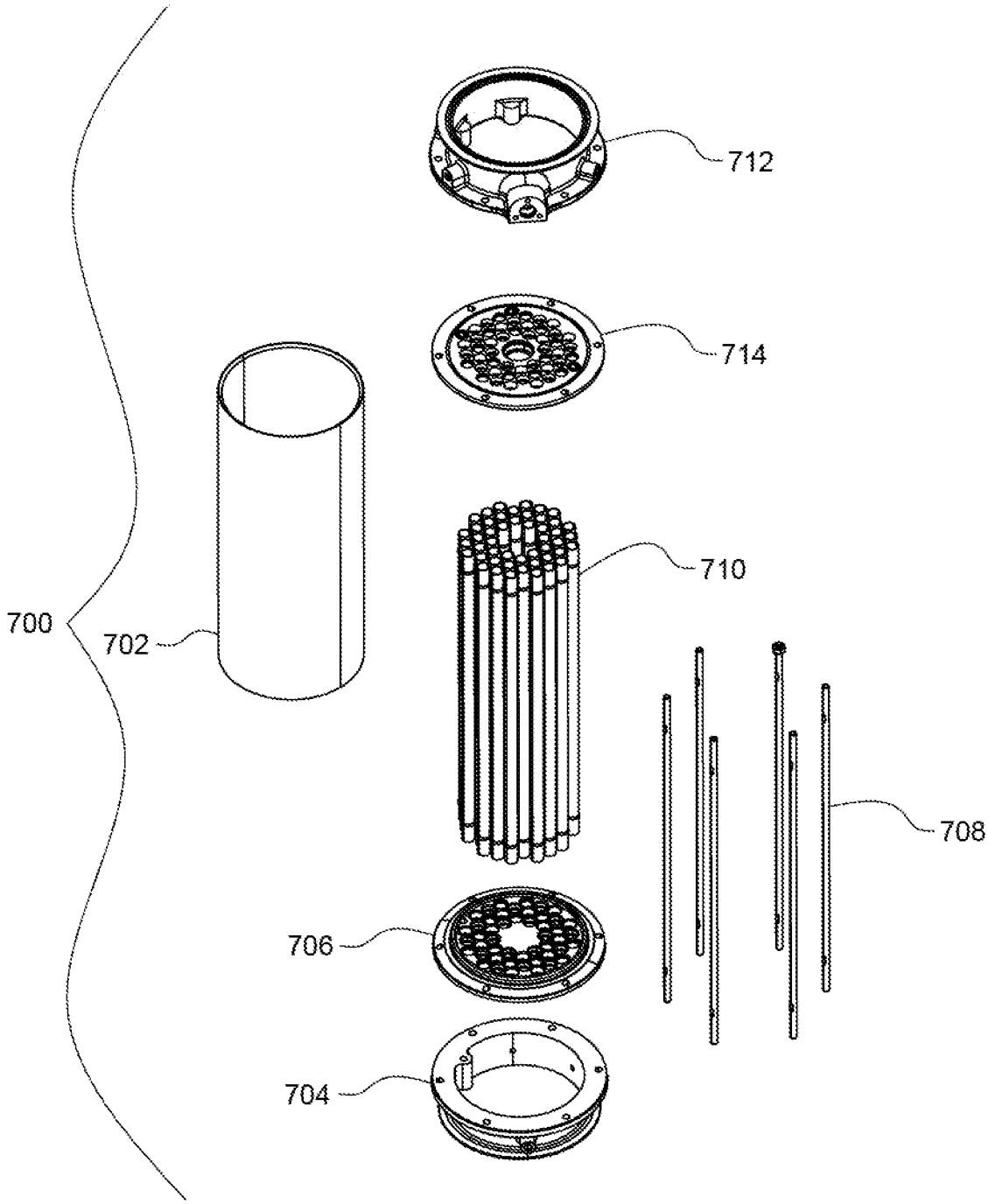



FIG.7

700

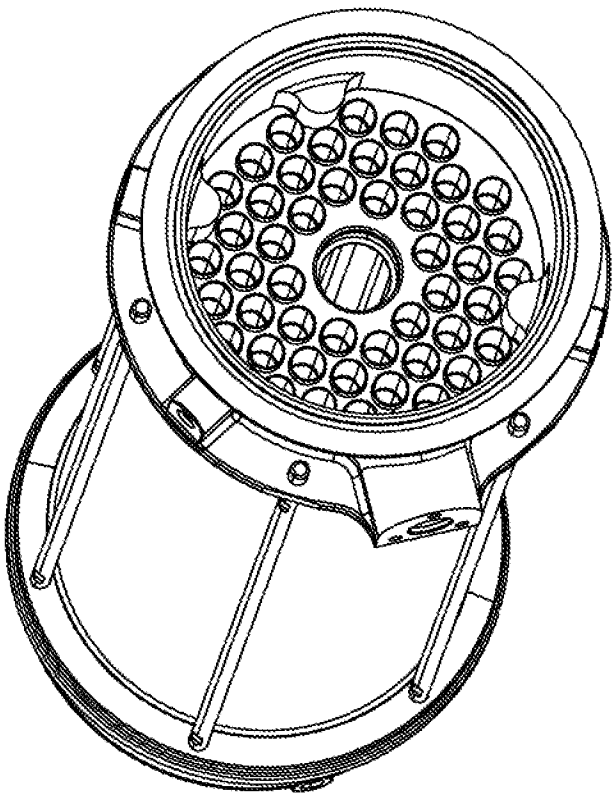


FIG.7A

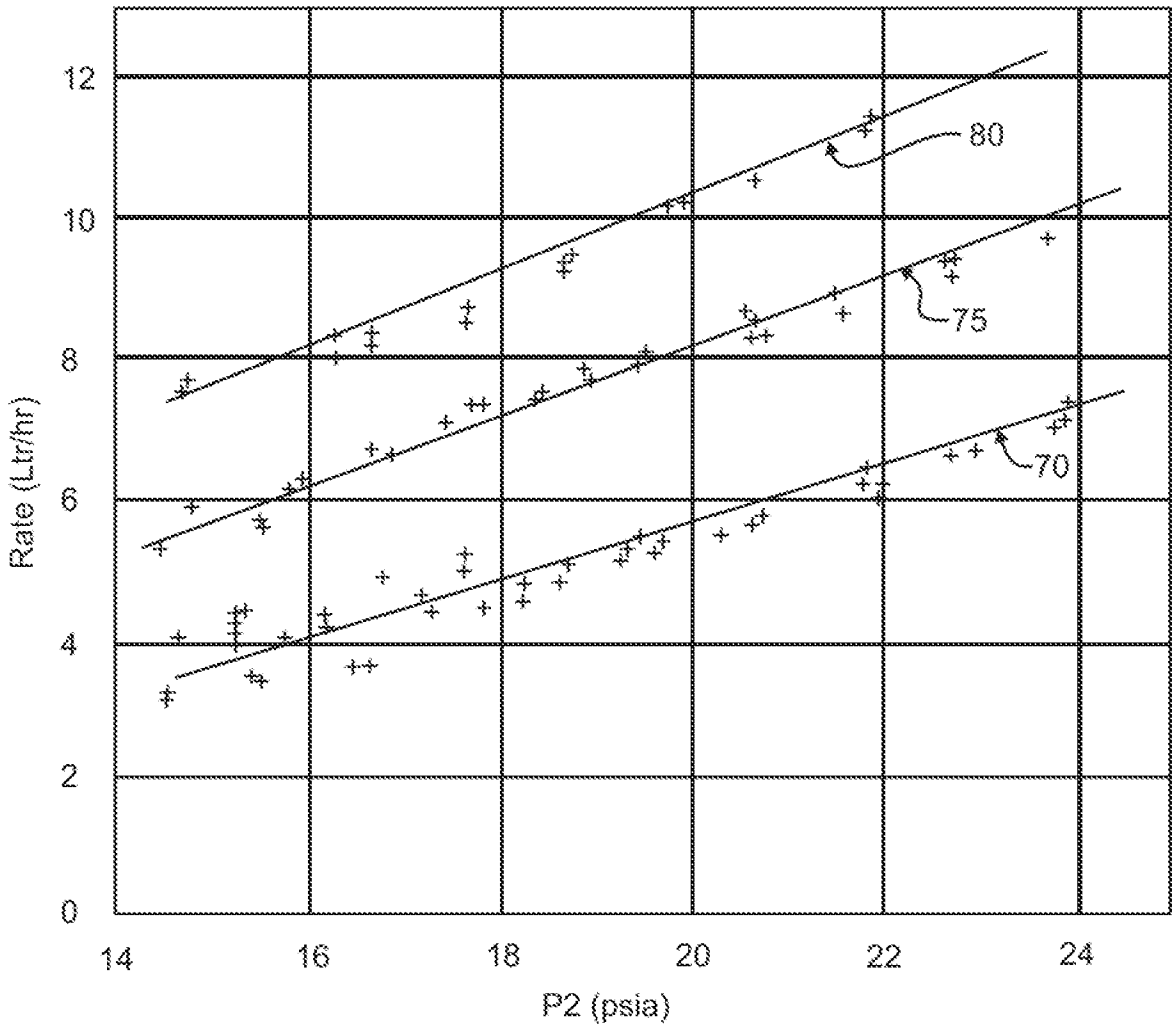



FIG. 7B

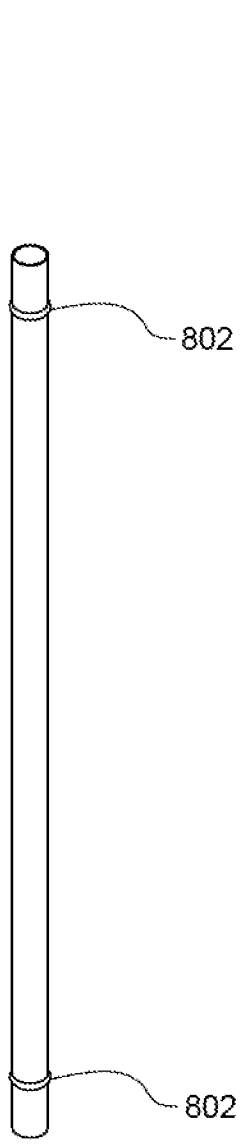



FIG.8

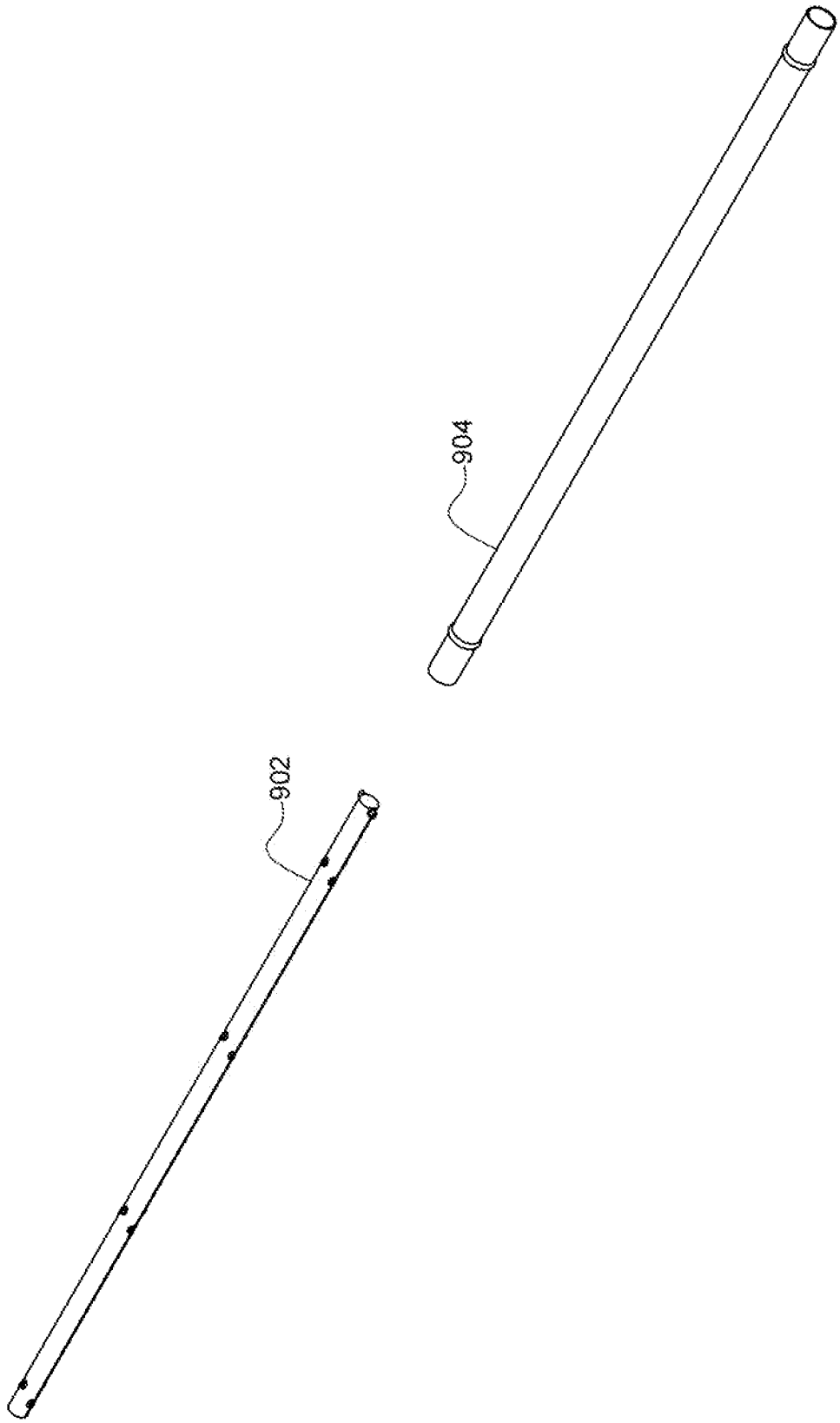



FIG.9

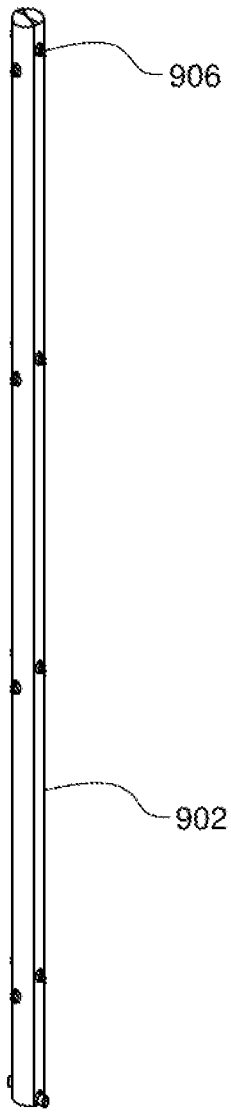



FIG.9A

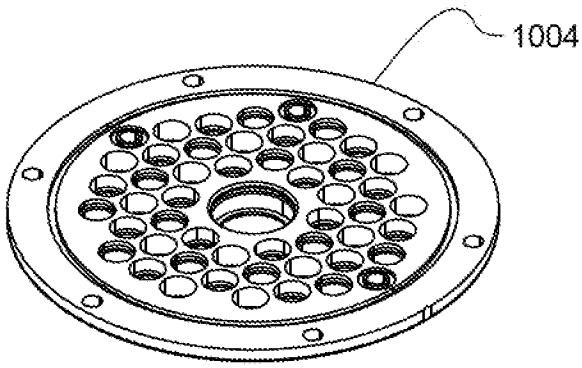



FIG.10A

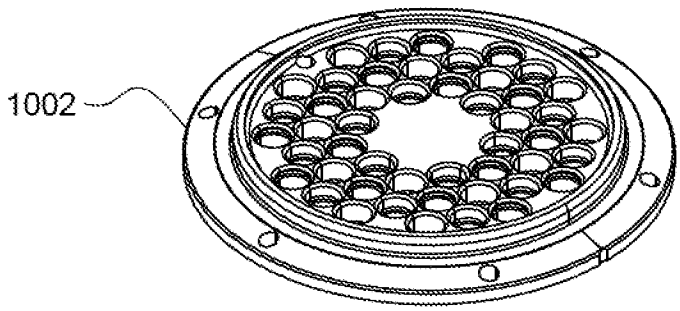



FIG.10

1100

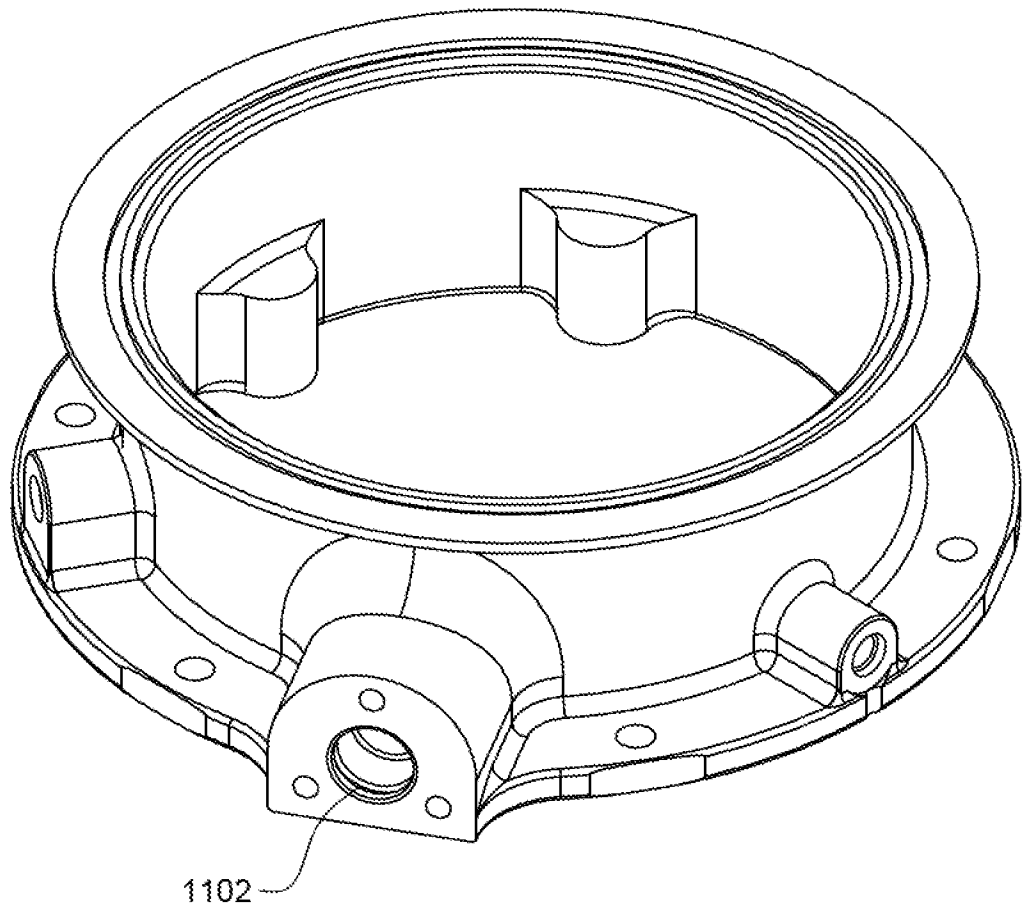



FIG.11

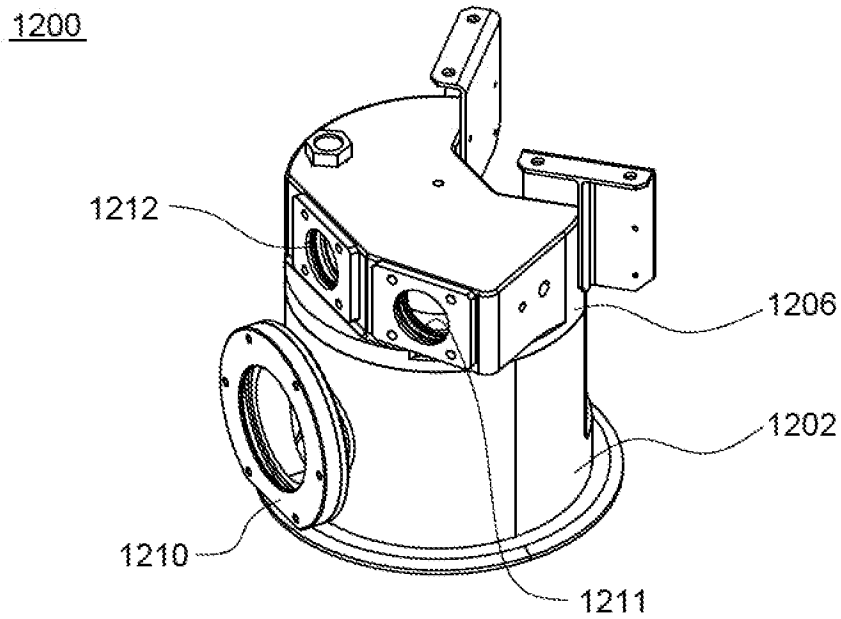



FIG. 12A

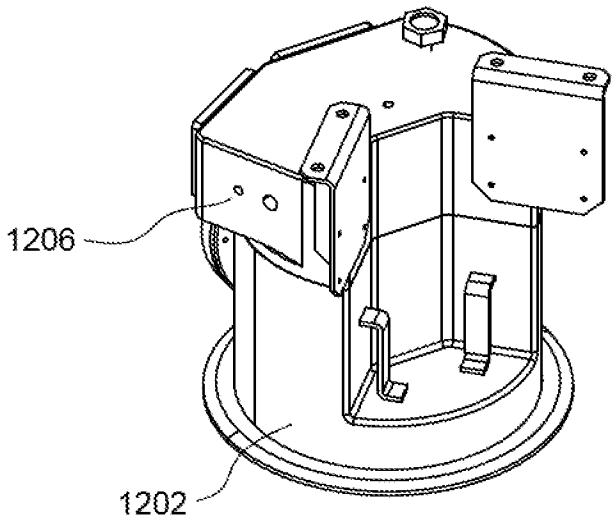



FIG. 12

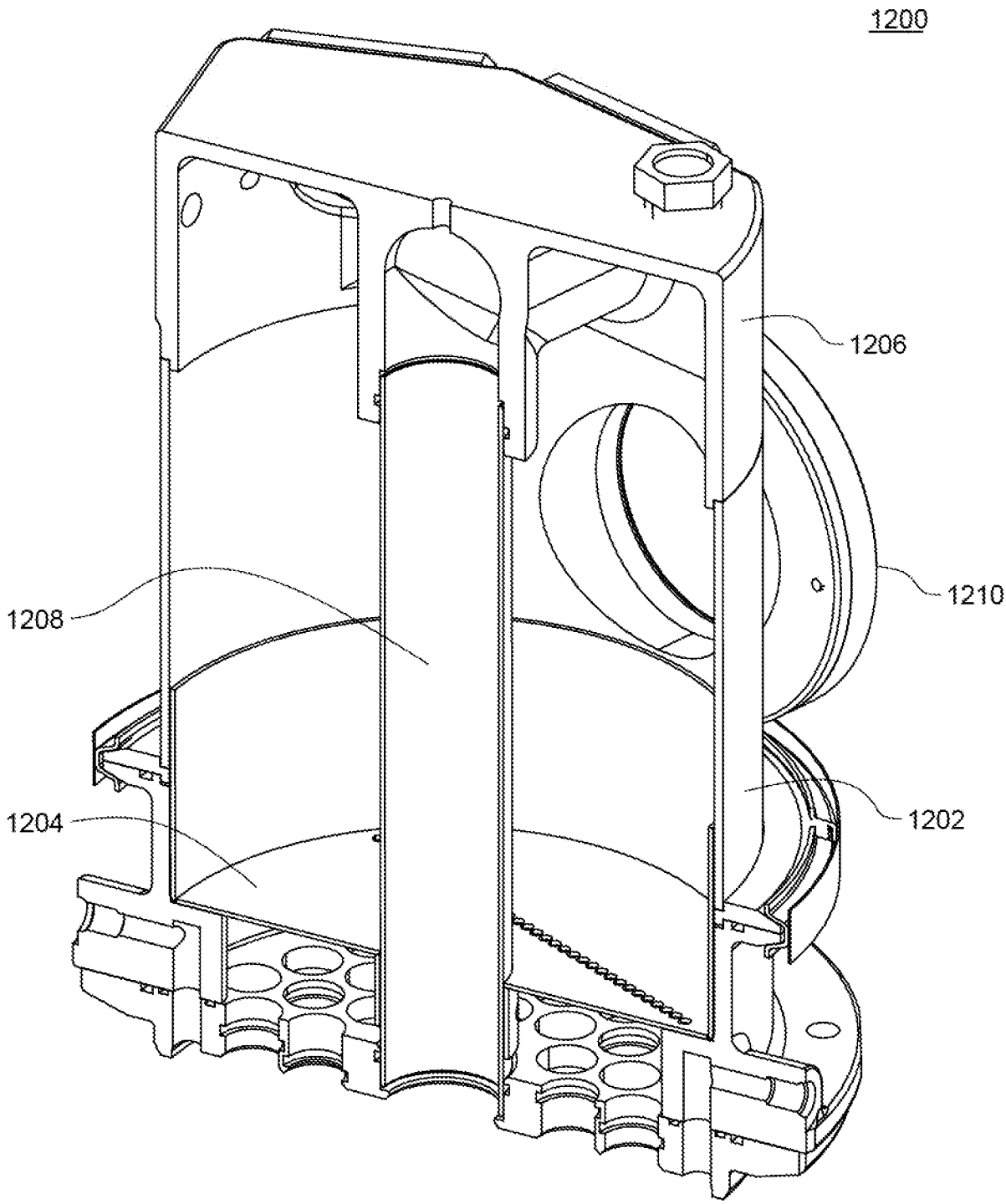



FIG.12B

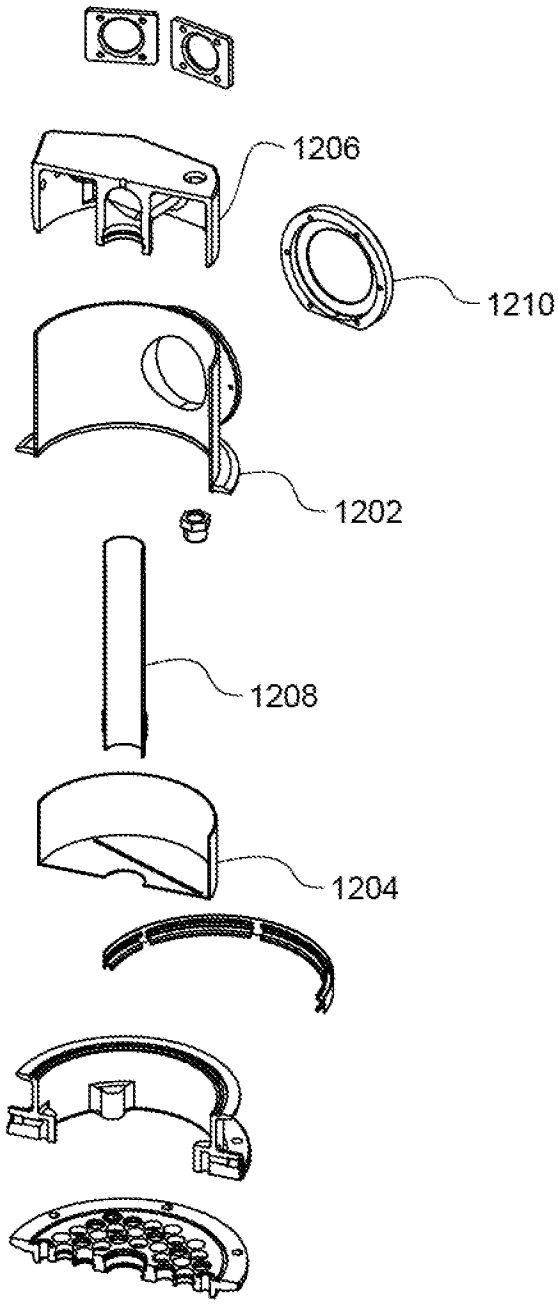



FIG.12C

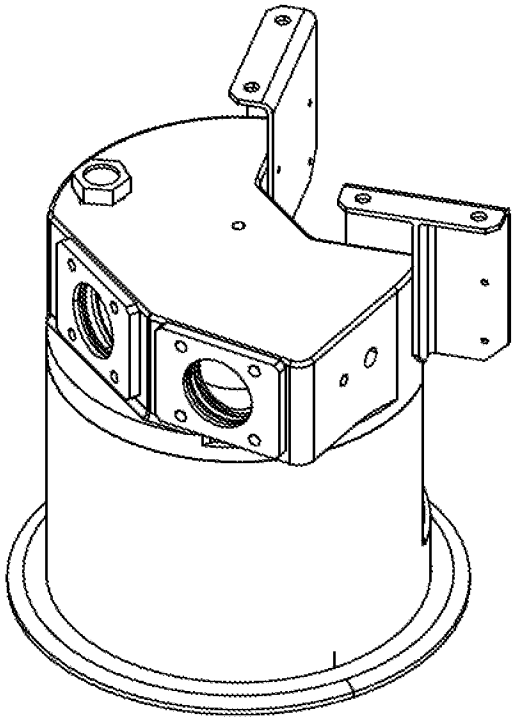
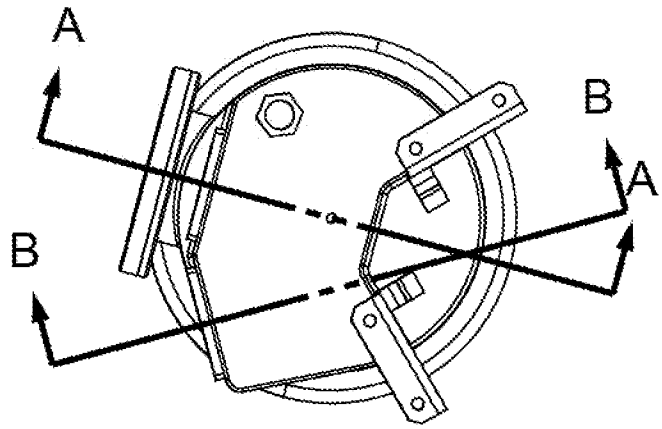


FIG.12D



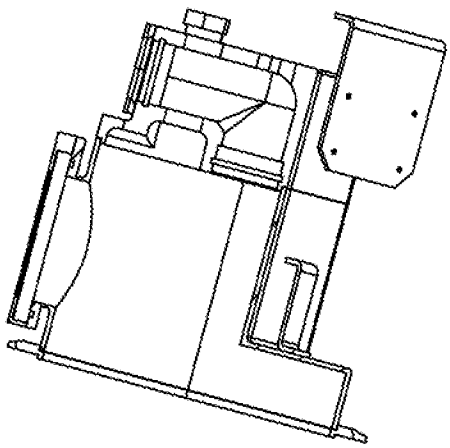



FIG. 12E

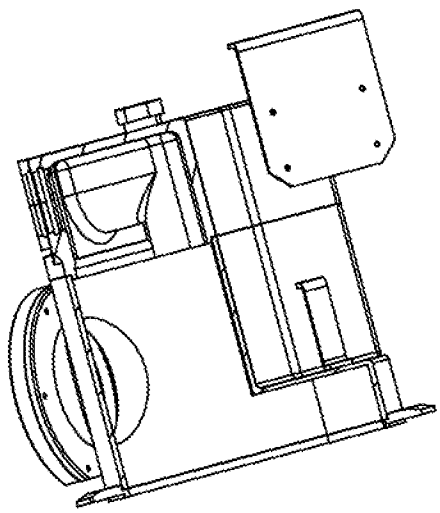


FIG. 12F

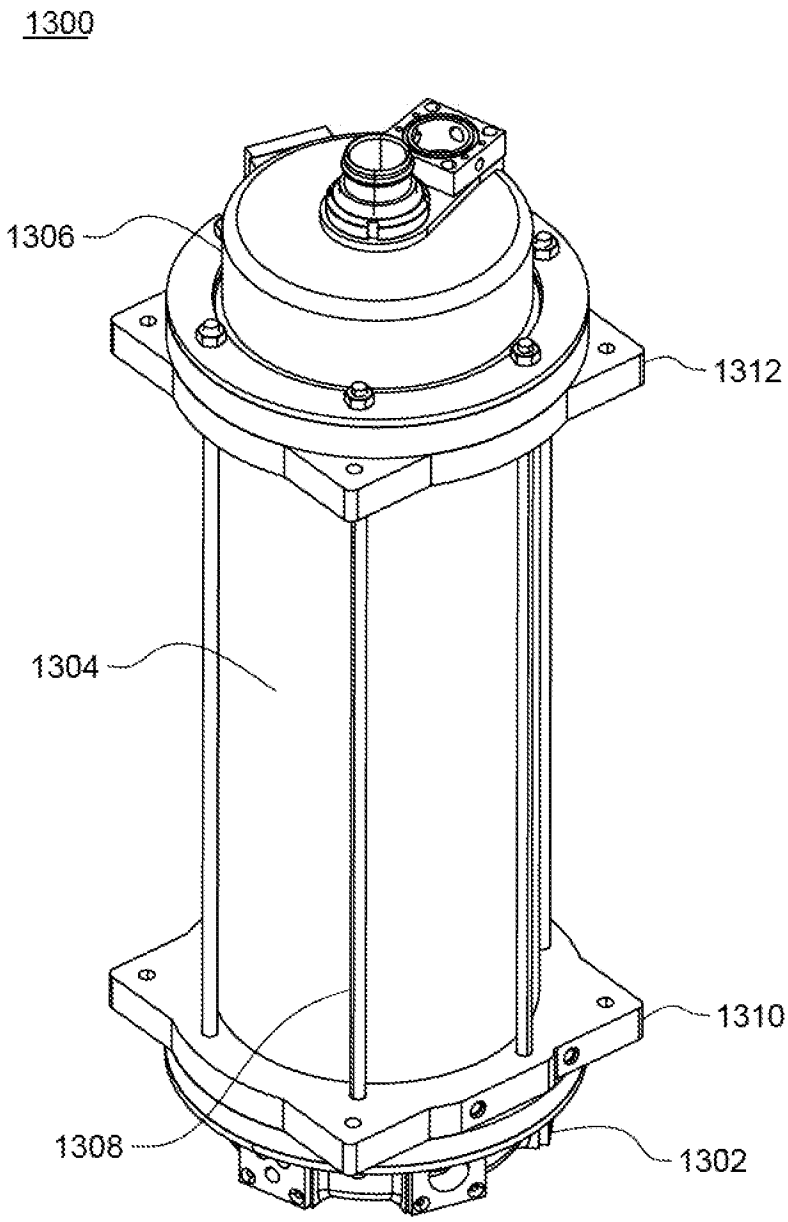



FIG.13

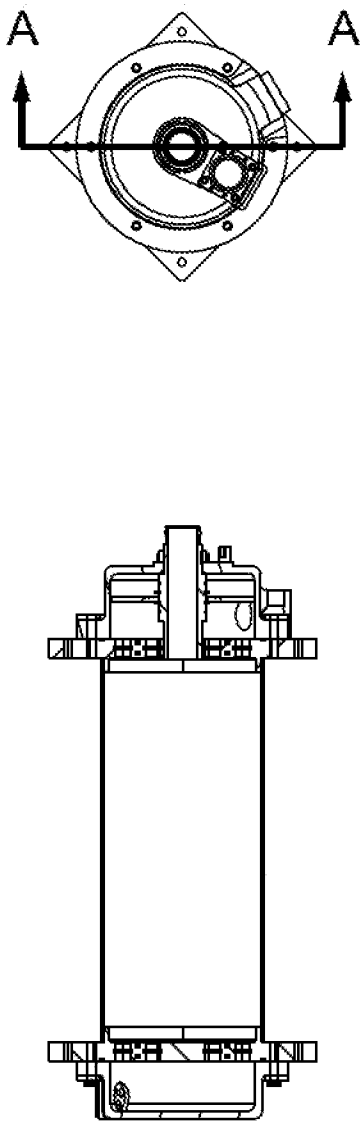



FIG. 13A

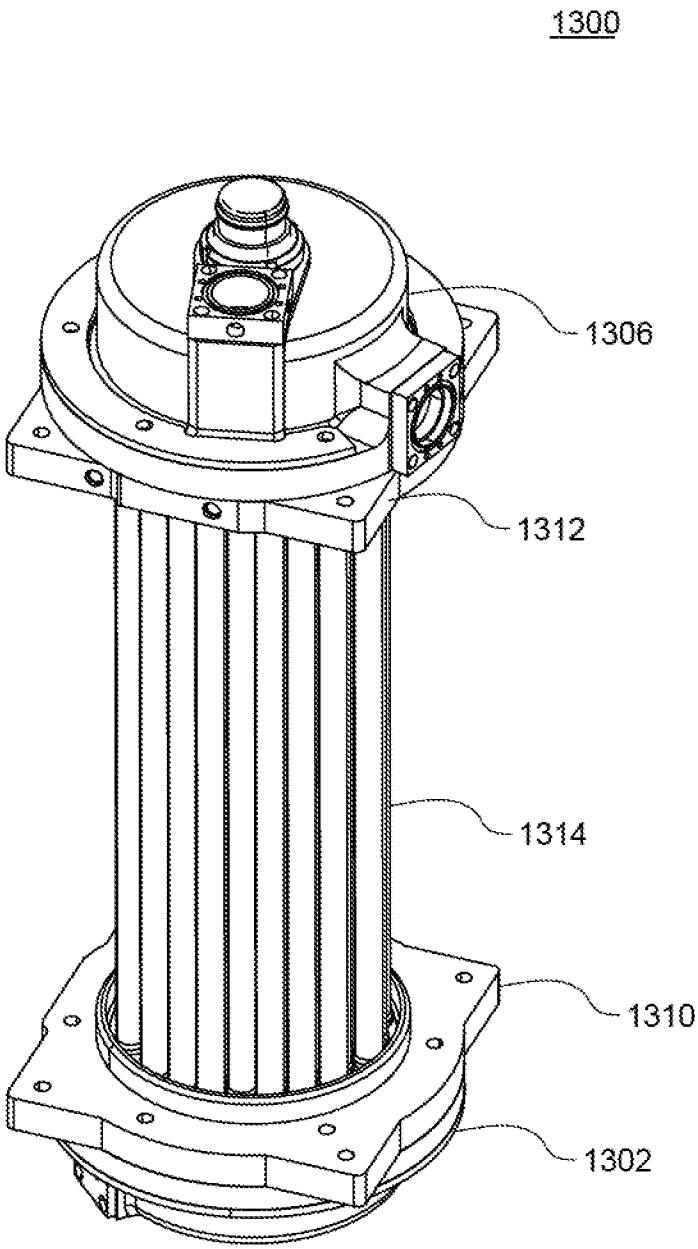



FIG.13B

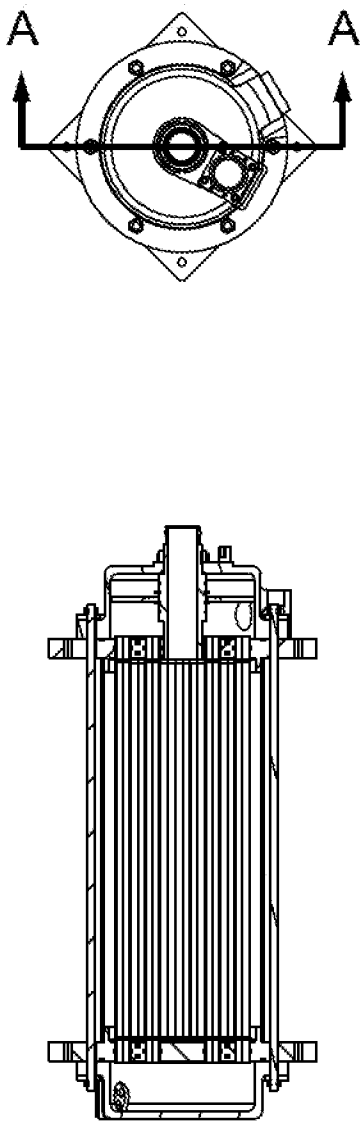



FIG.13C

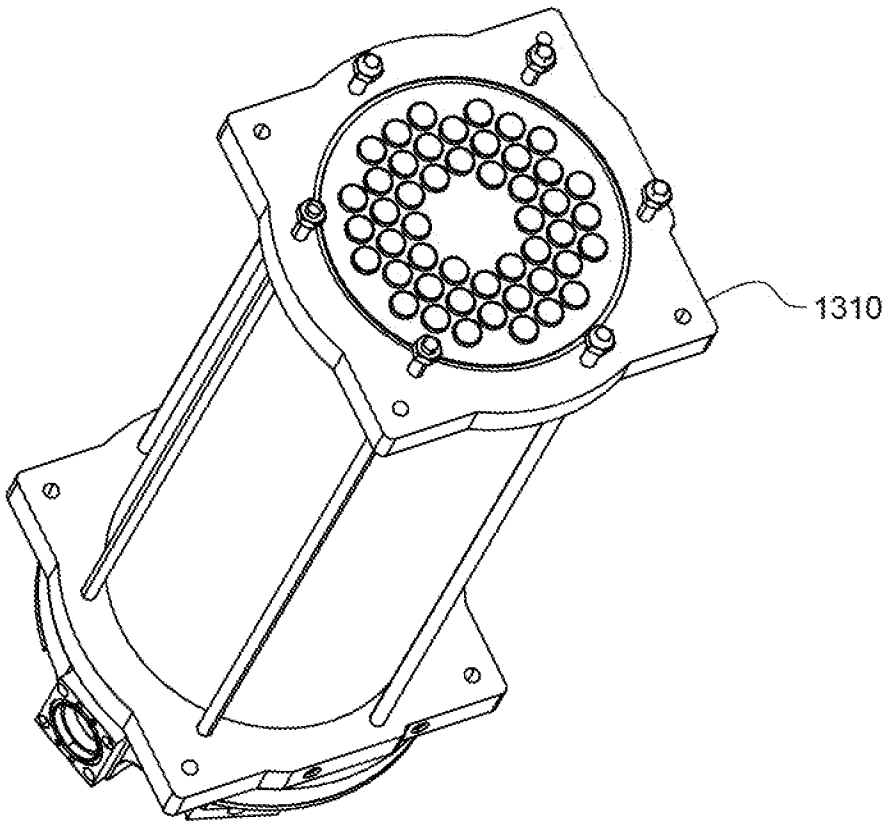



FIG.13D

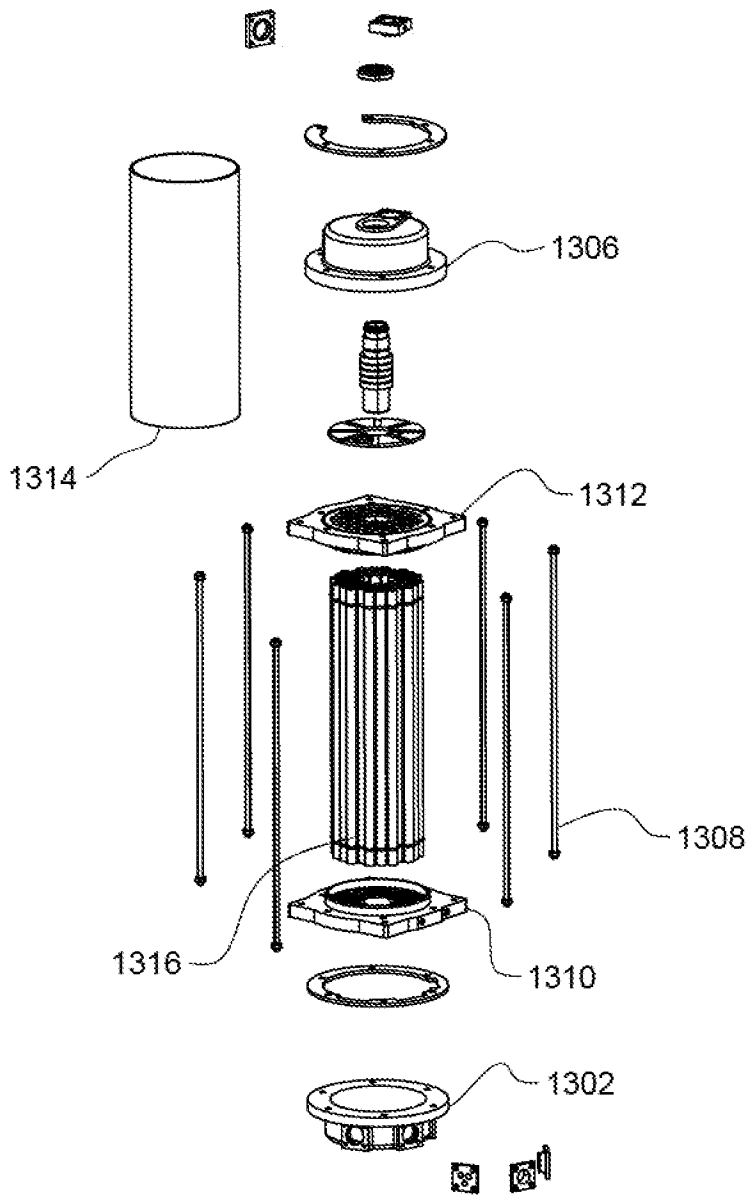



FIG.13E

1400

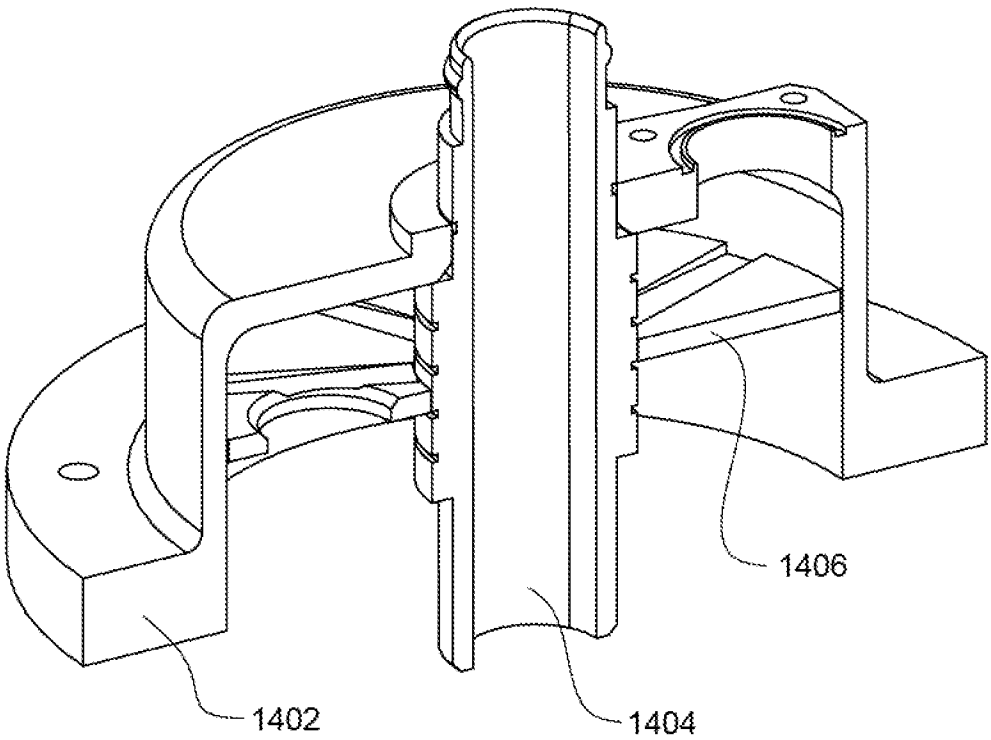



FIG.14

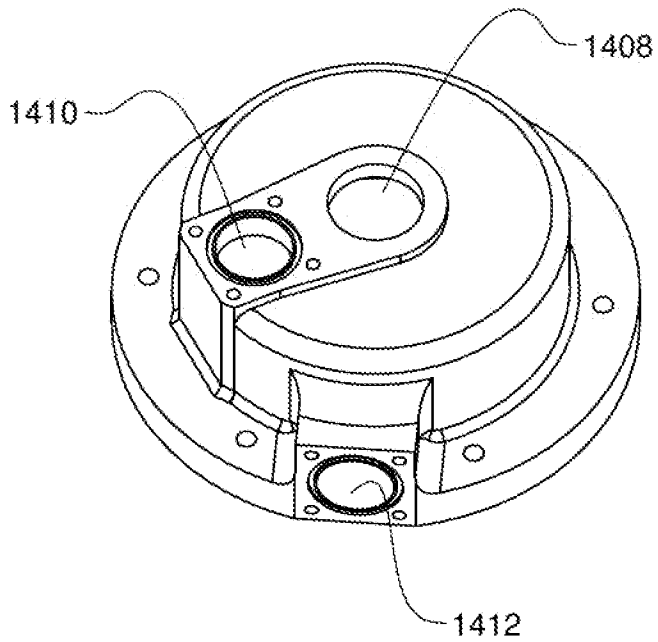



FIG.14A

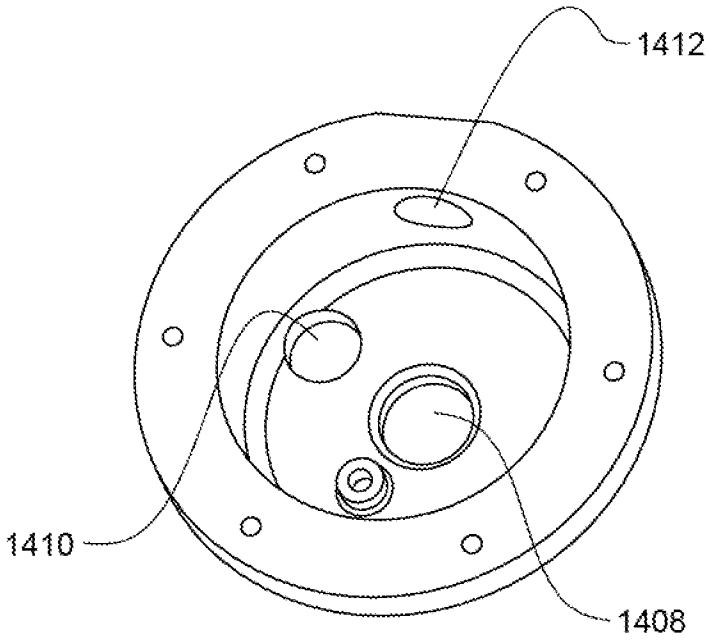



FIG.14B

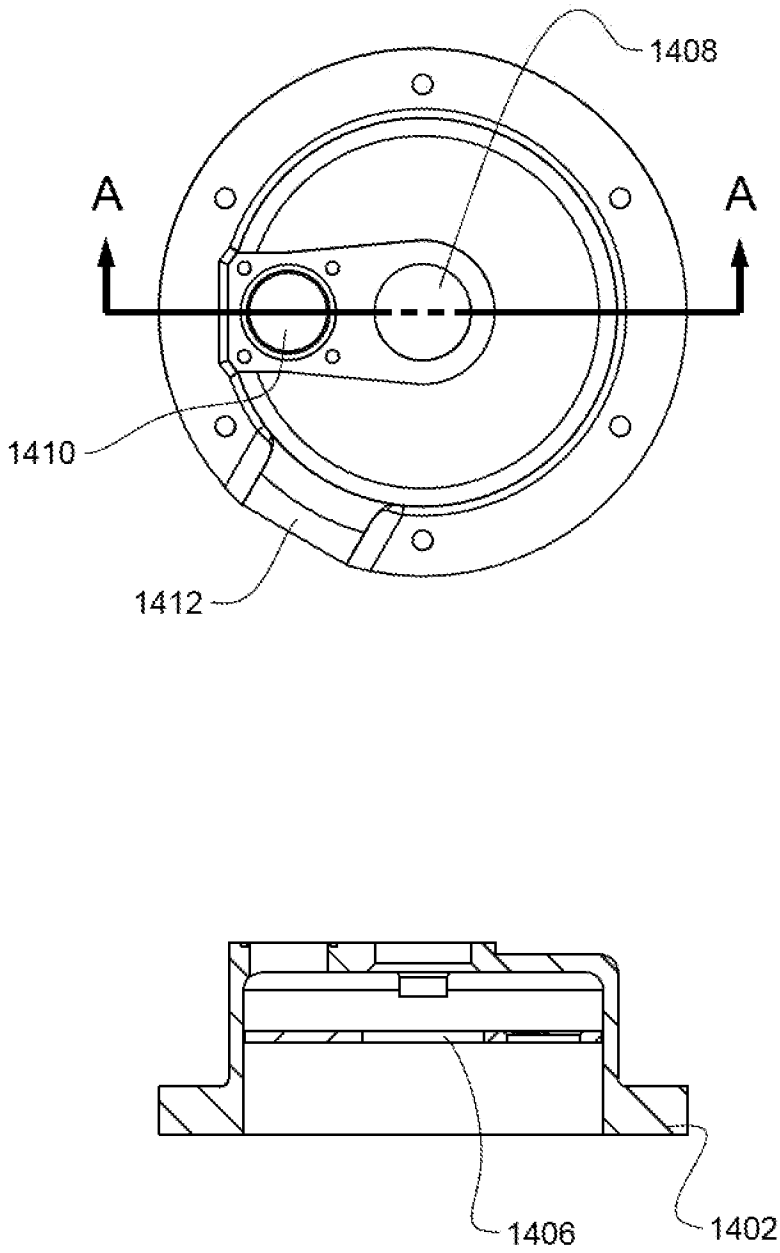



FIG.14C

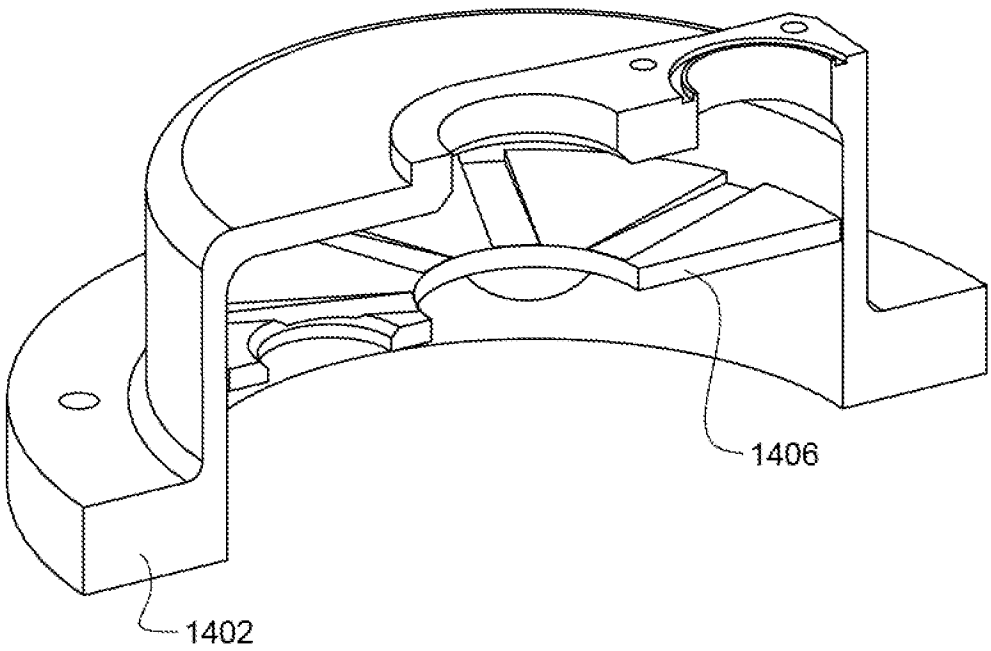



FIG.14D

1500

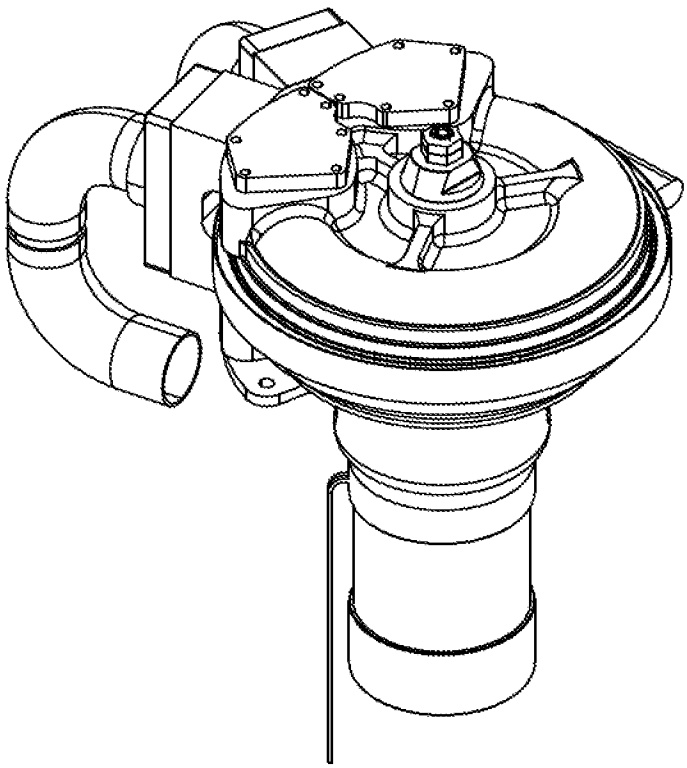


FIG.15

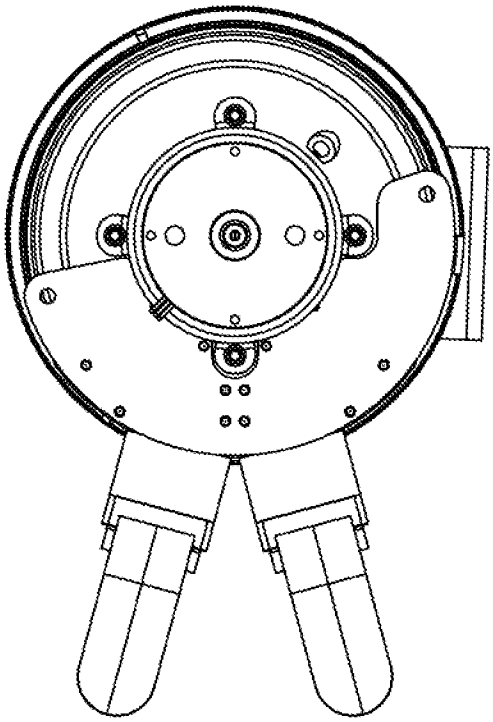


FIG.15A

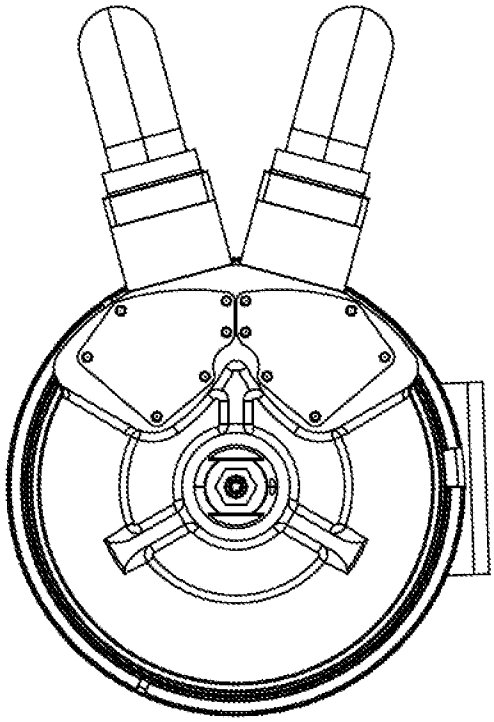


FIG.15B

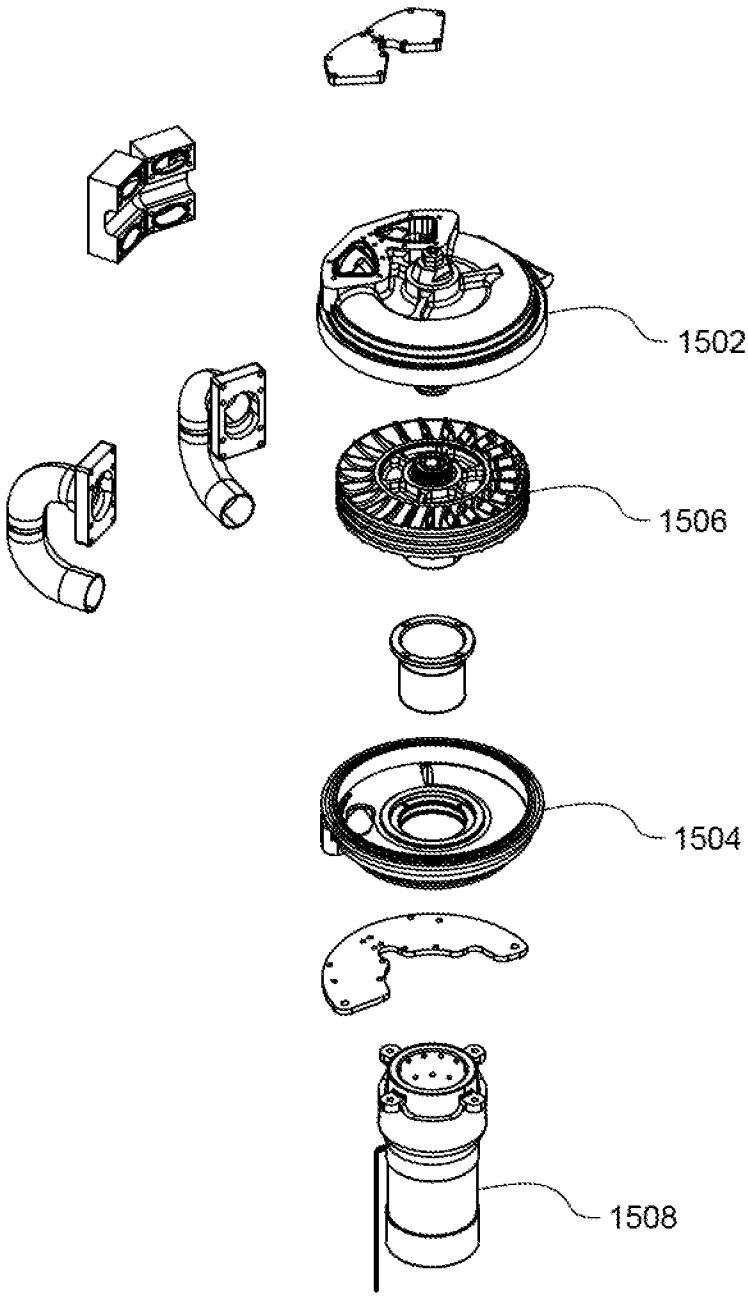



FIG.15C

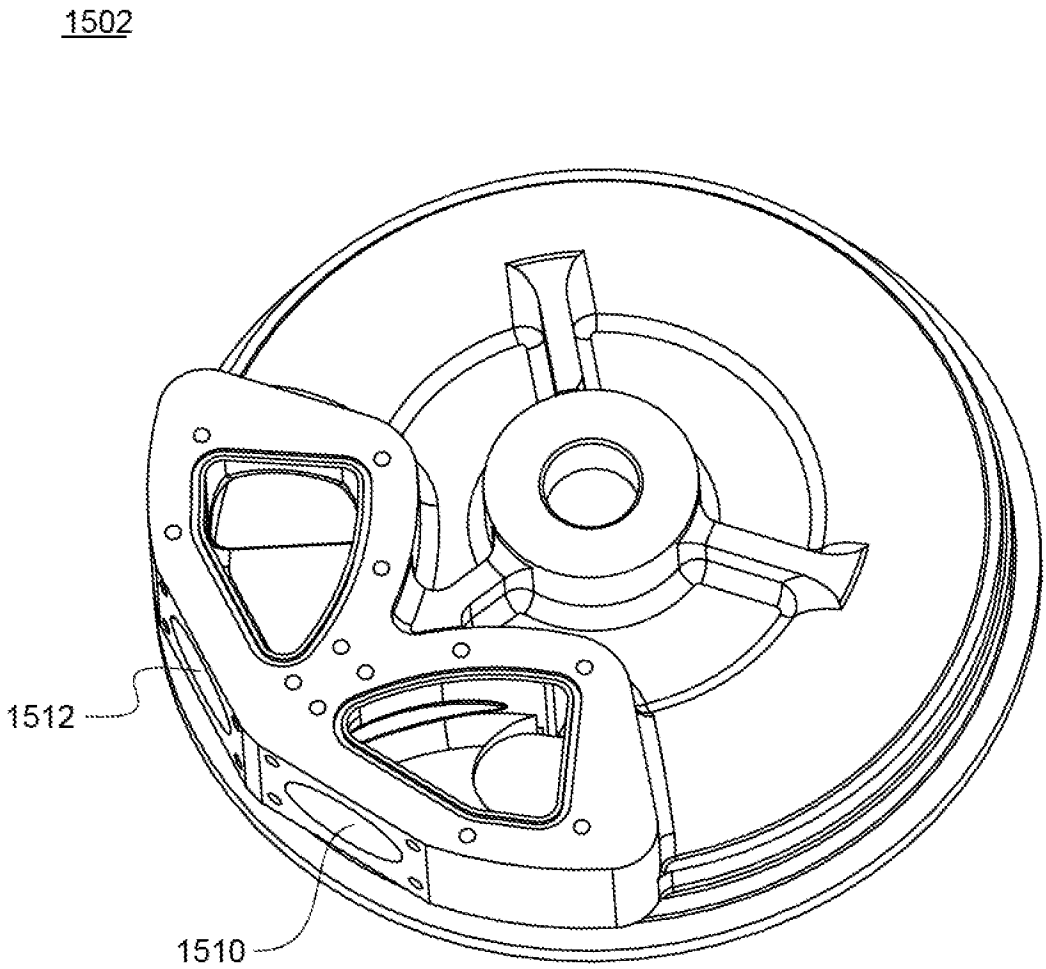



FIG.15D

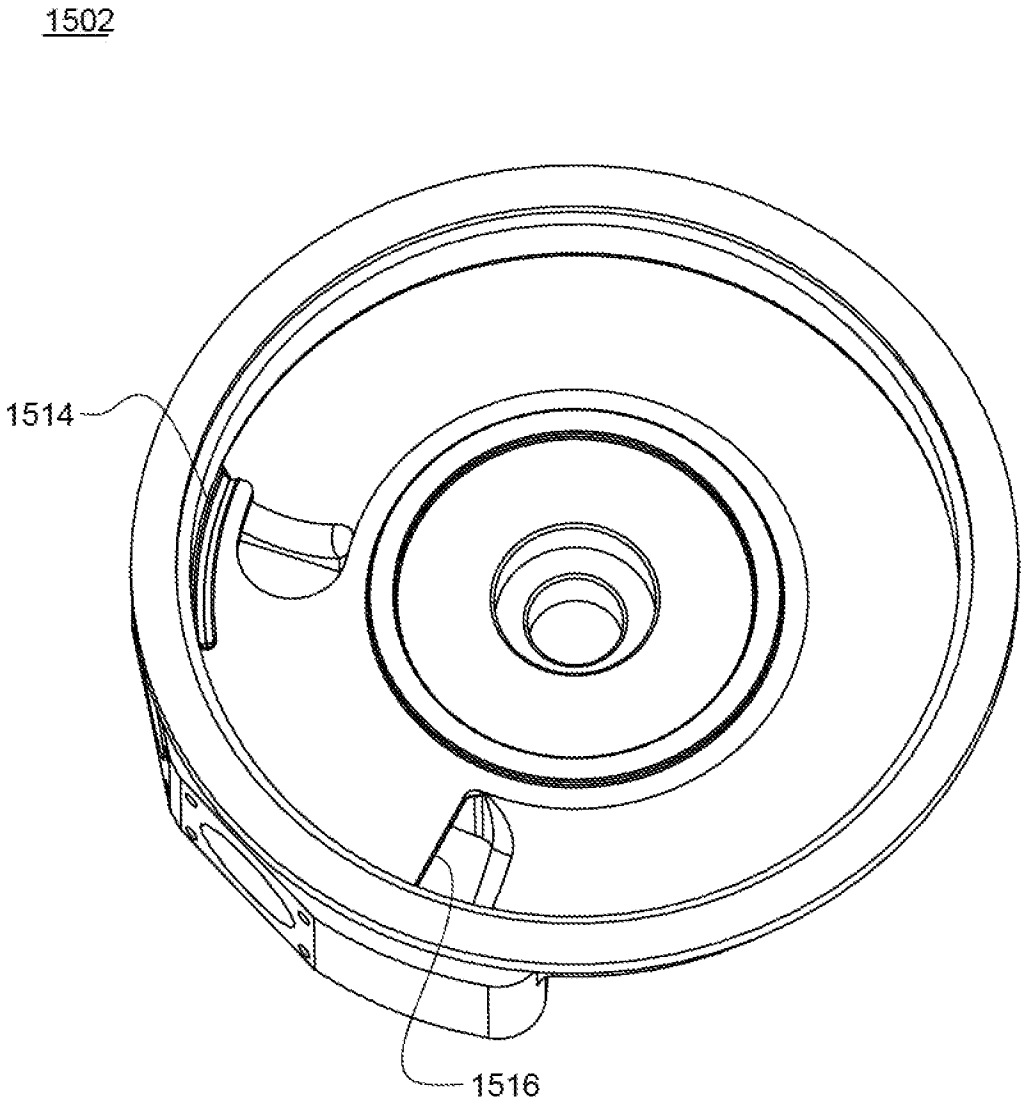



FIG.15E

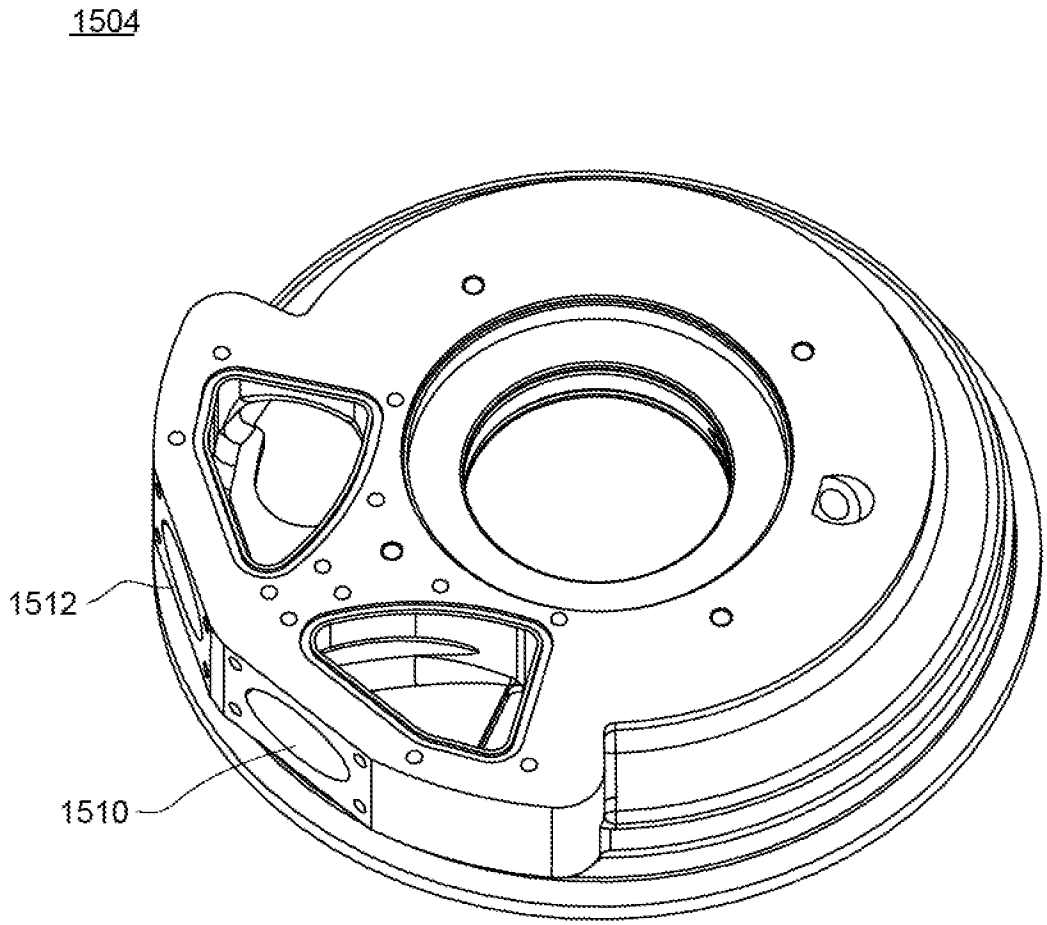



FIG.15F

1504

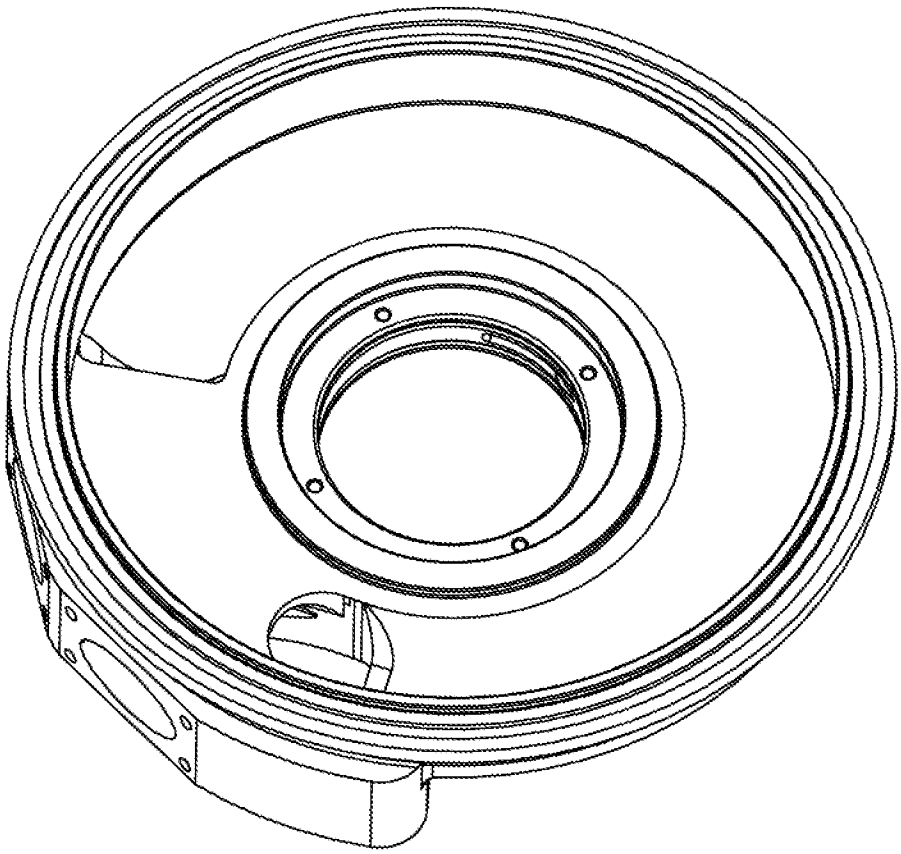


FIG.15G

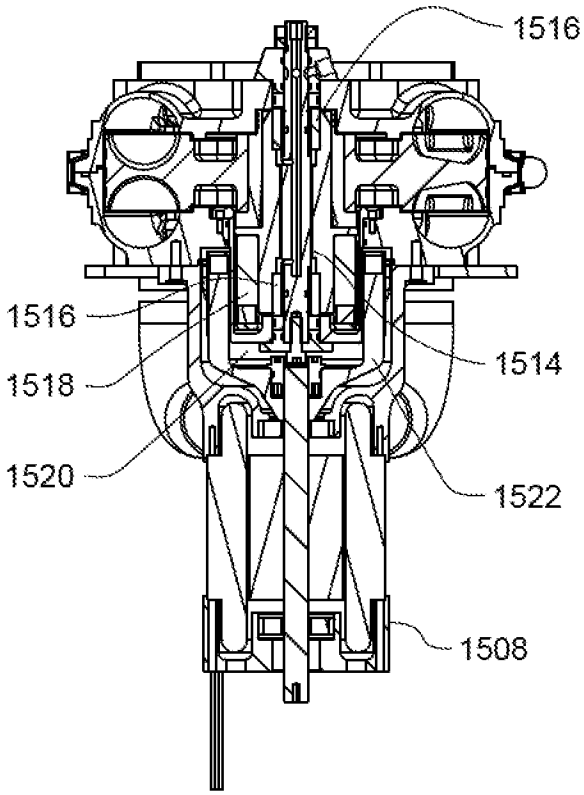



FIG.15H

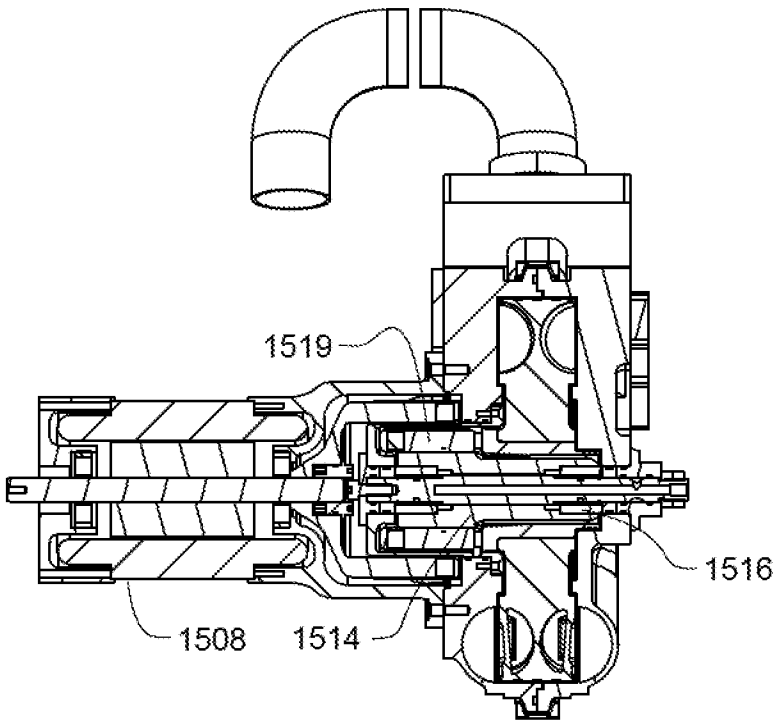
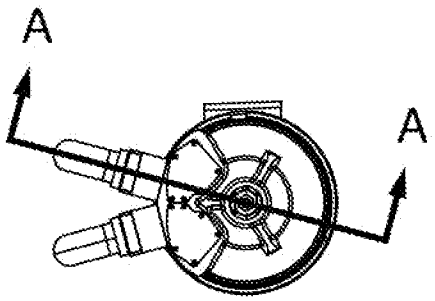



FIG.15I



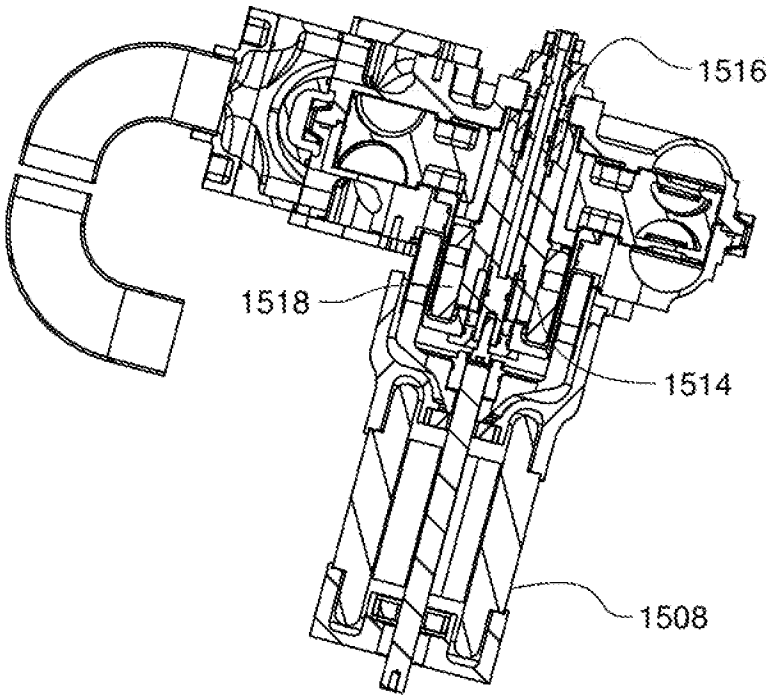




FIG.15J

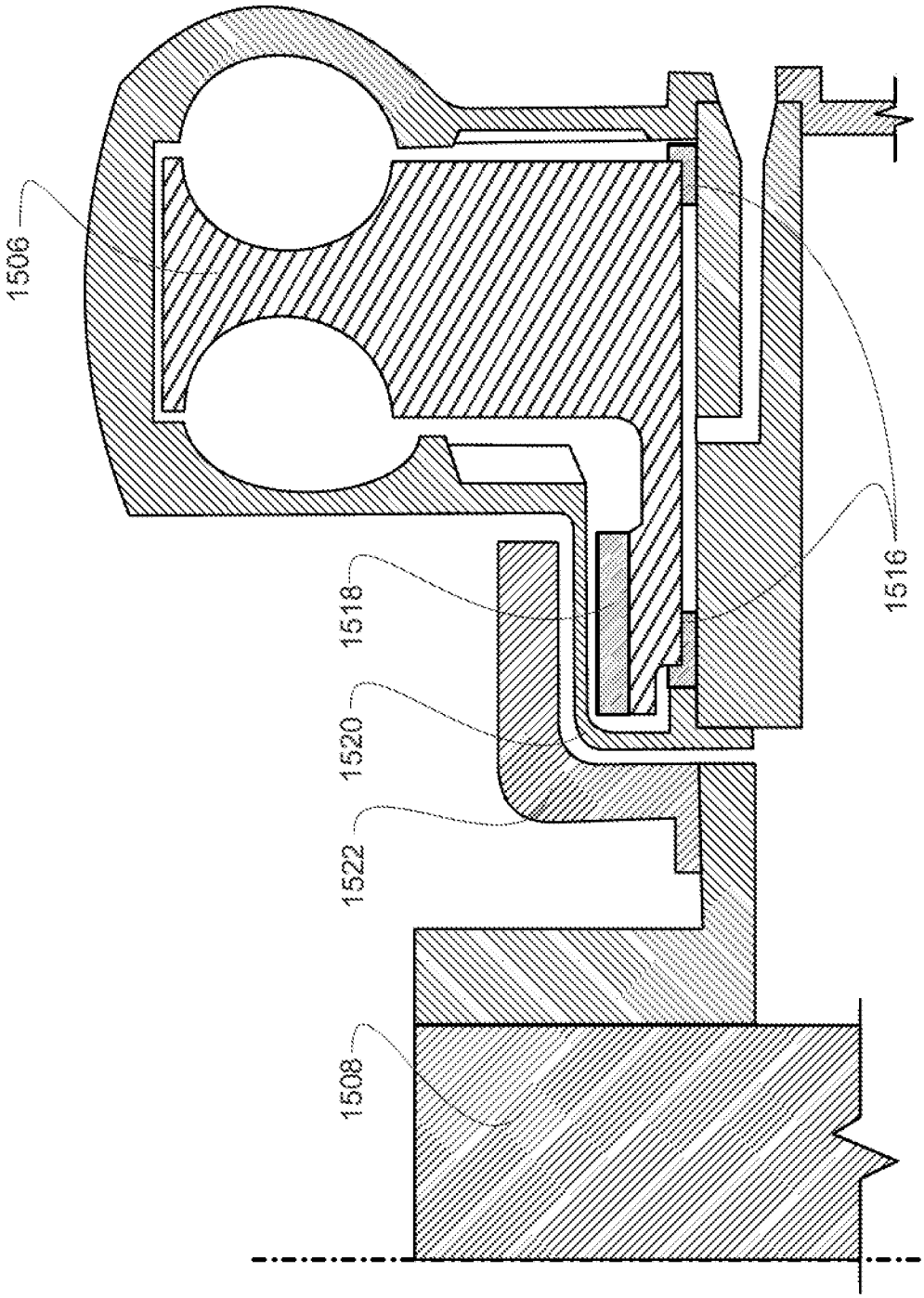



FIG. 15K

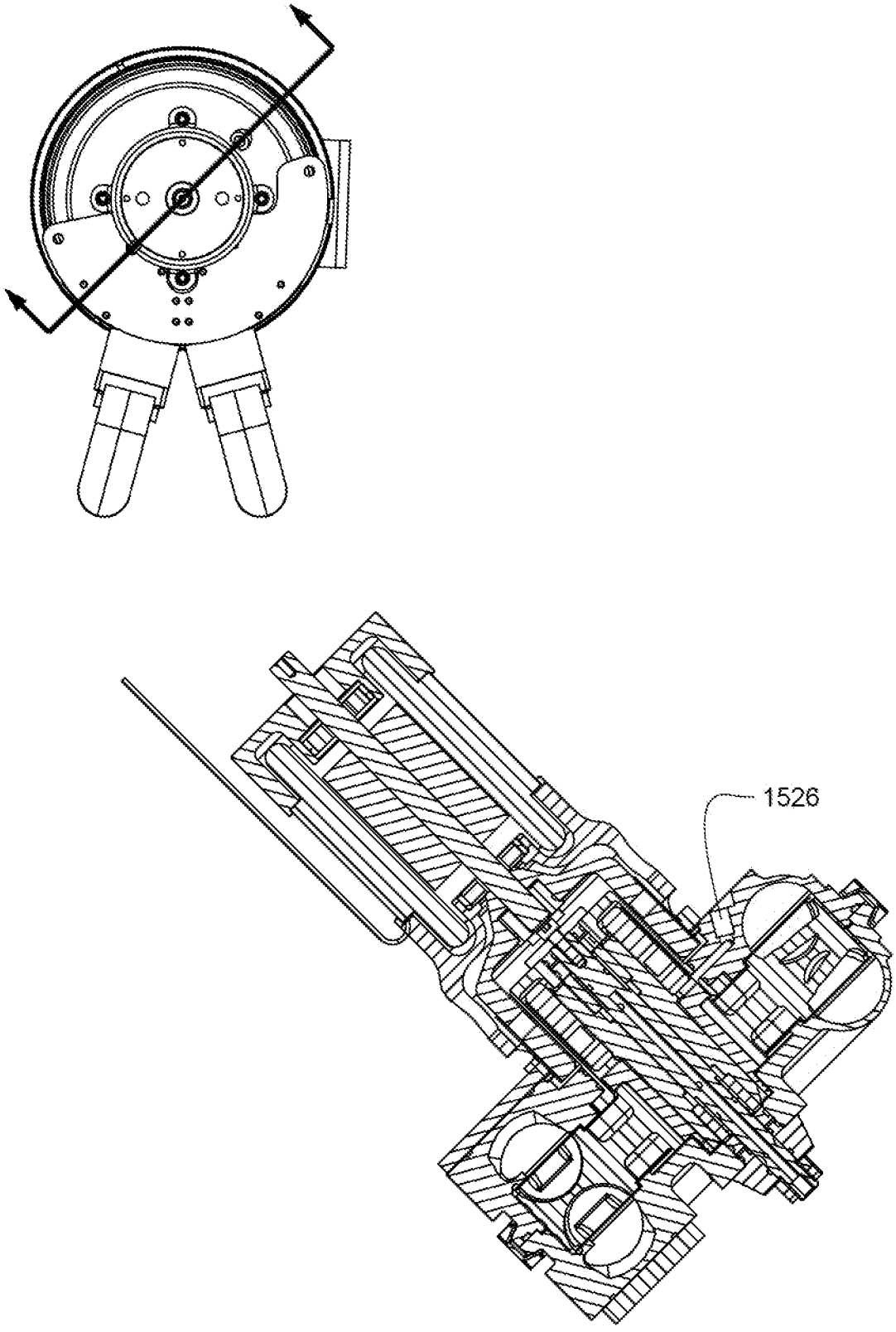



FIG.15L

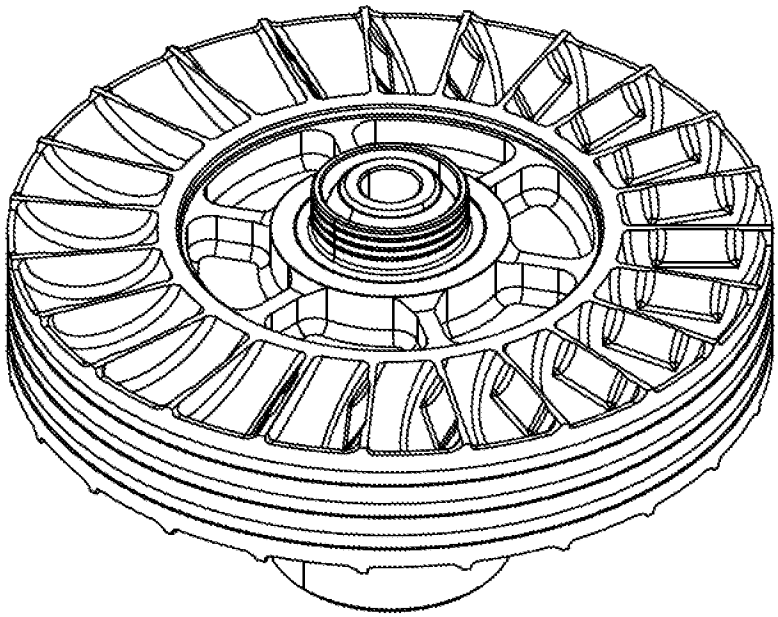


FIG.16

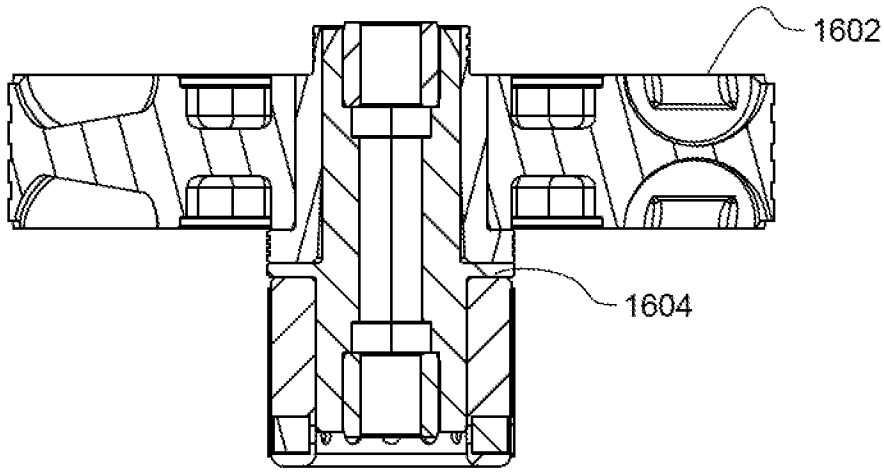



FIG.16A

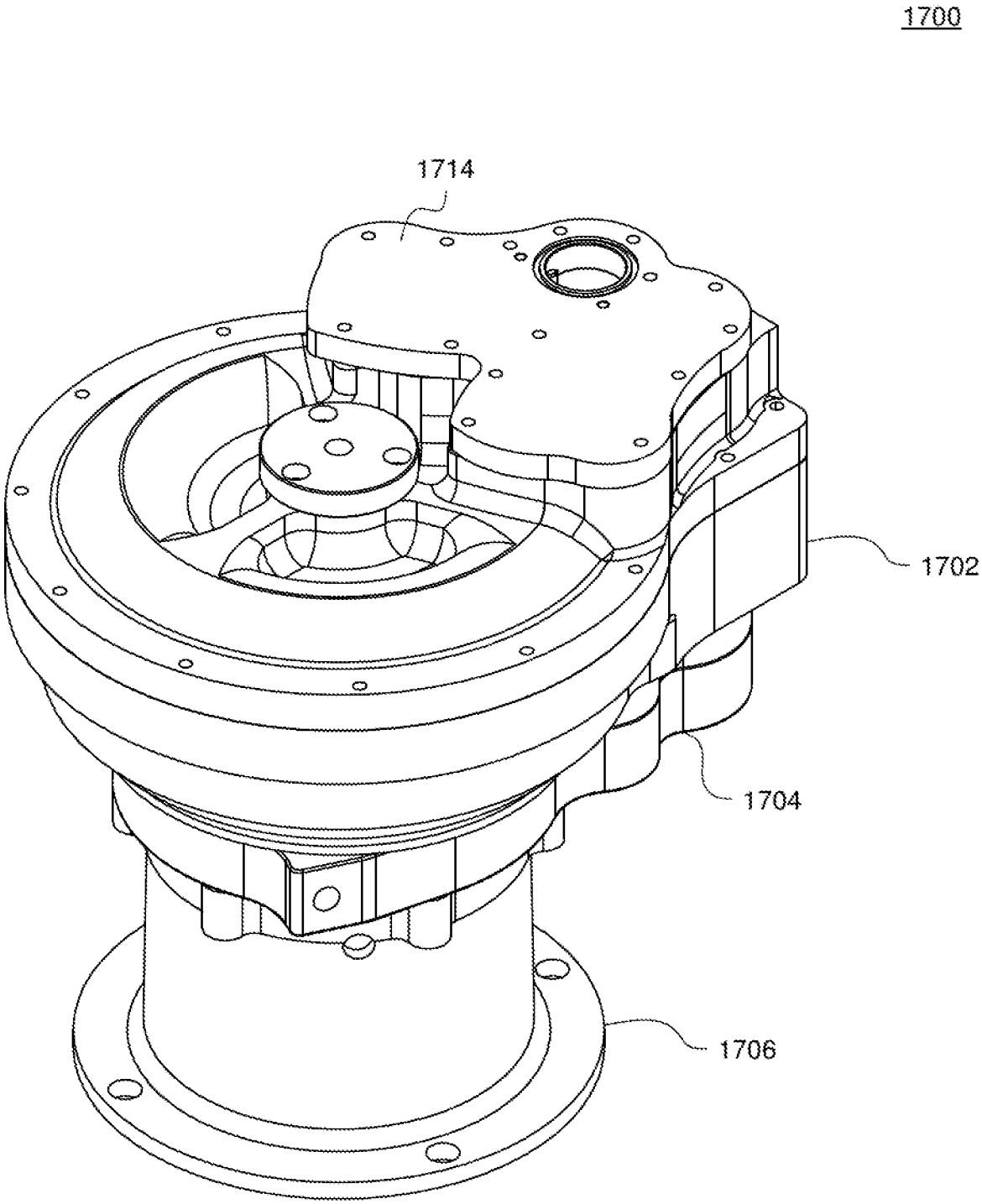



FIG.17

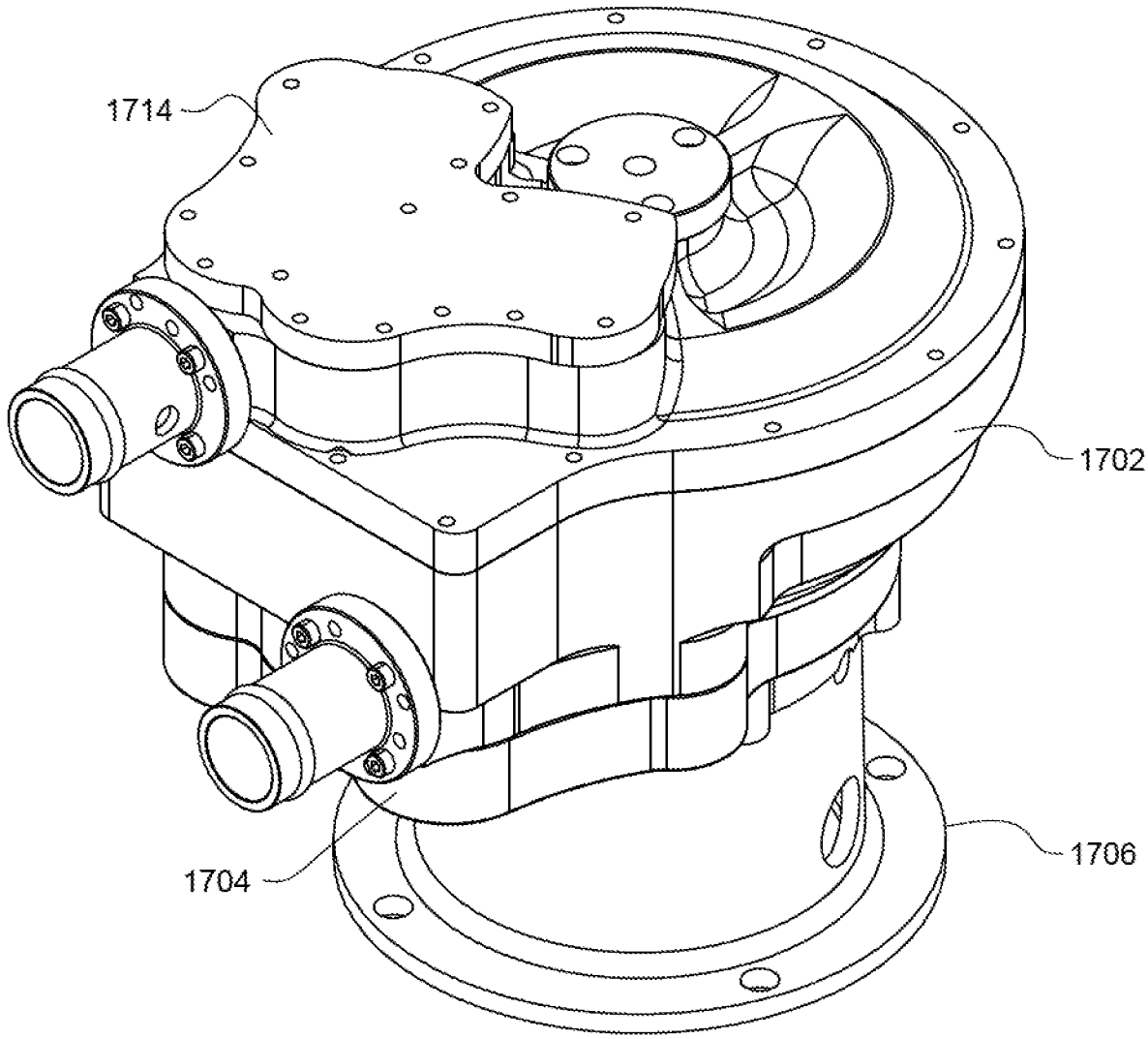



FIG.17A

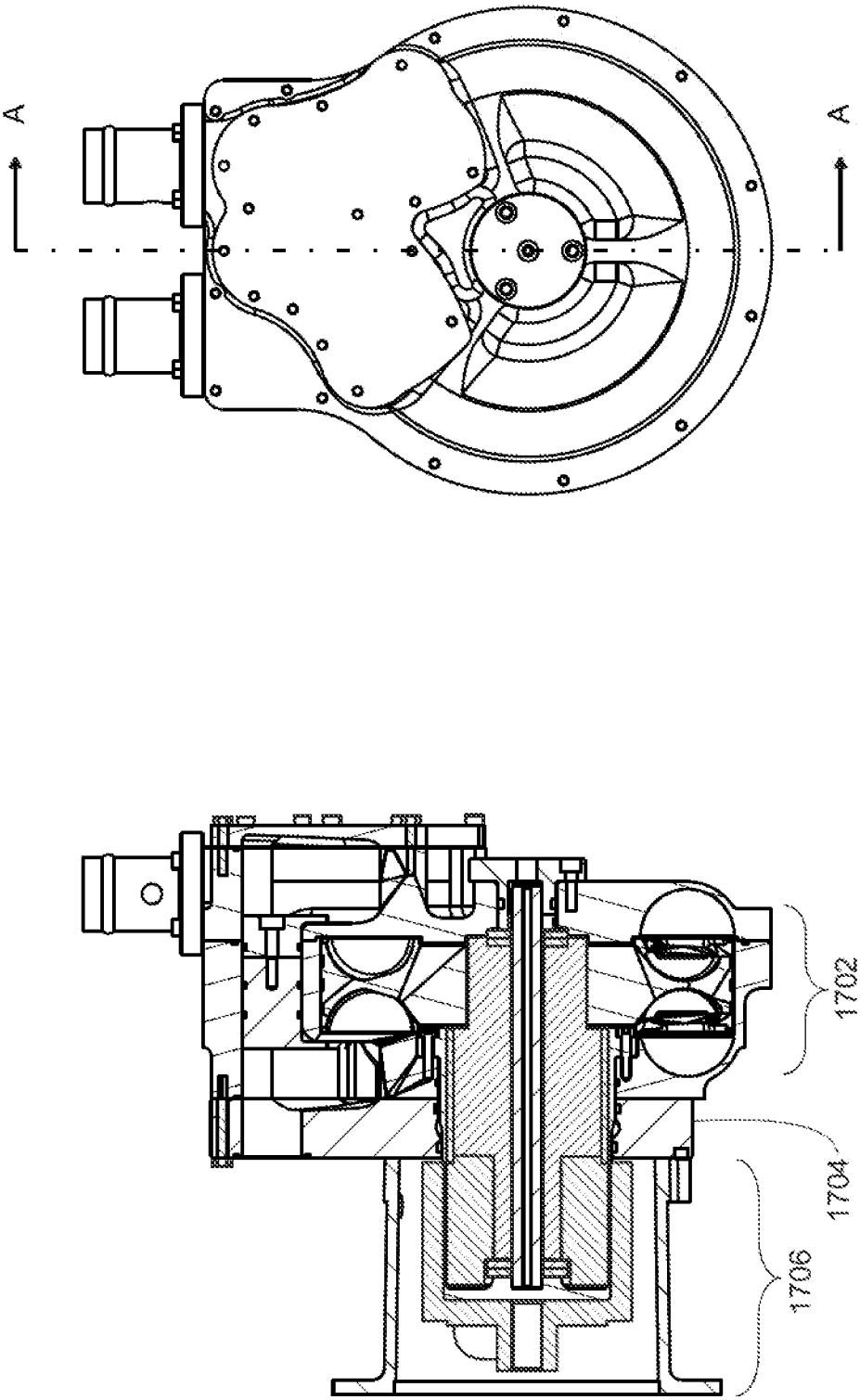



FIG. 17B

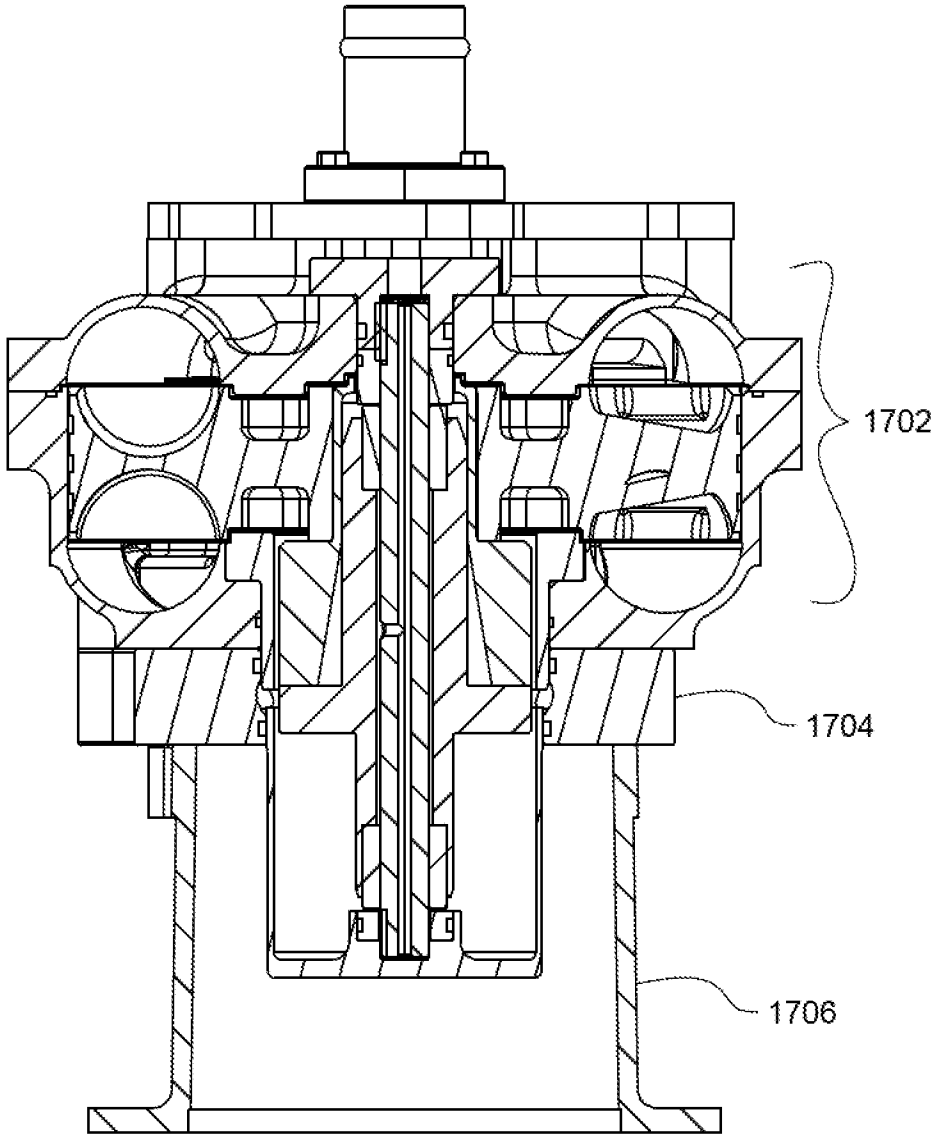



FIG.17C

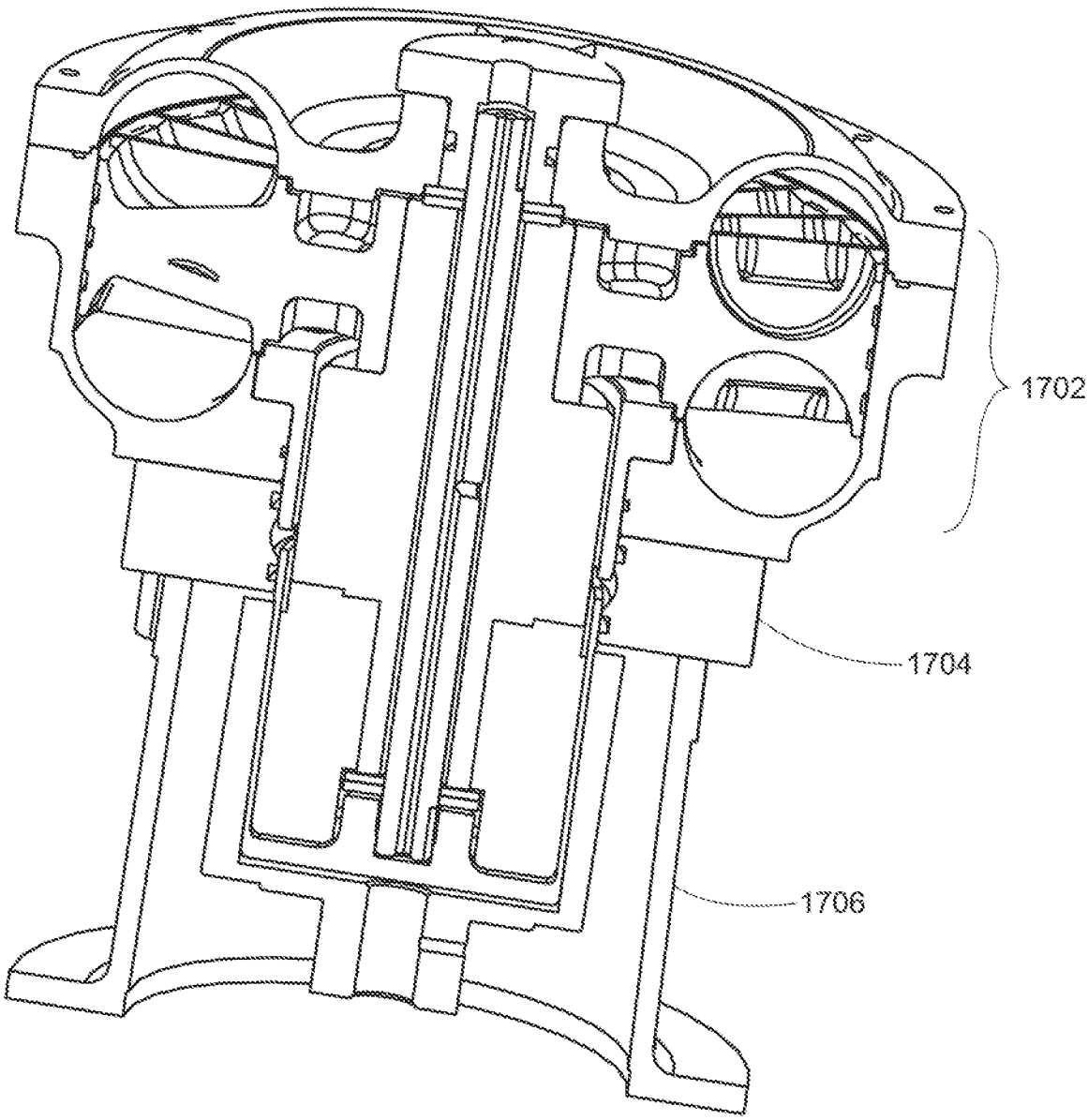



FIG. 17D

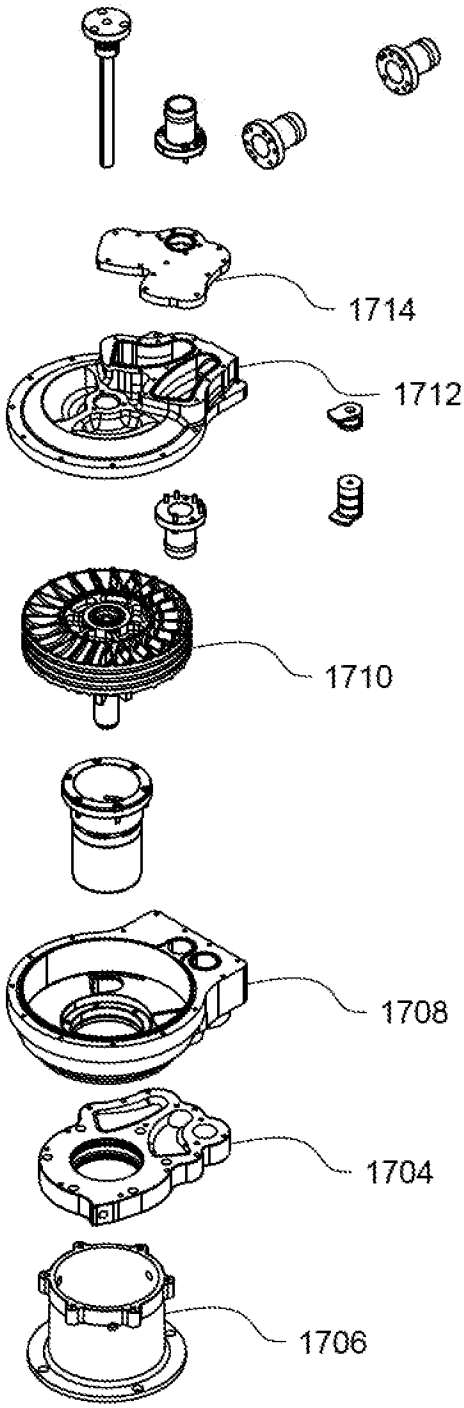



FIG.17E

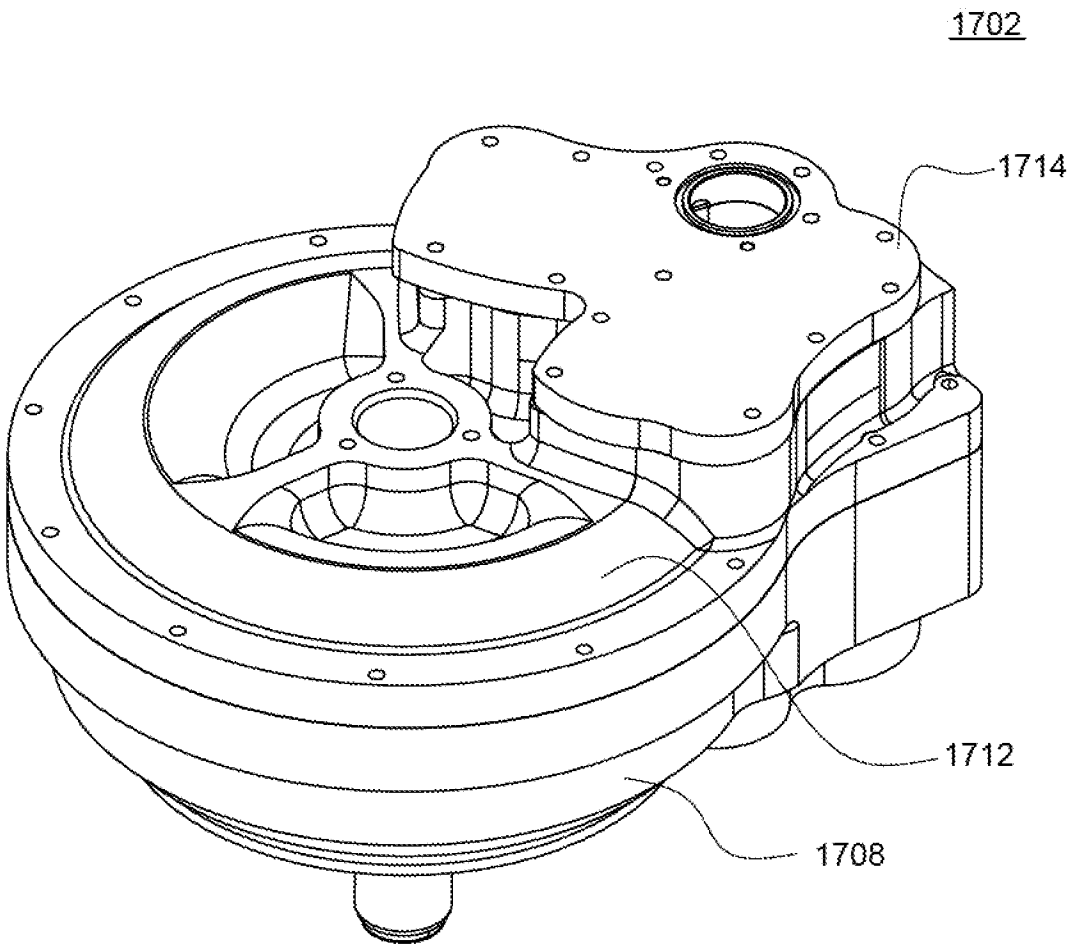



FIG. 17F

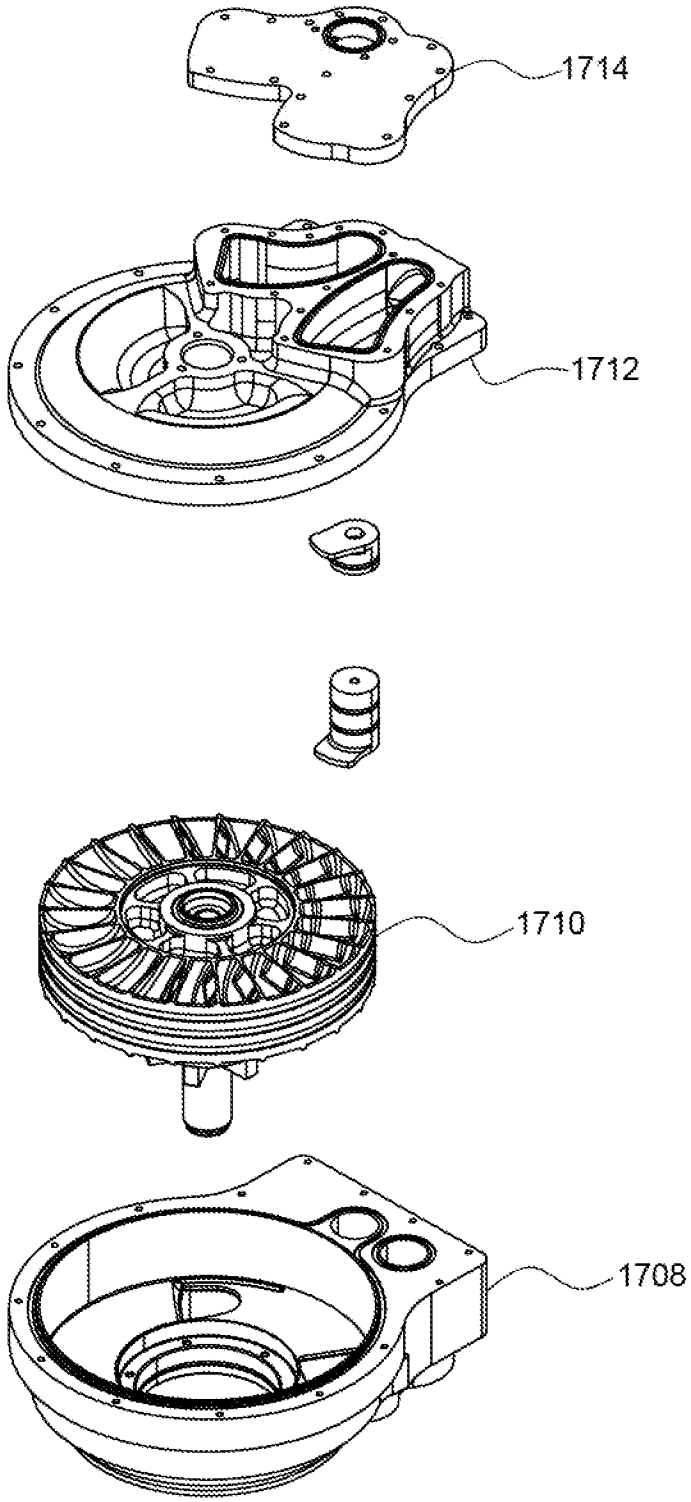



FIG. 17G

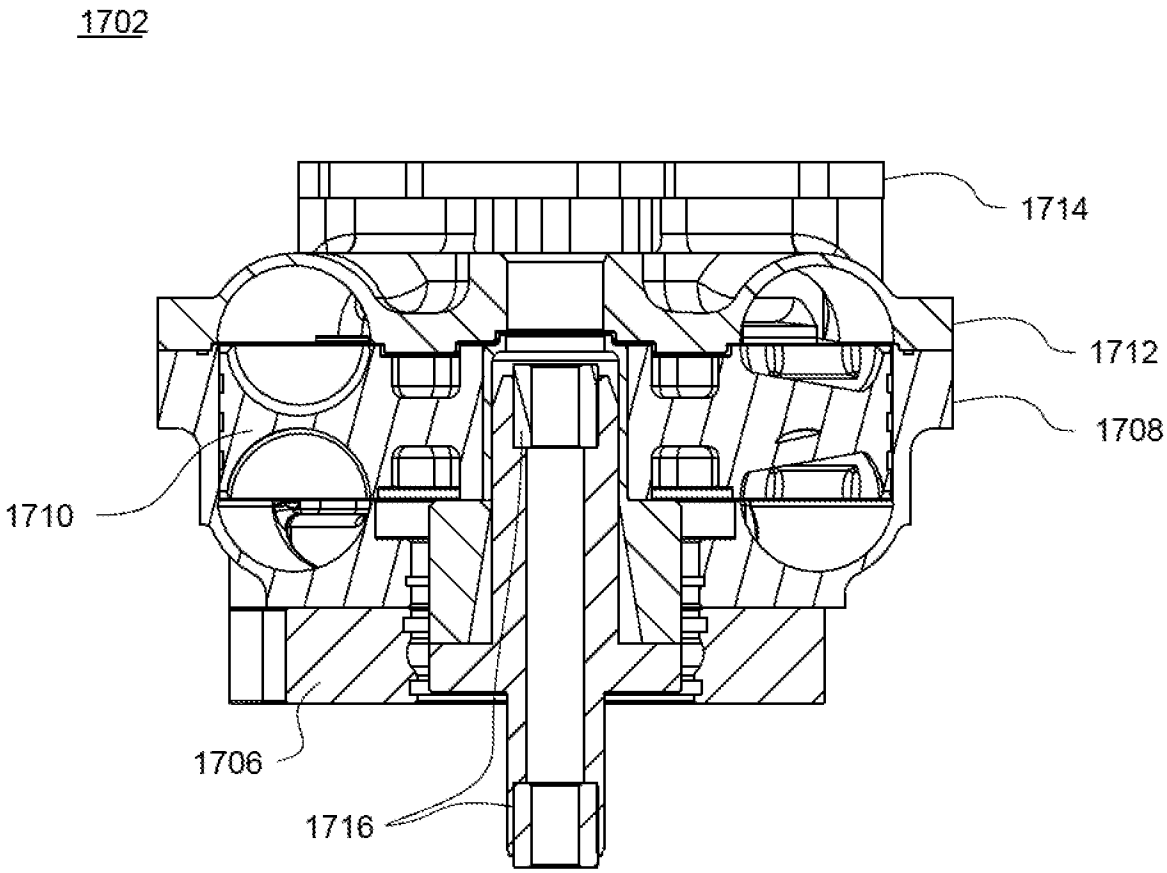



FIG.17H

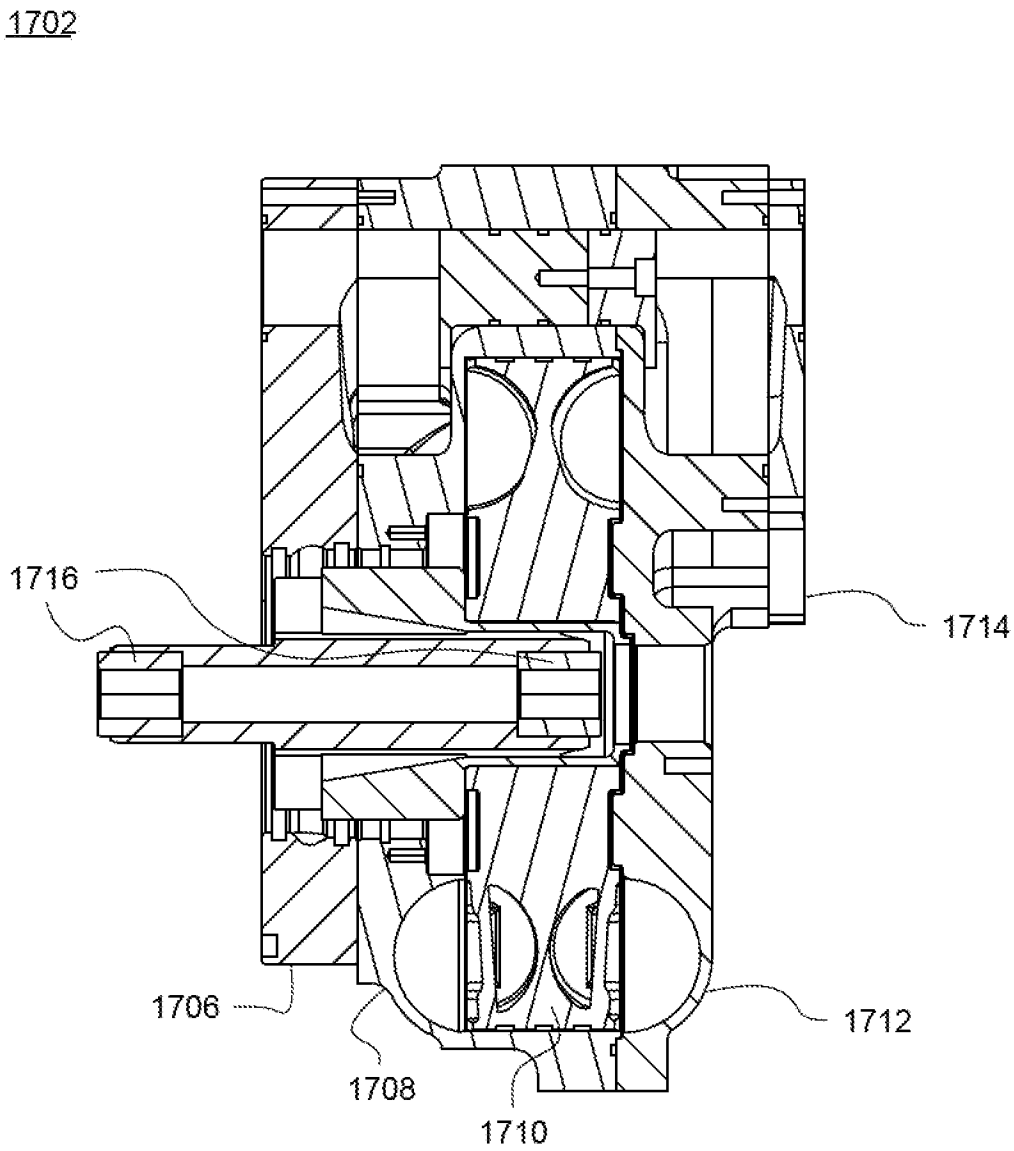



FIG.17I

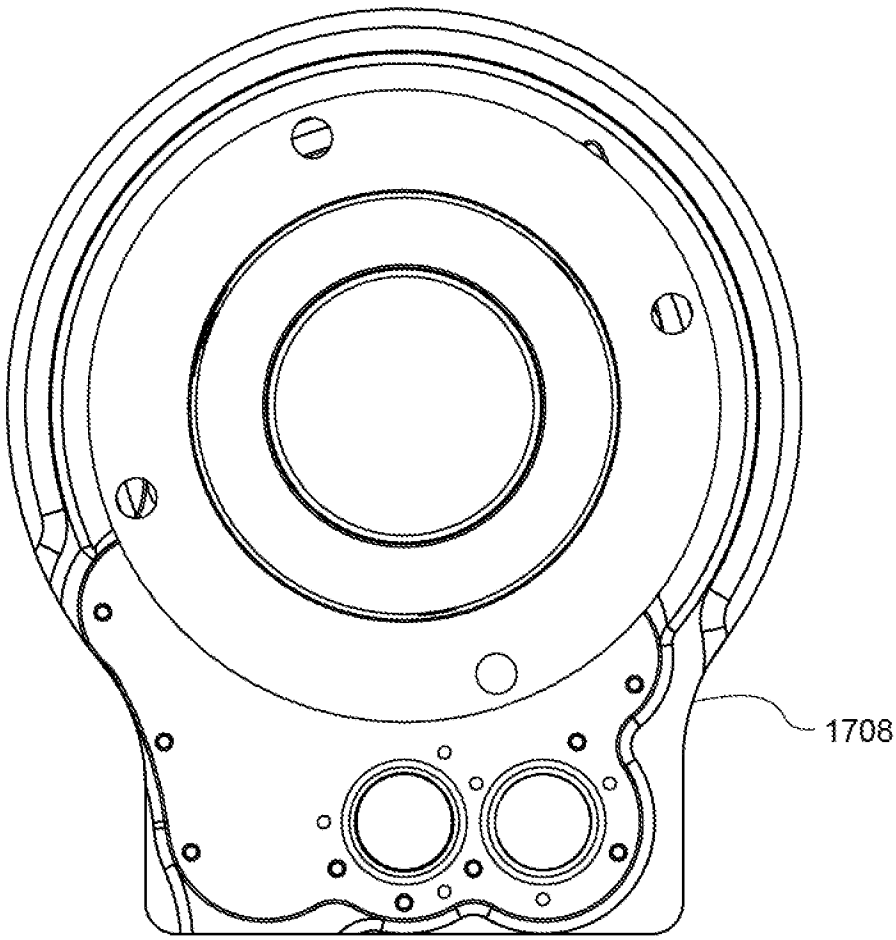



FIG.17J

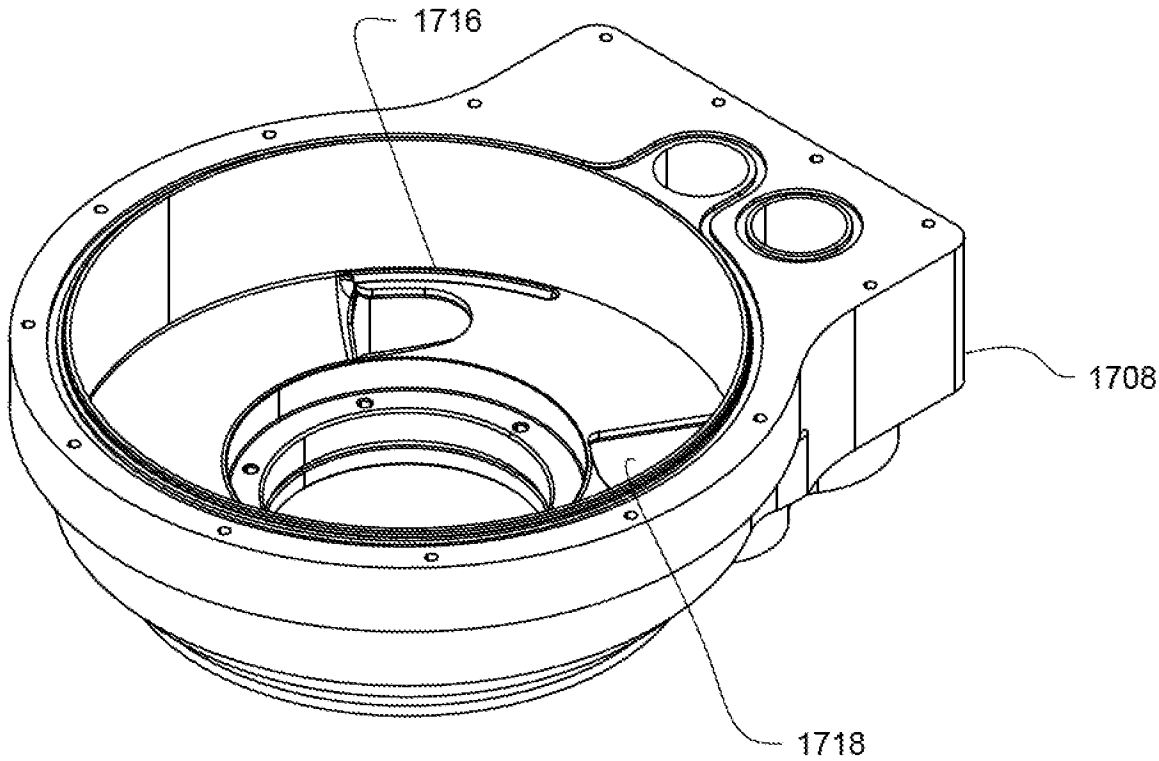



FIG.17K

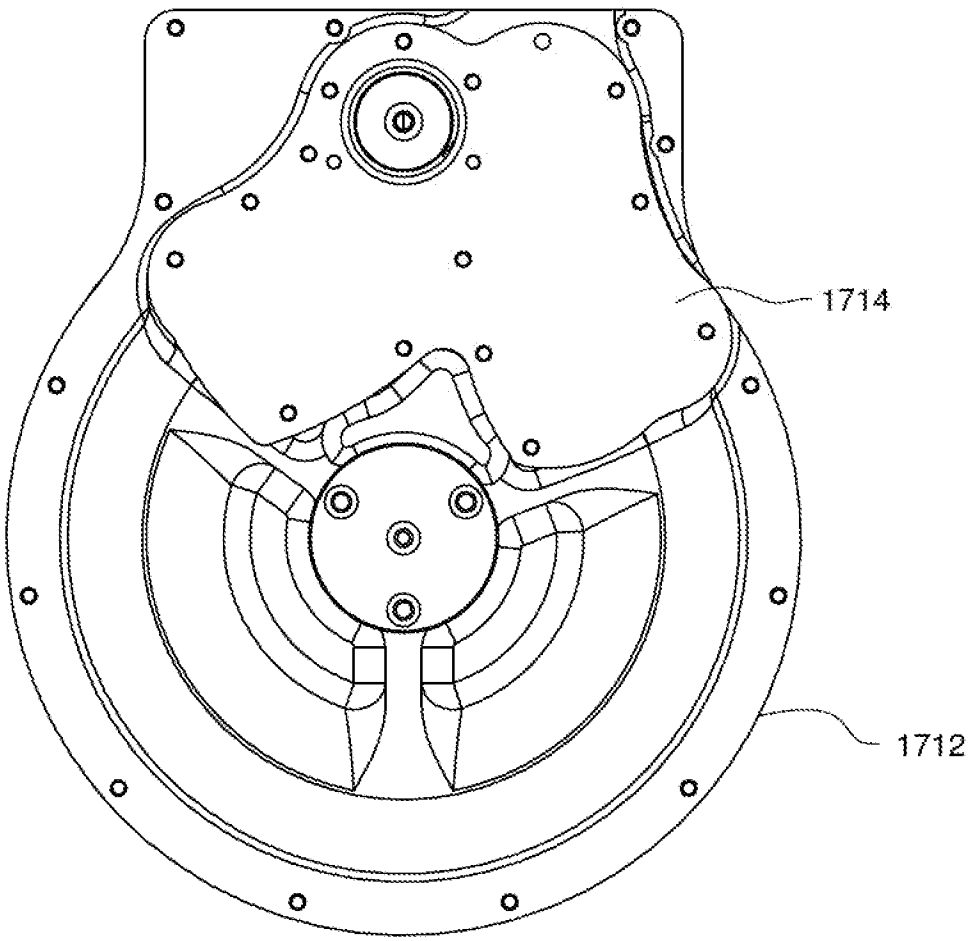



FIG.17L

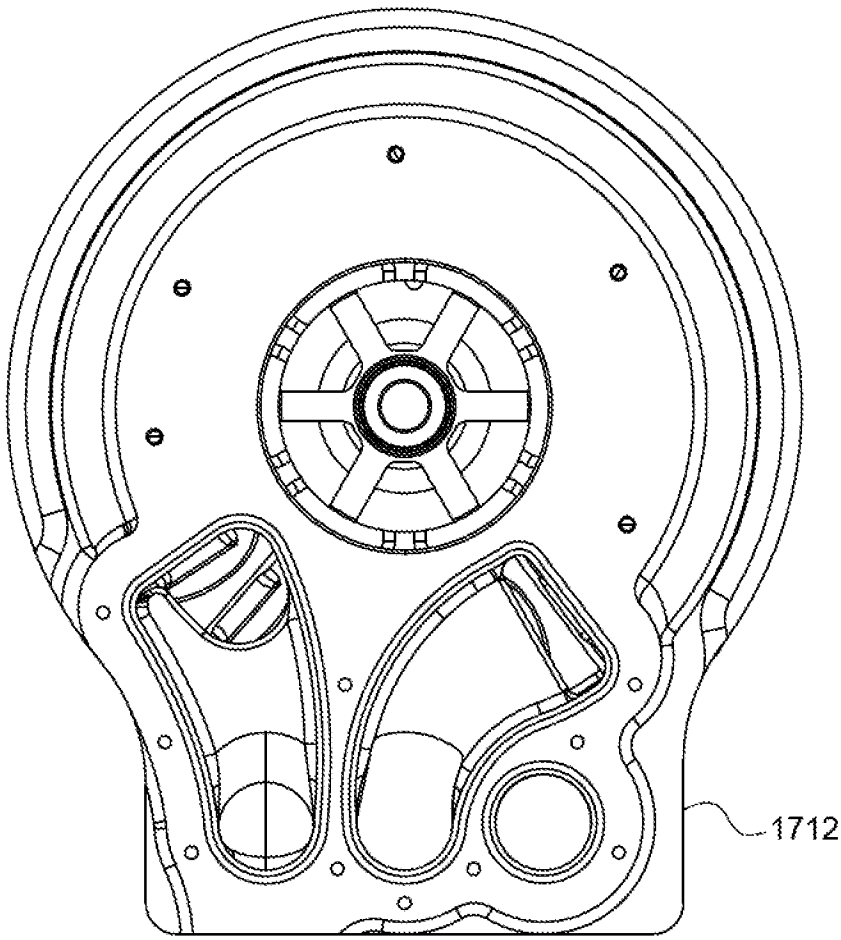



FIG. 17M

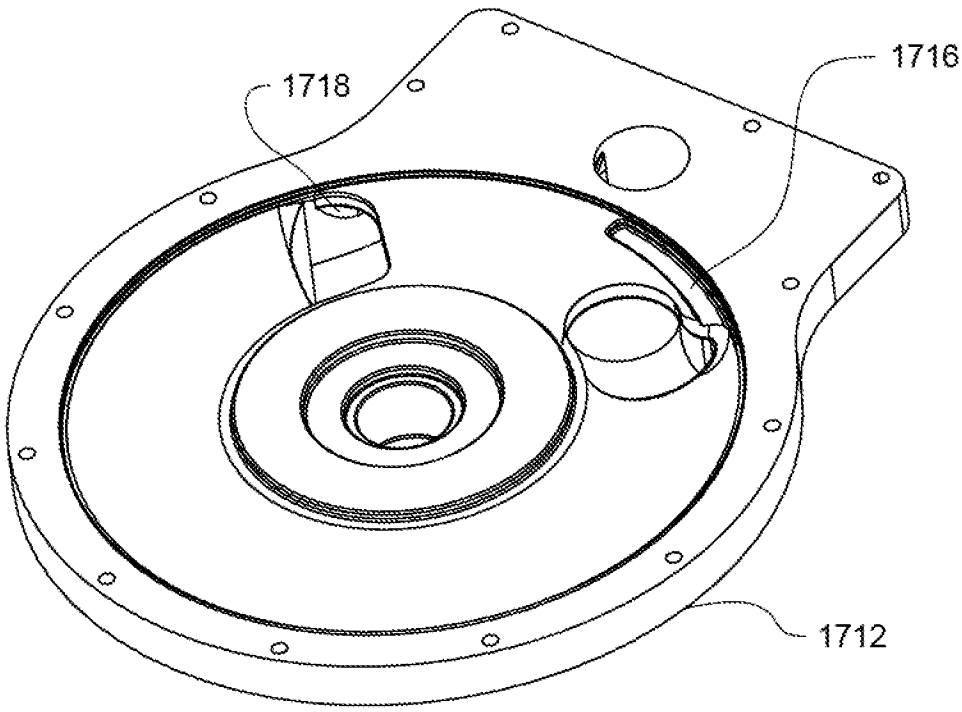



FIG.17N

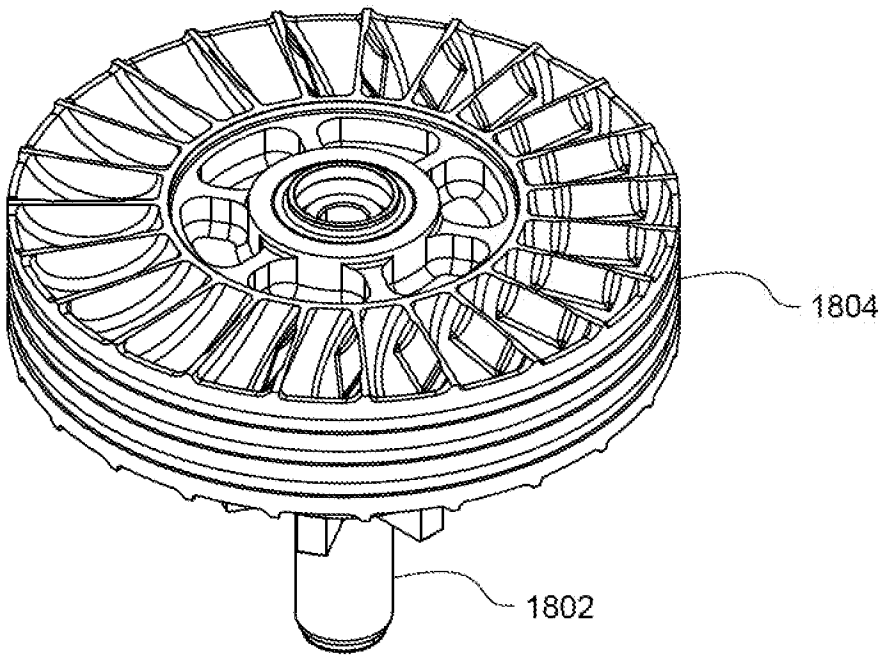



FIG.18

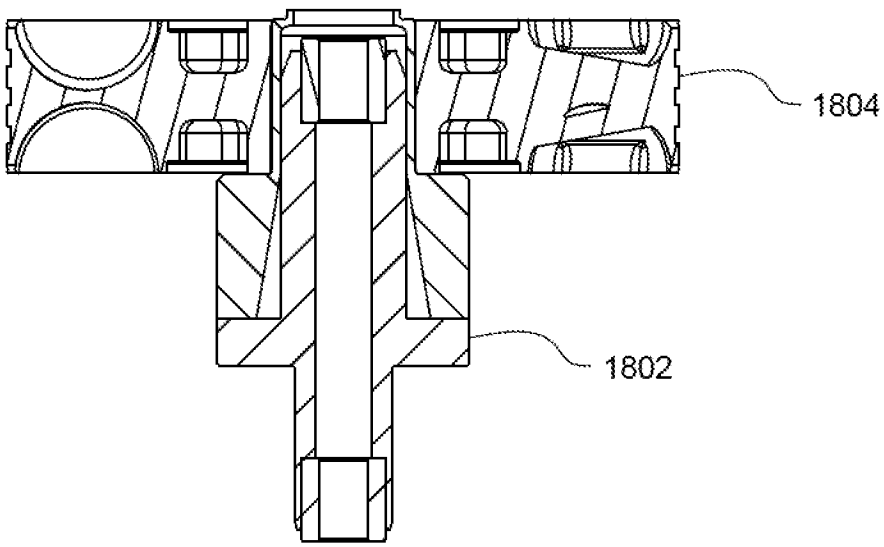



FIG.18A

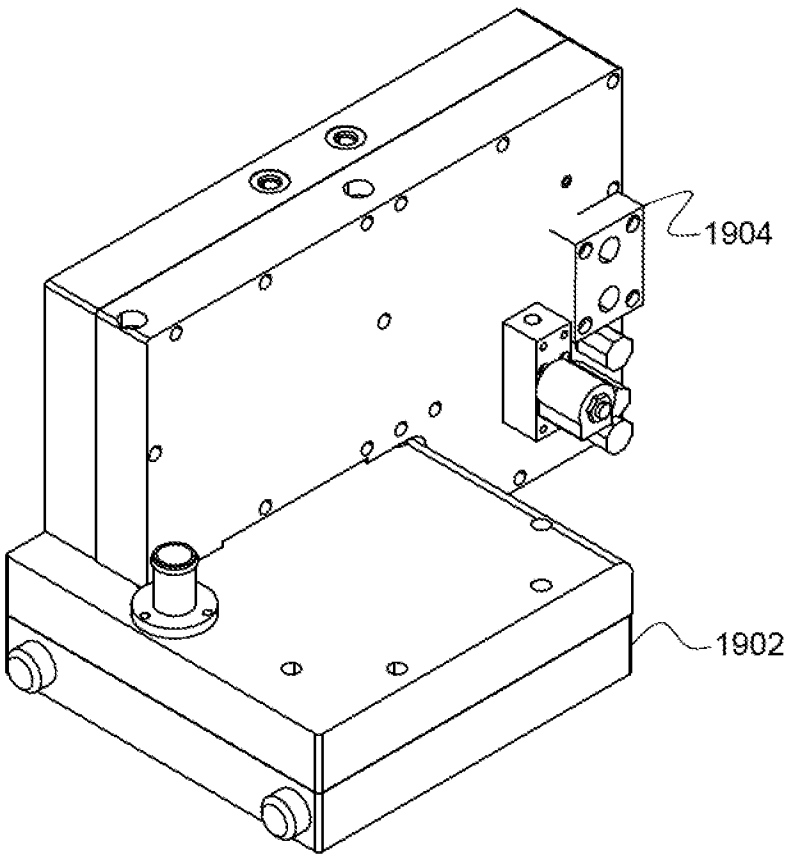



FIG. 19

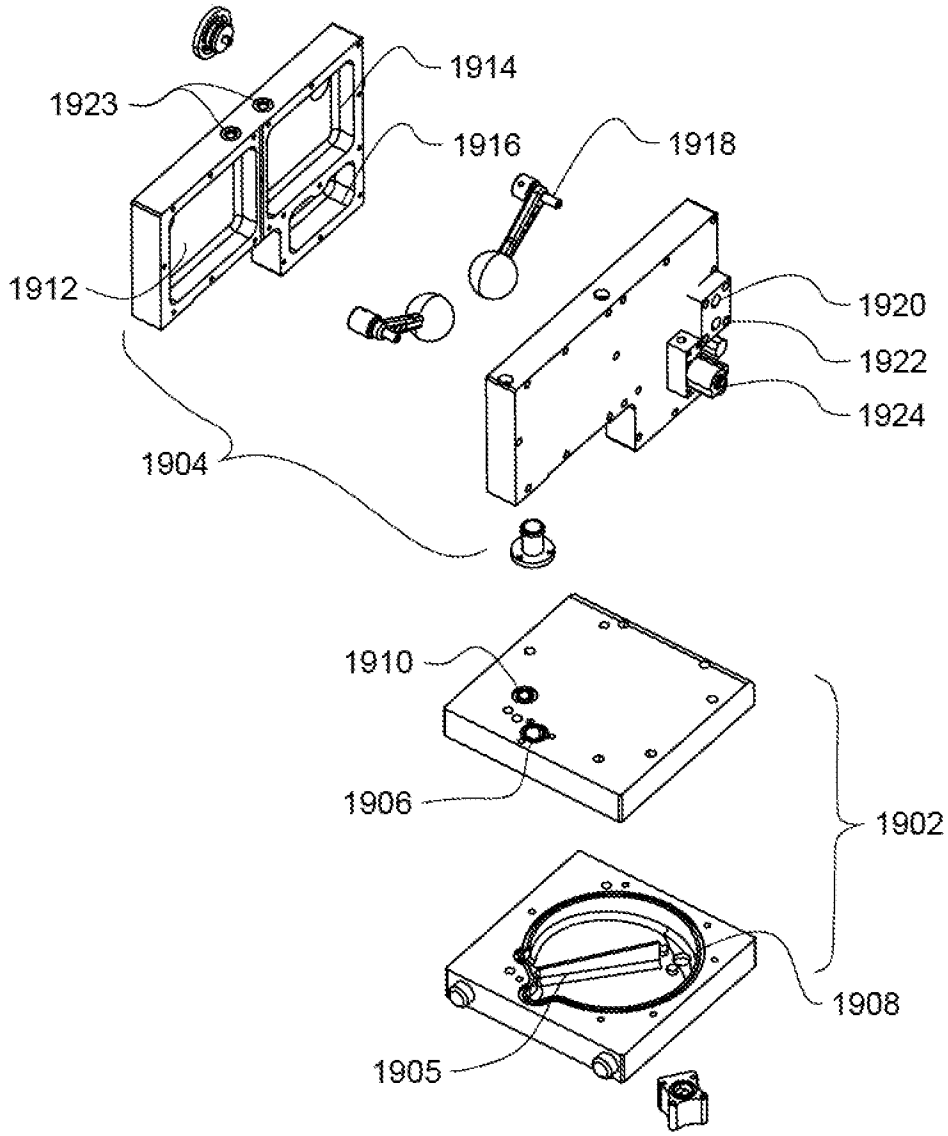

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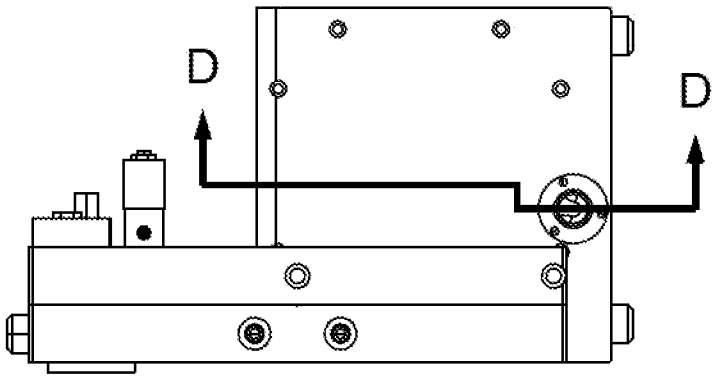
FIG.19A



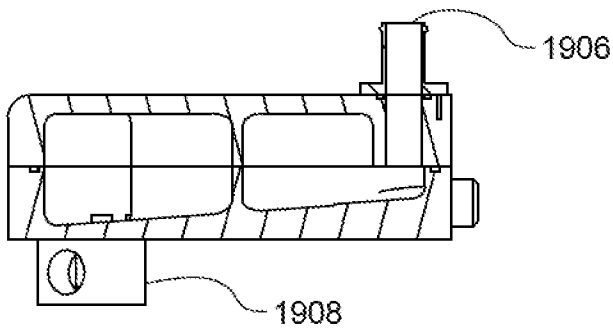
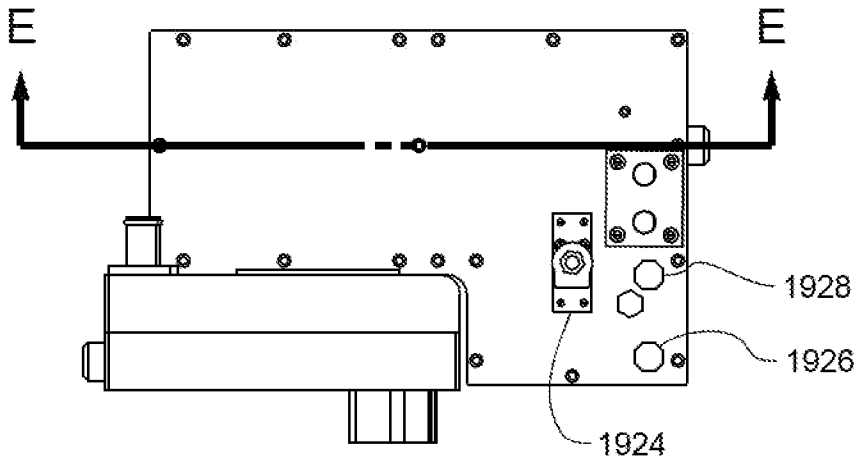




FIG.19B



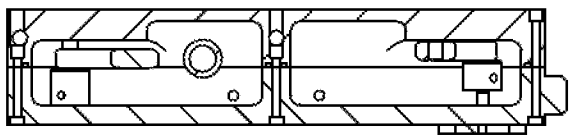



FIG.19C

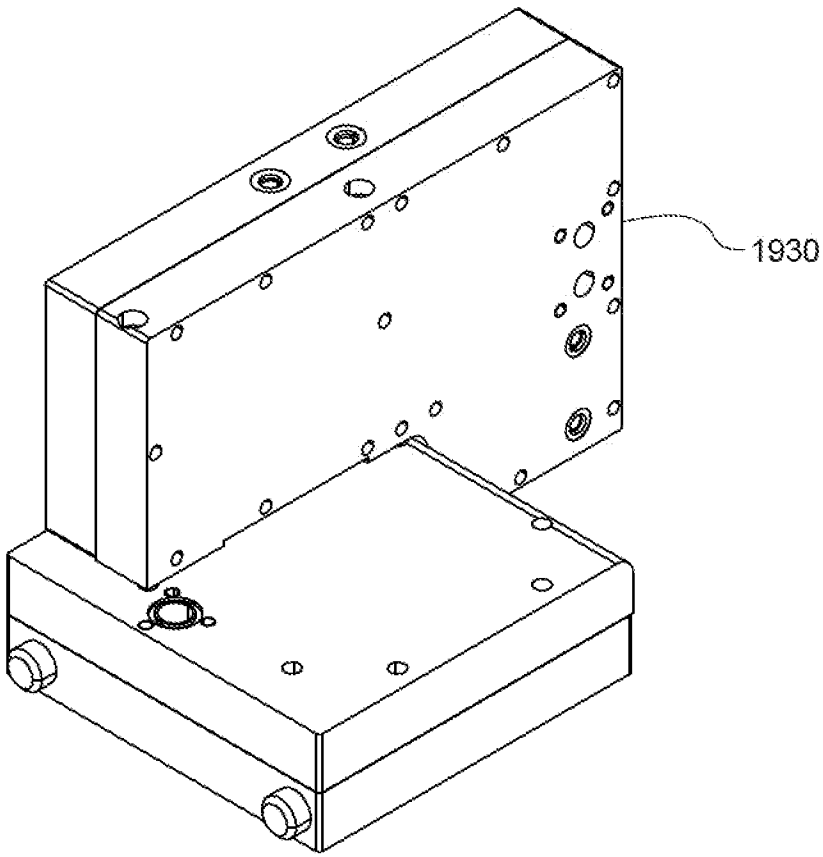



FIG.19D

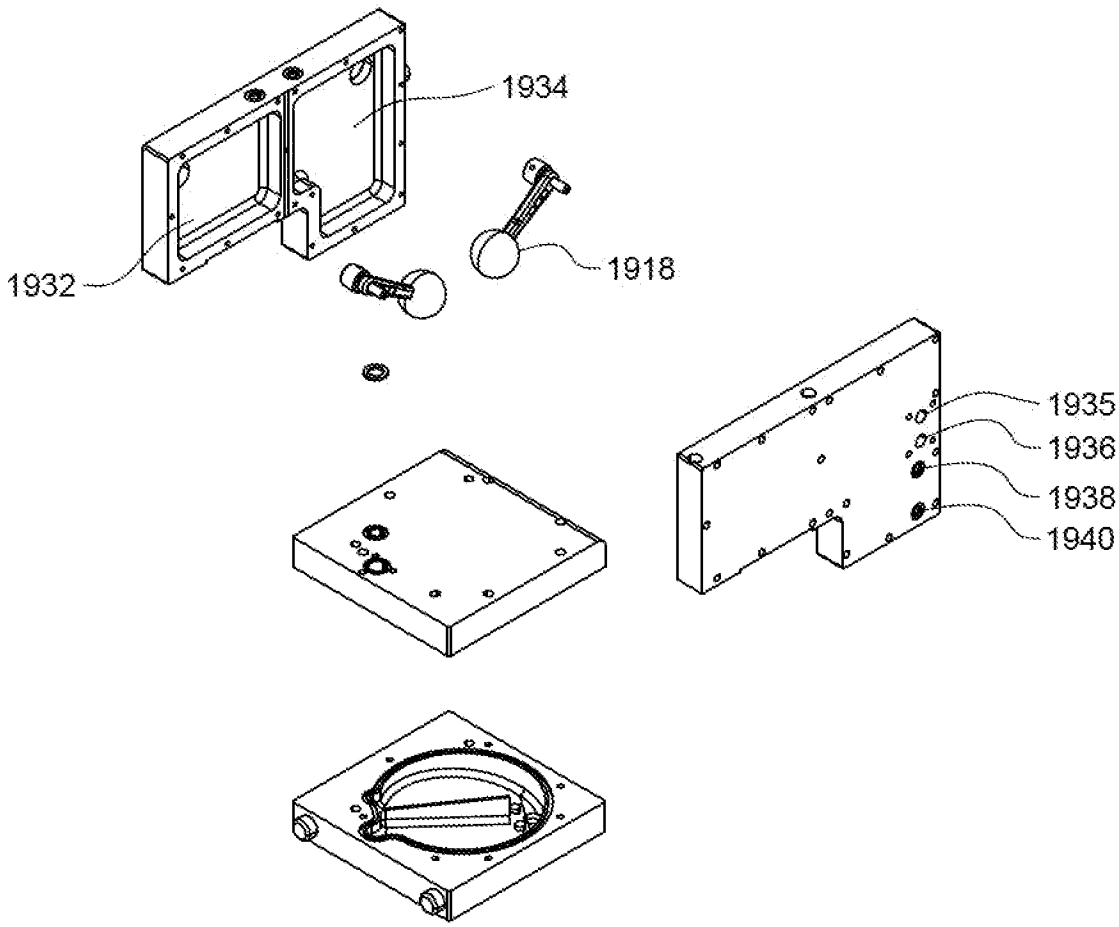



FIG.19E

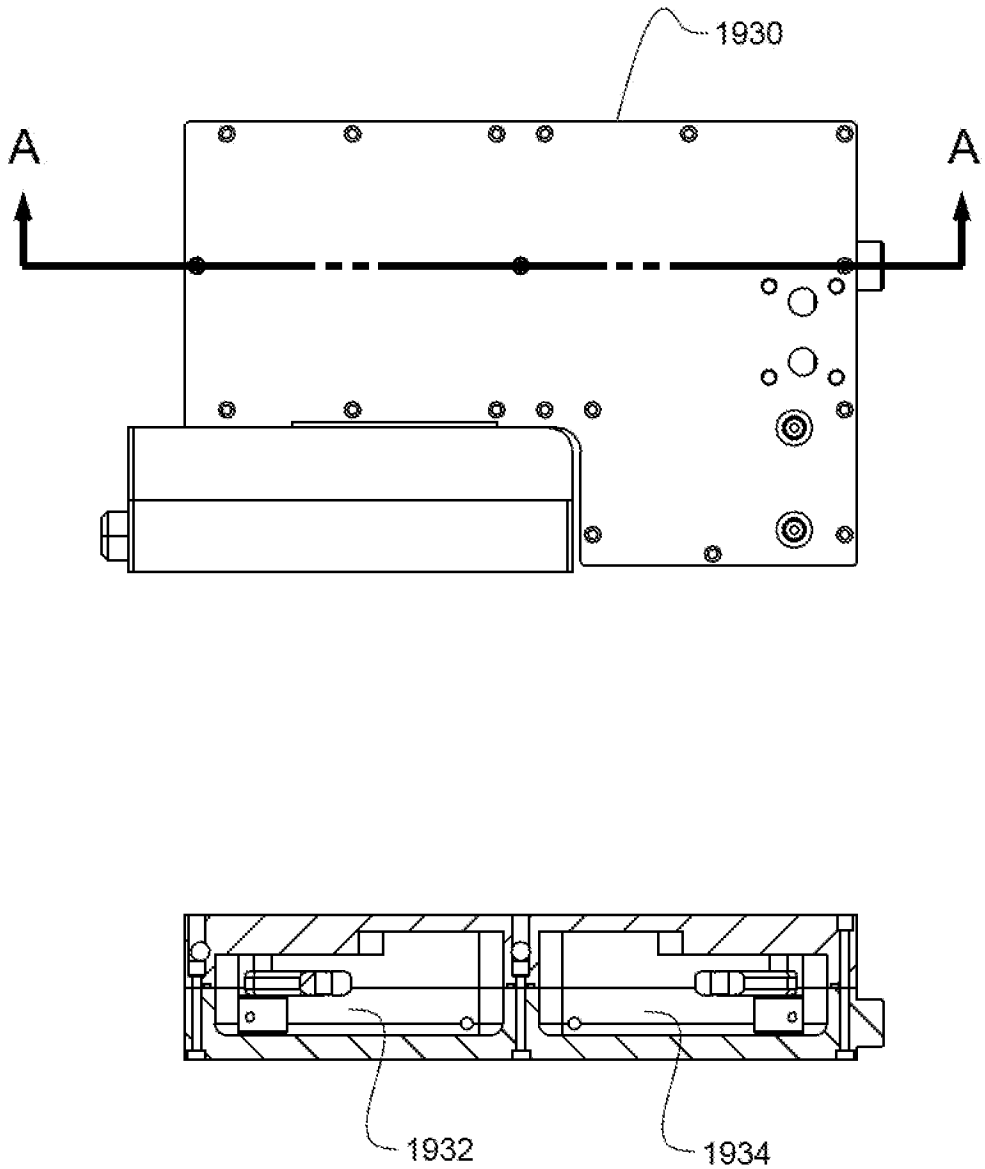



FIG.19F

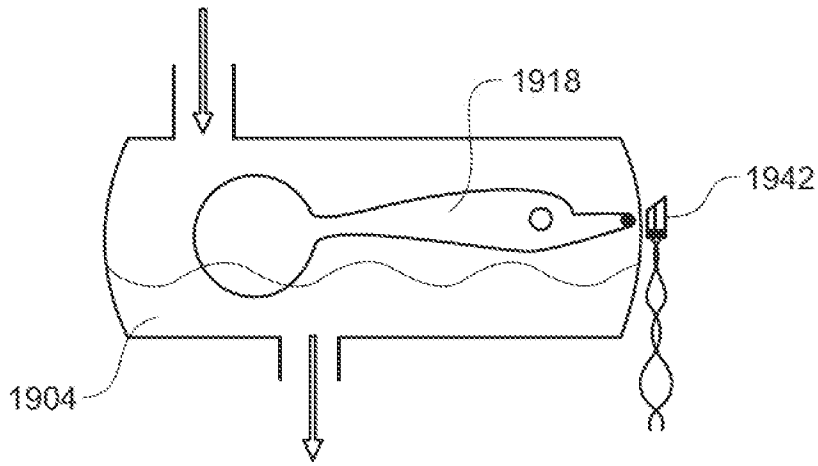



FIG. 19G

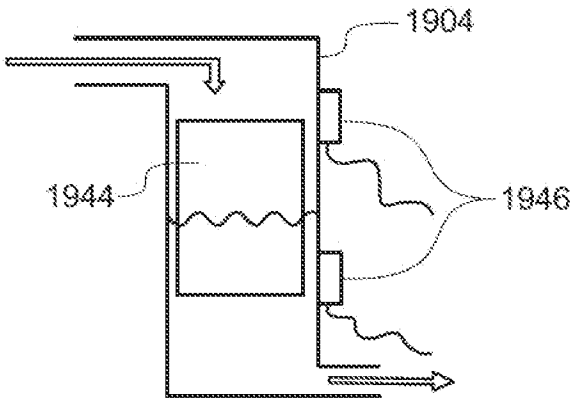



FIG. 19H

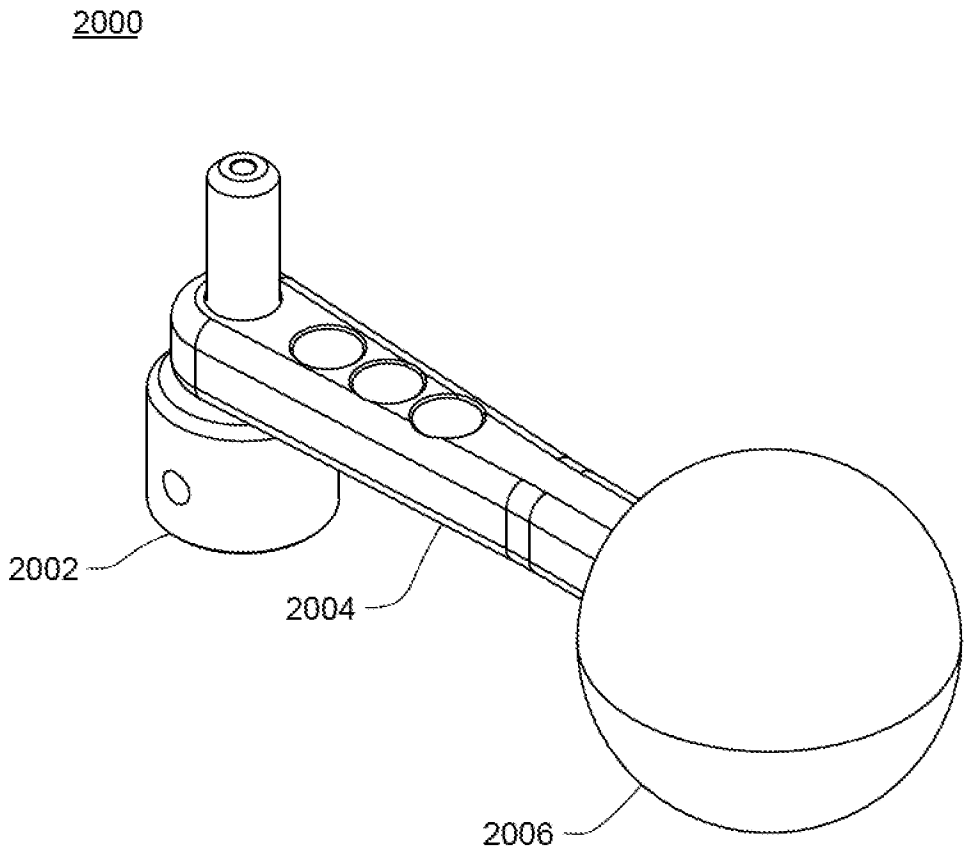



FIG.20

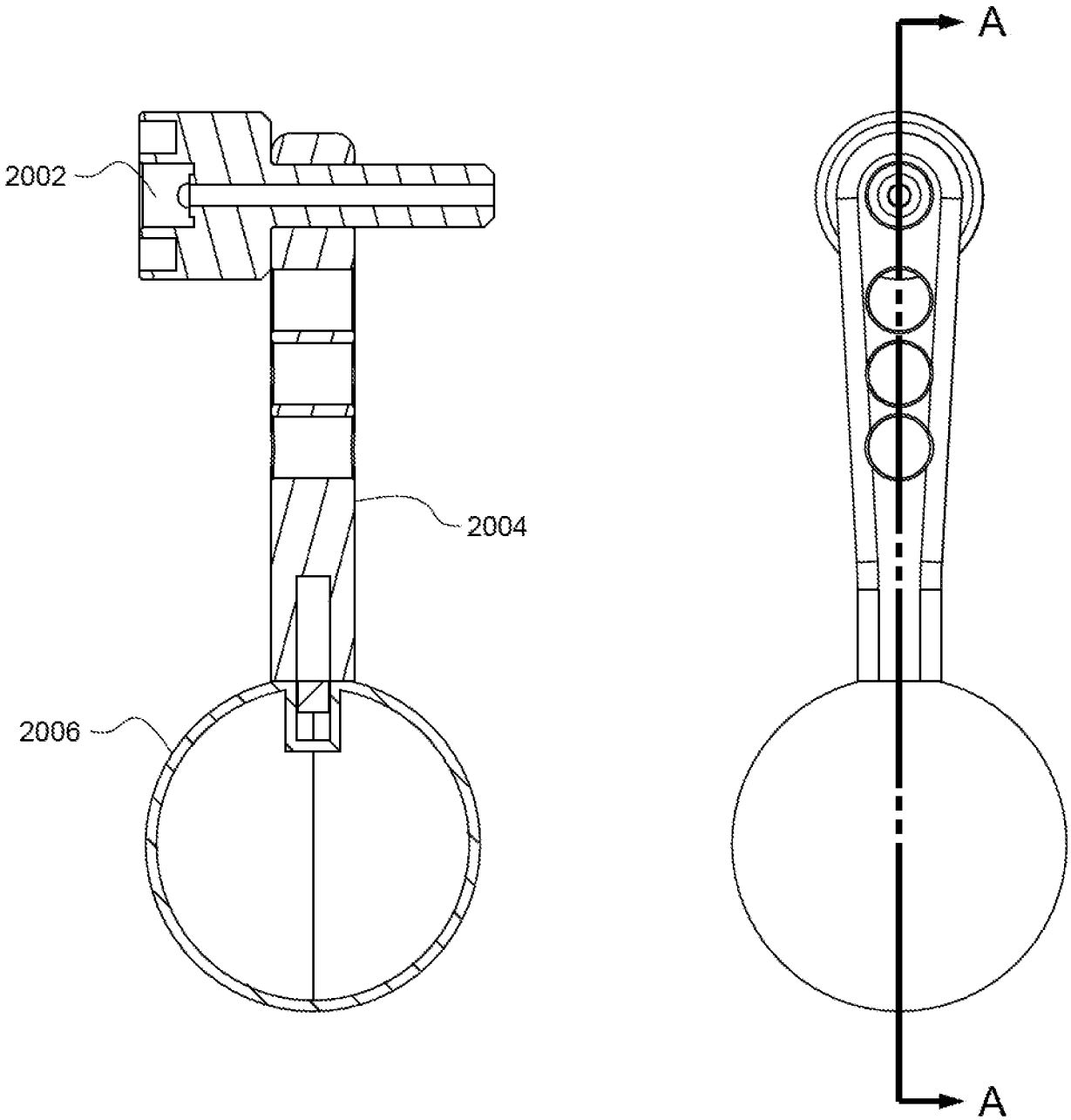



FIG.20A

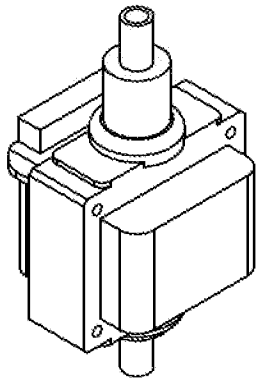


FIG.21A

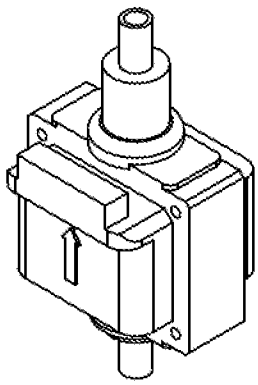


FIG.21

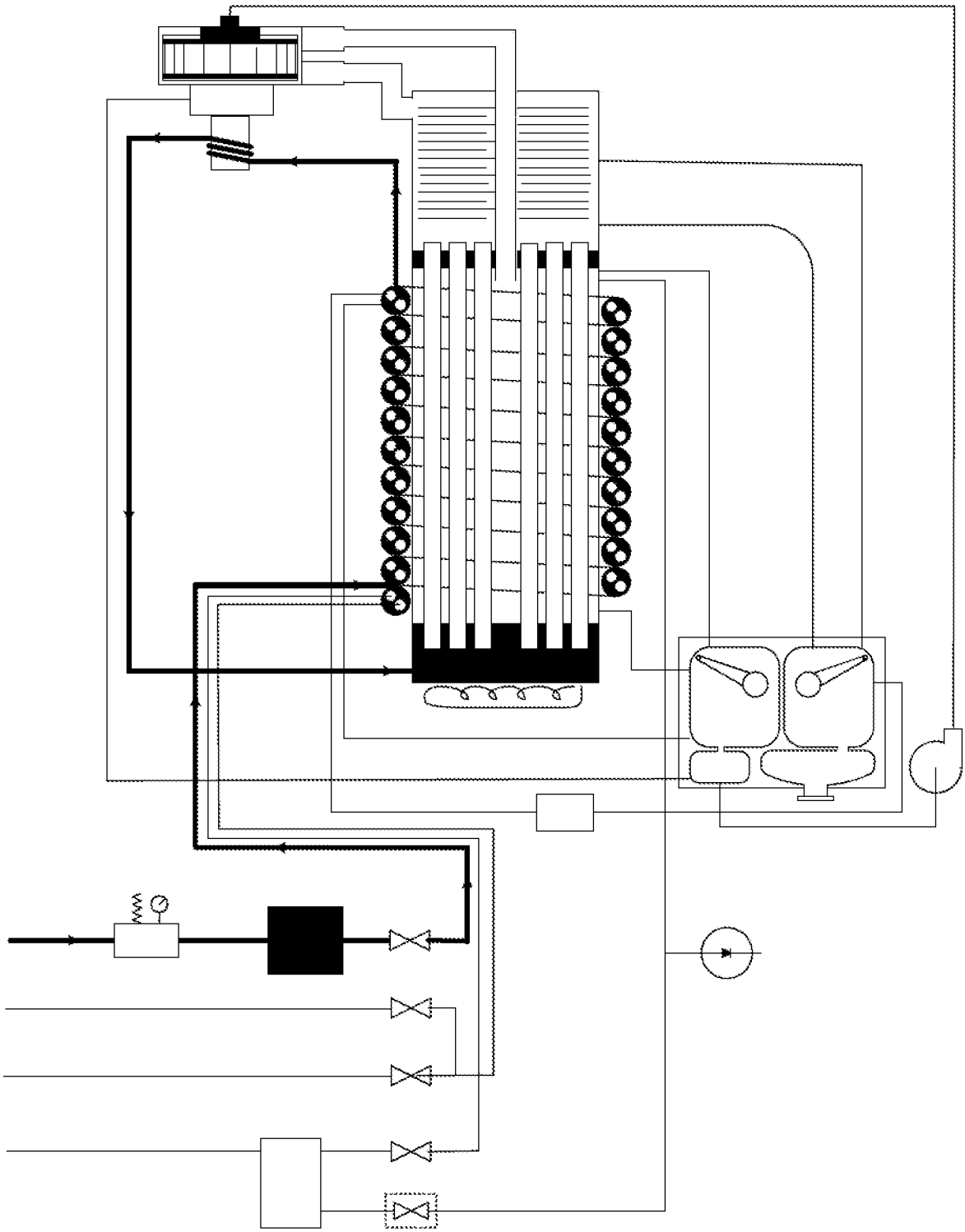


FIG. 22

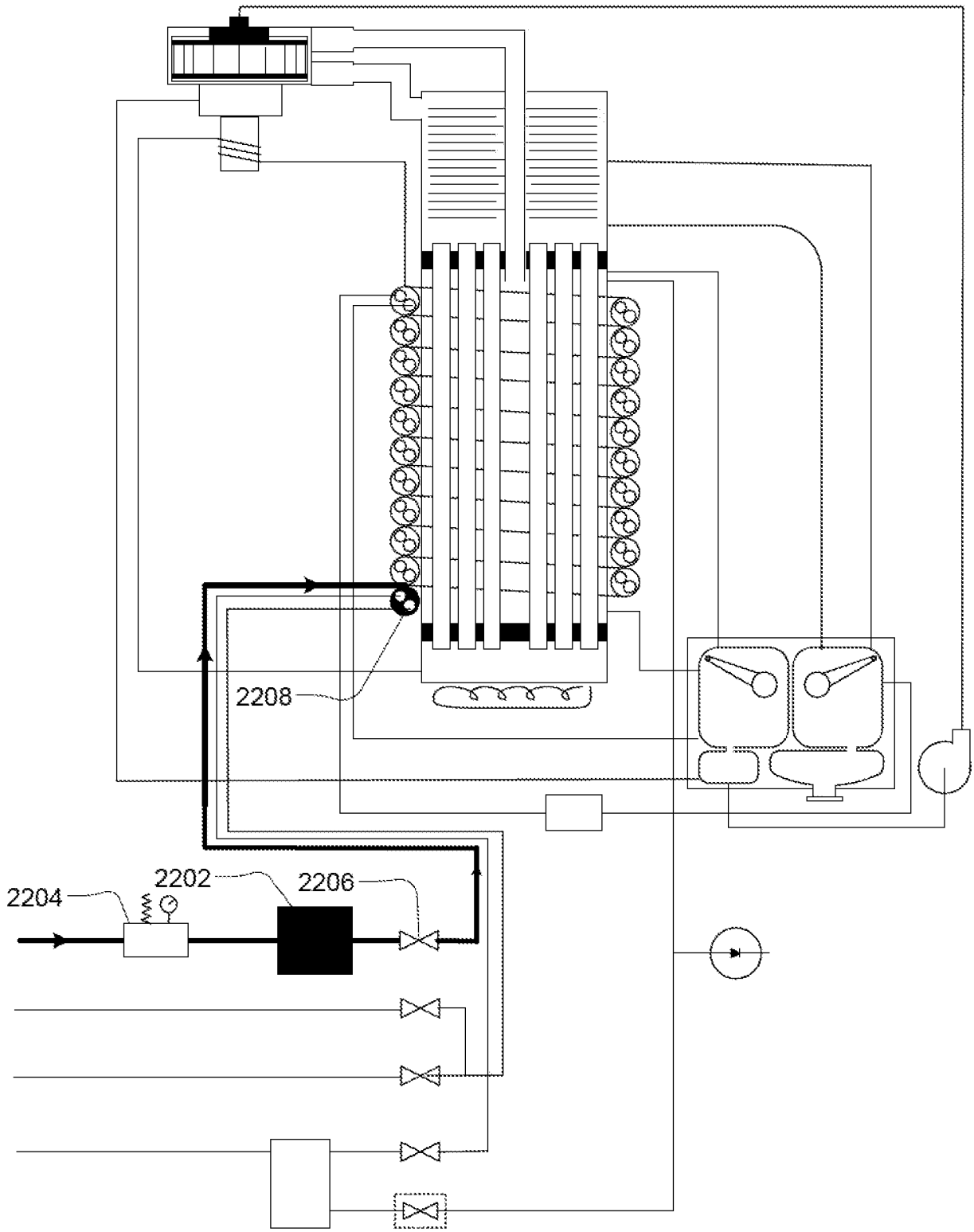



FIG. 22A

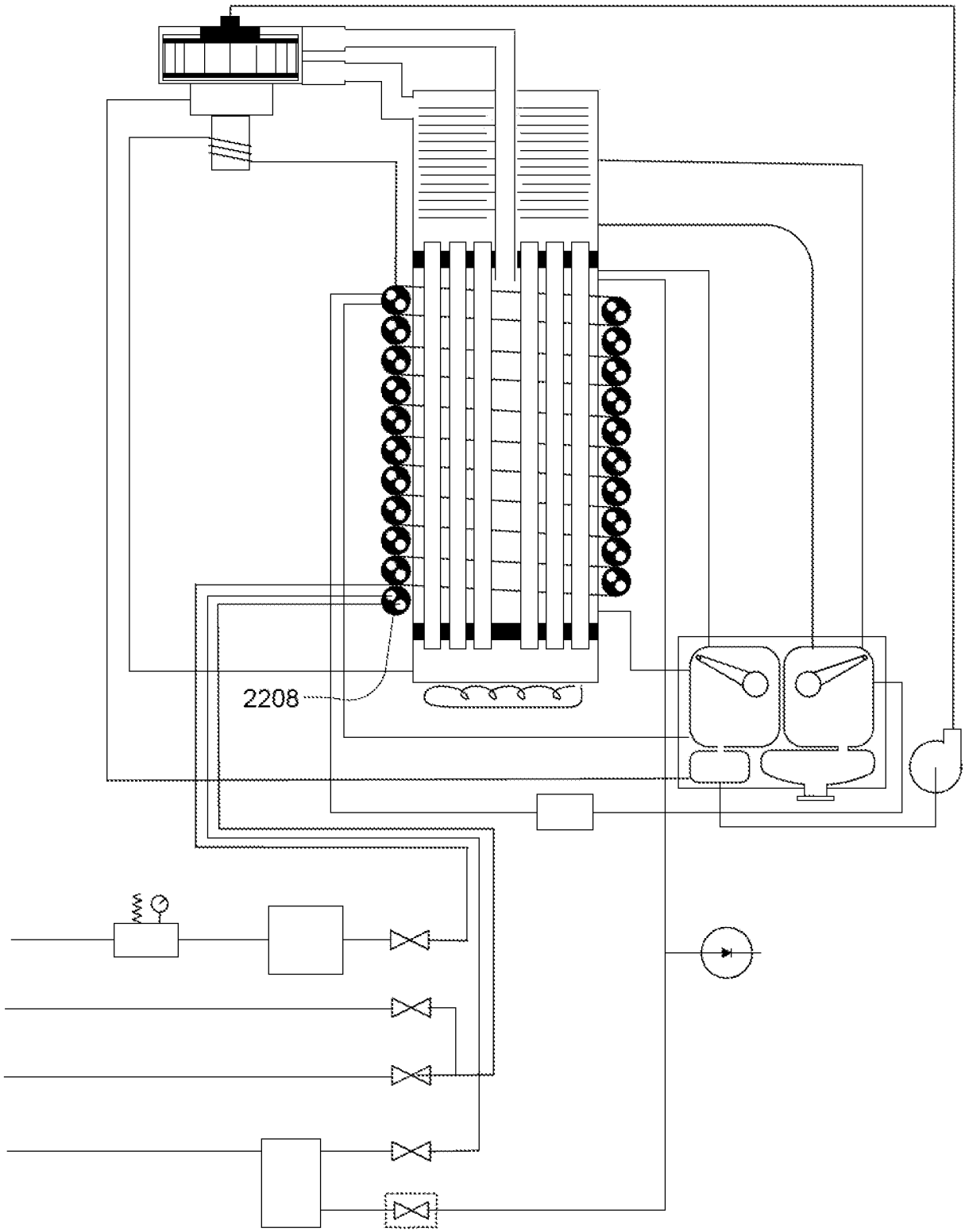



FIG. 22B

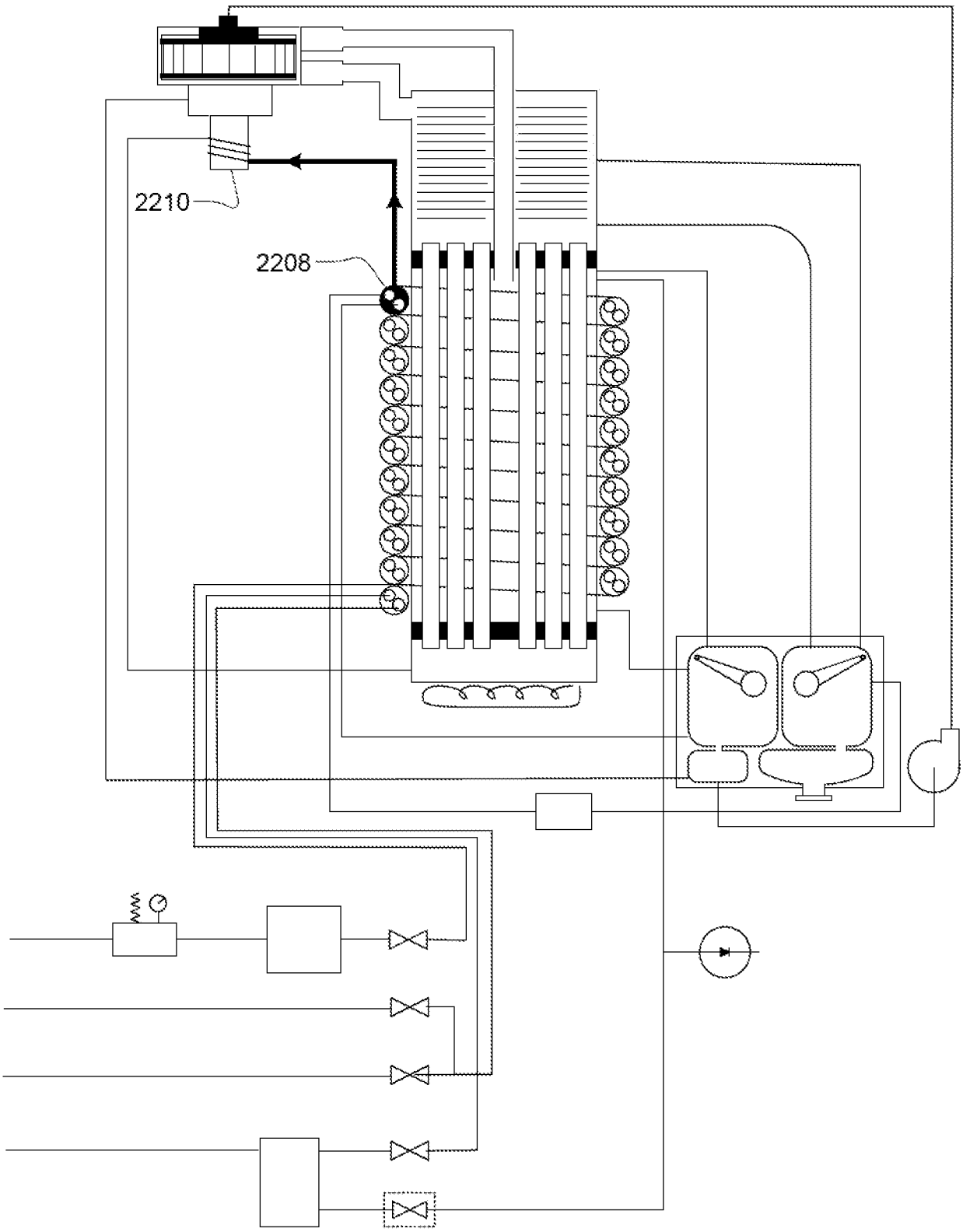



FIG. 22C

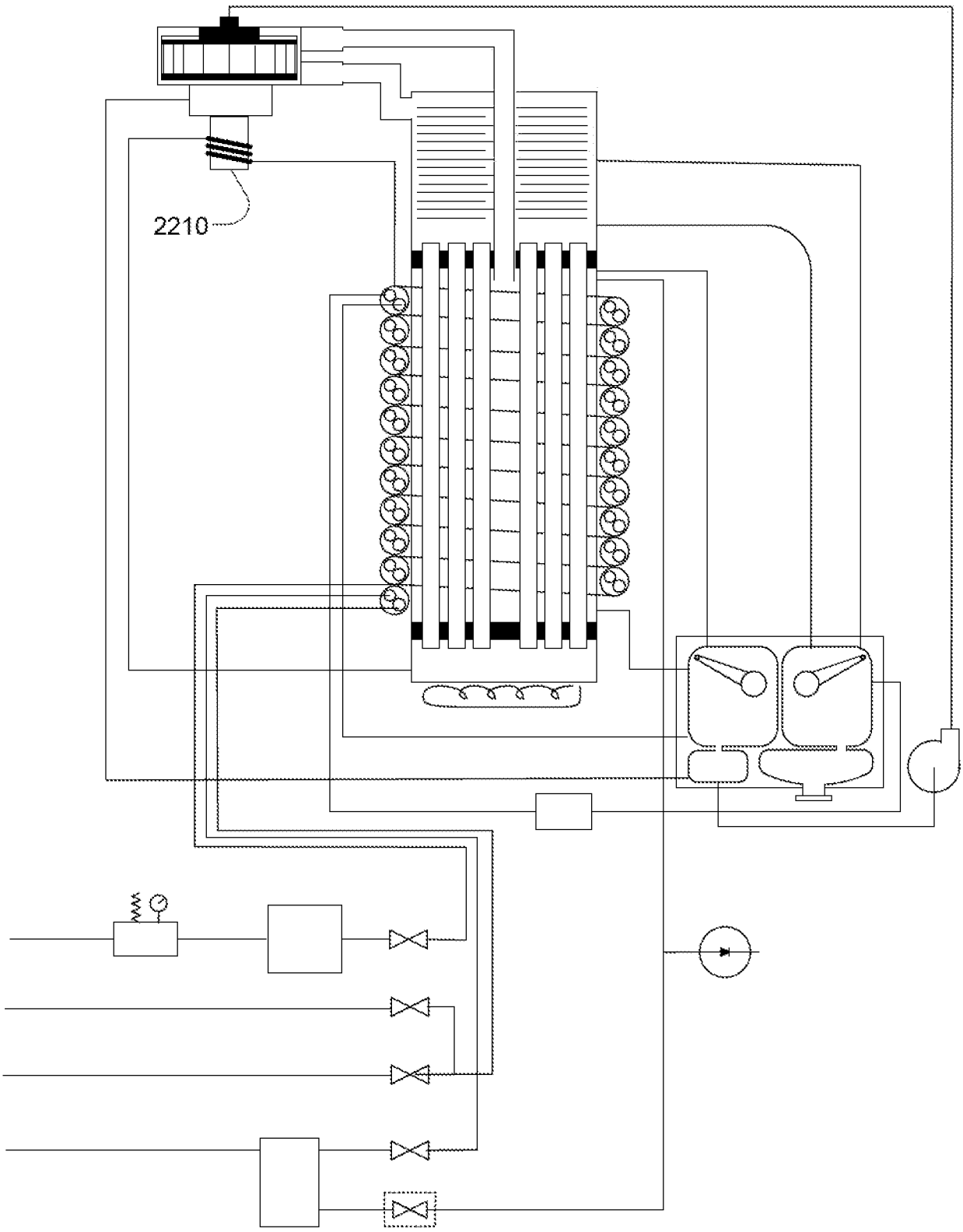



FIG. 22D

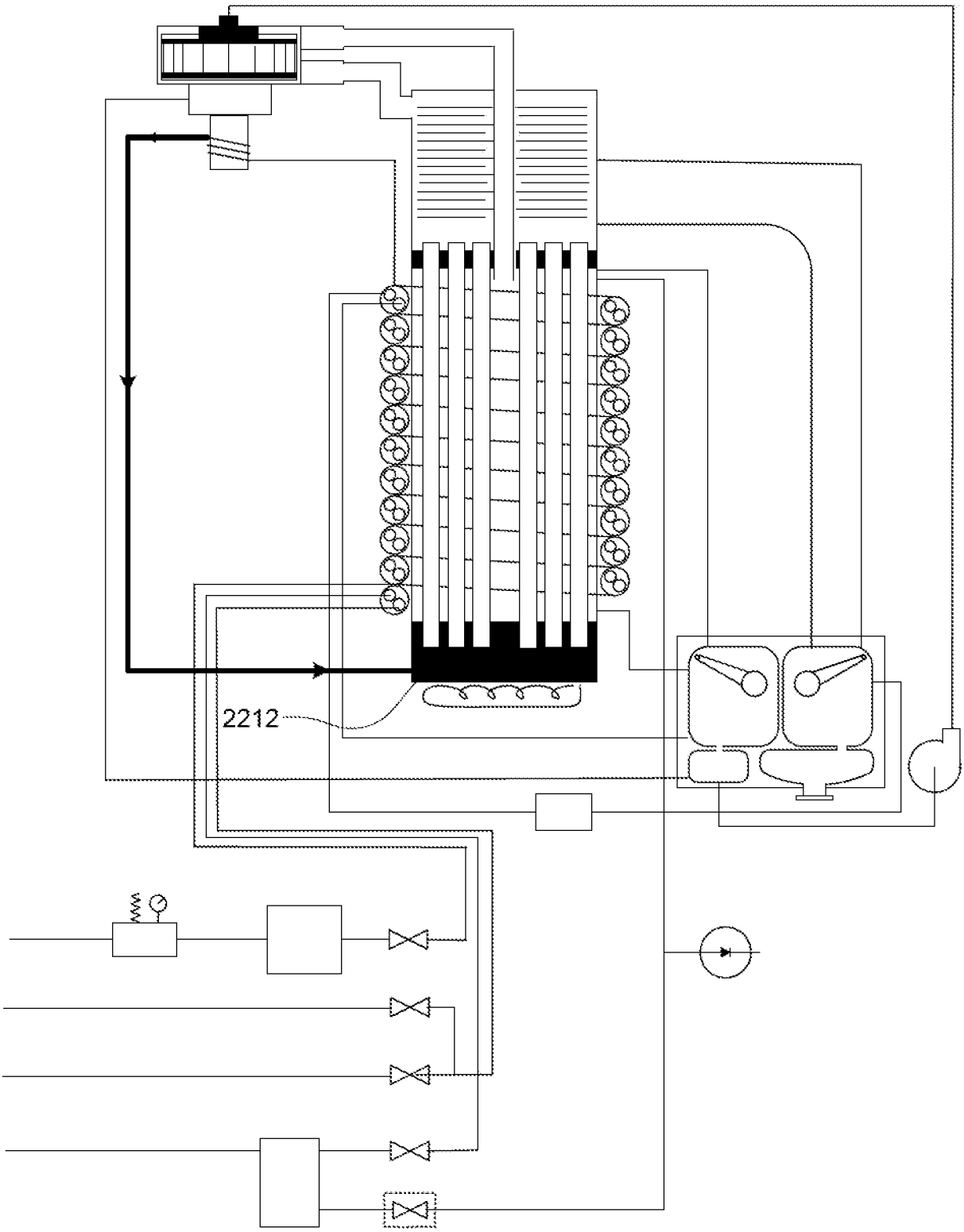



FIG. 22E

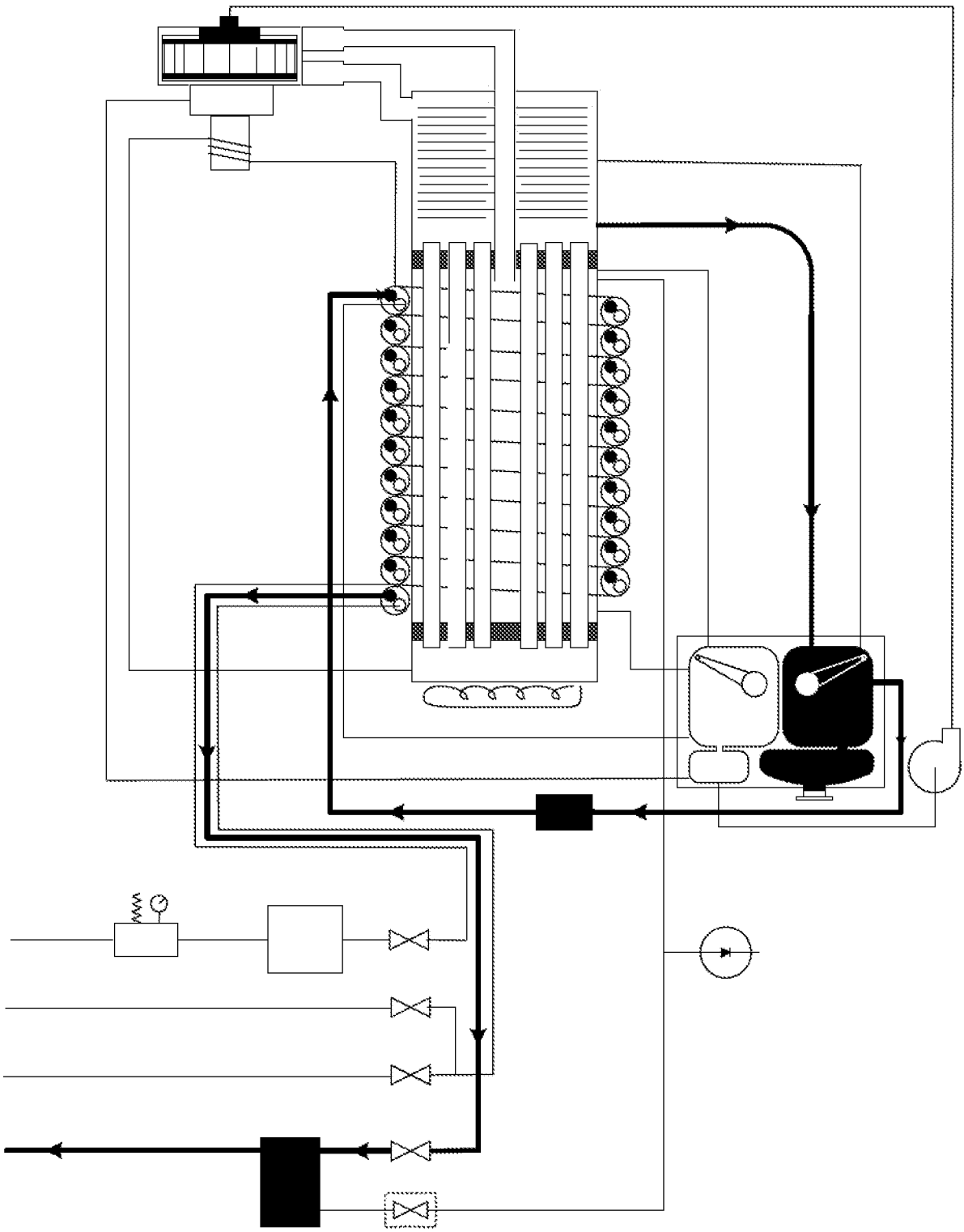


FIG. 23

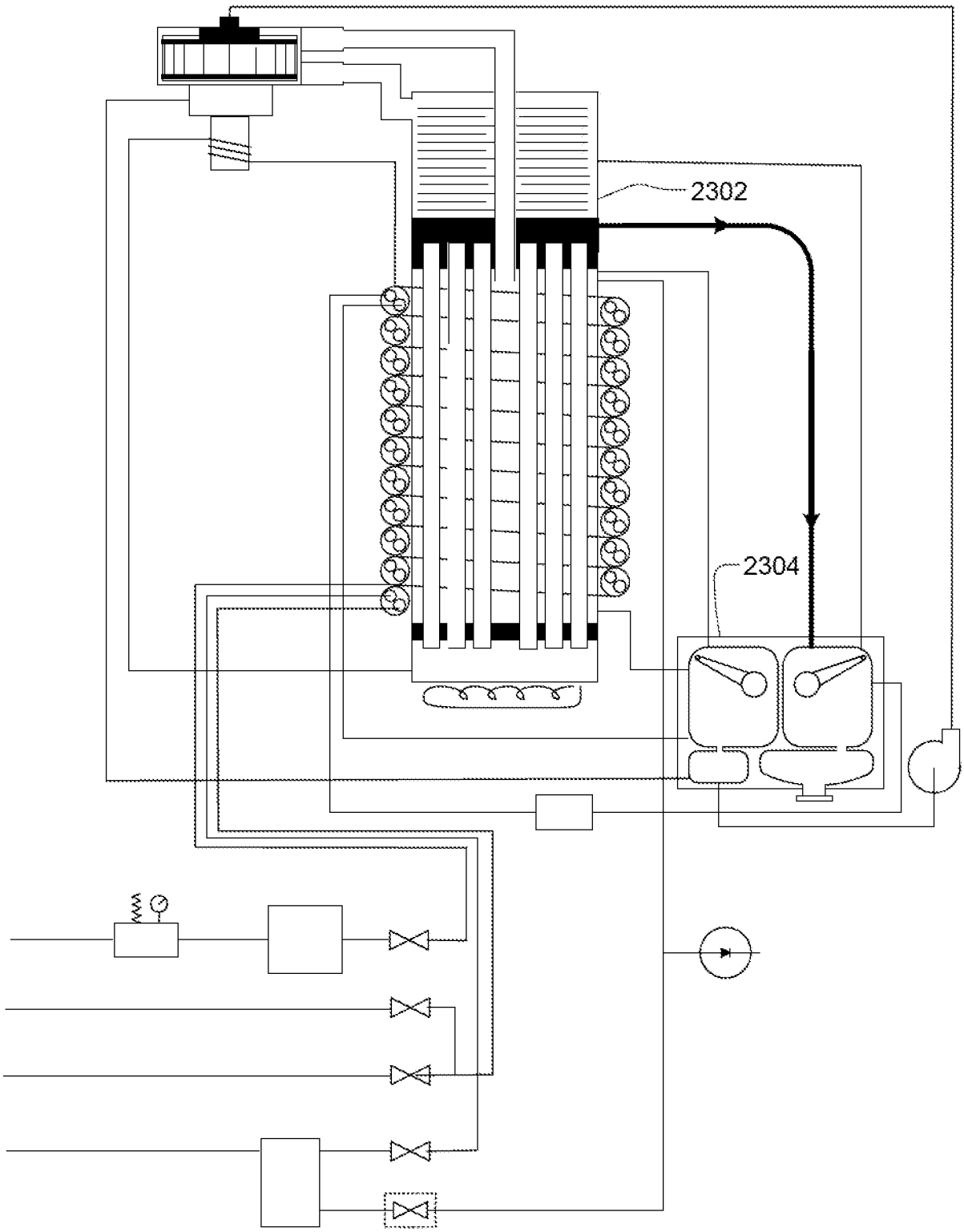



FIG. 23A

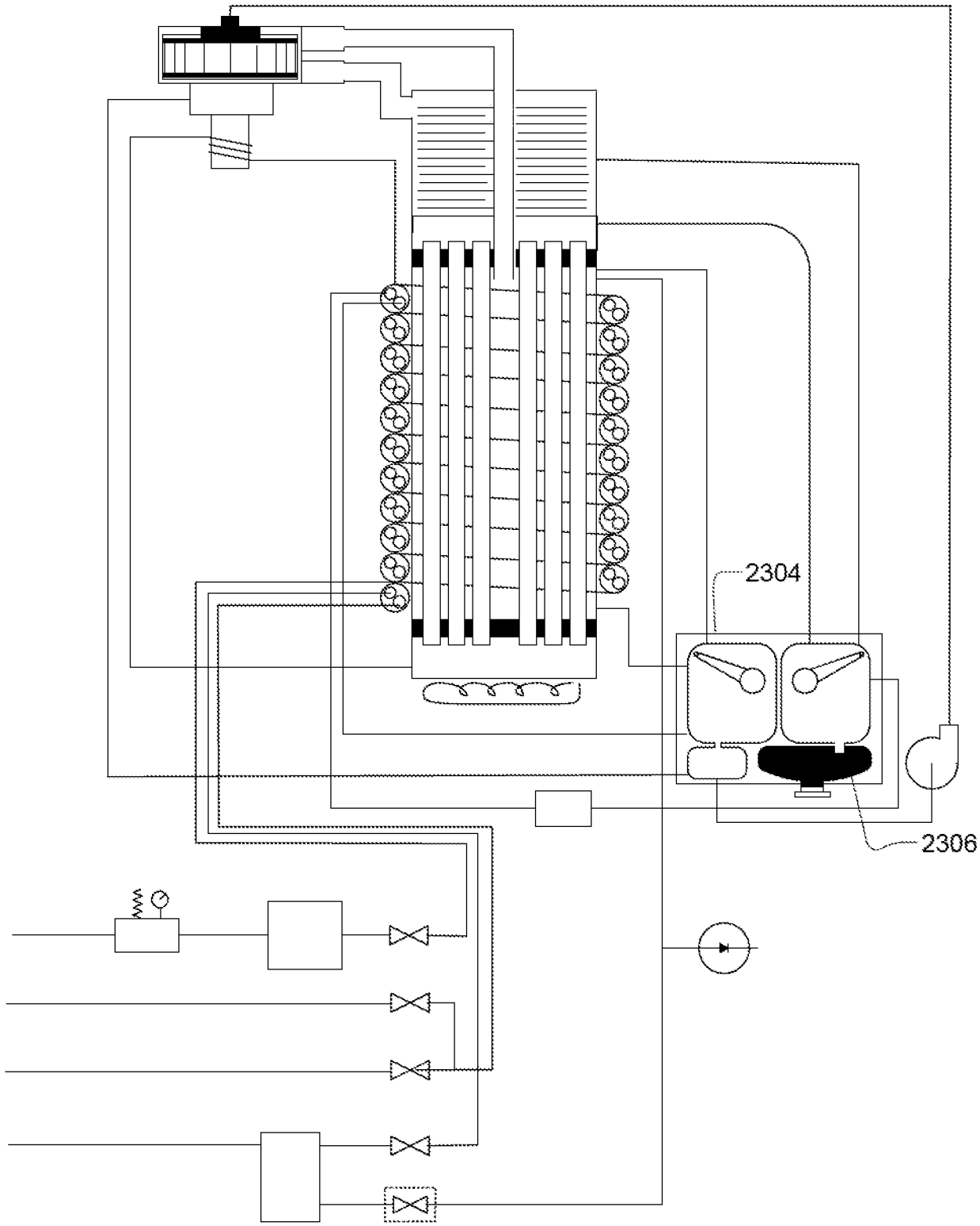



FIG. 23B

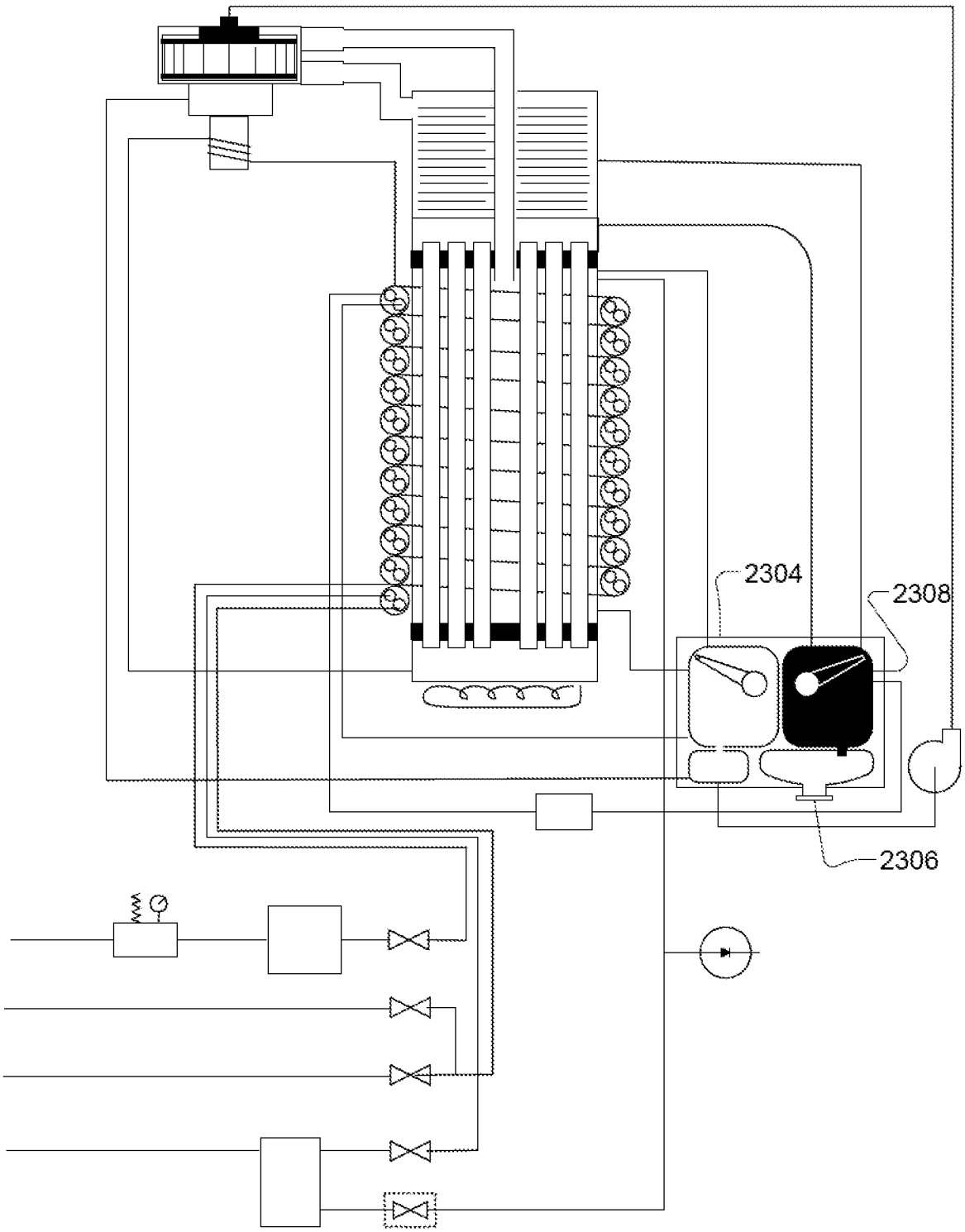



FIG. 23C

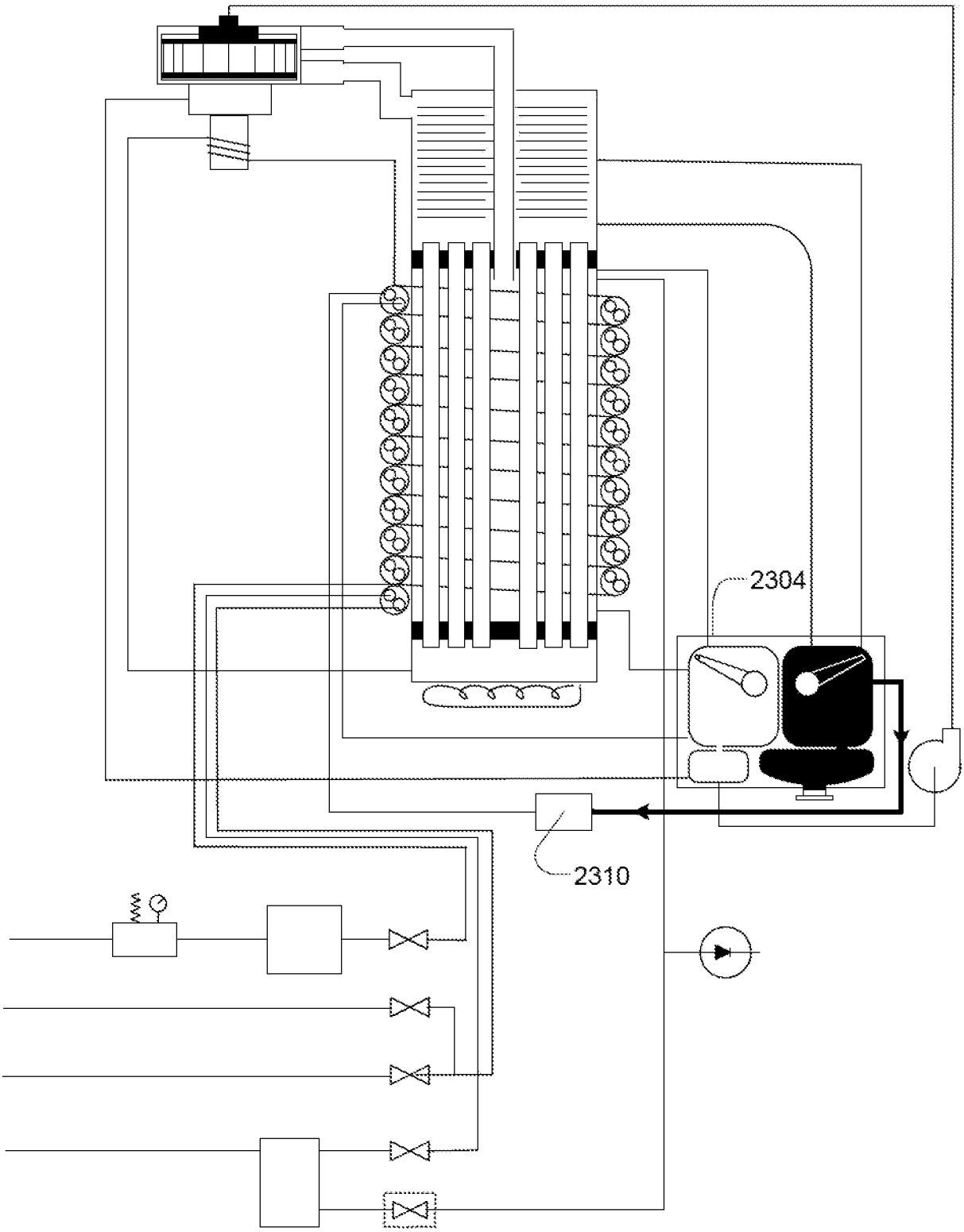



FIG. 23D

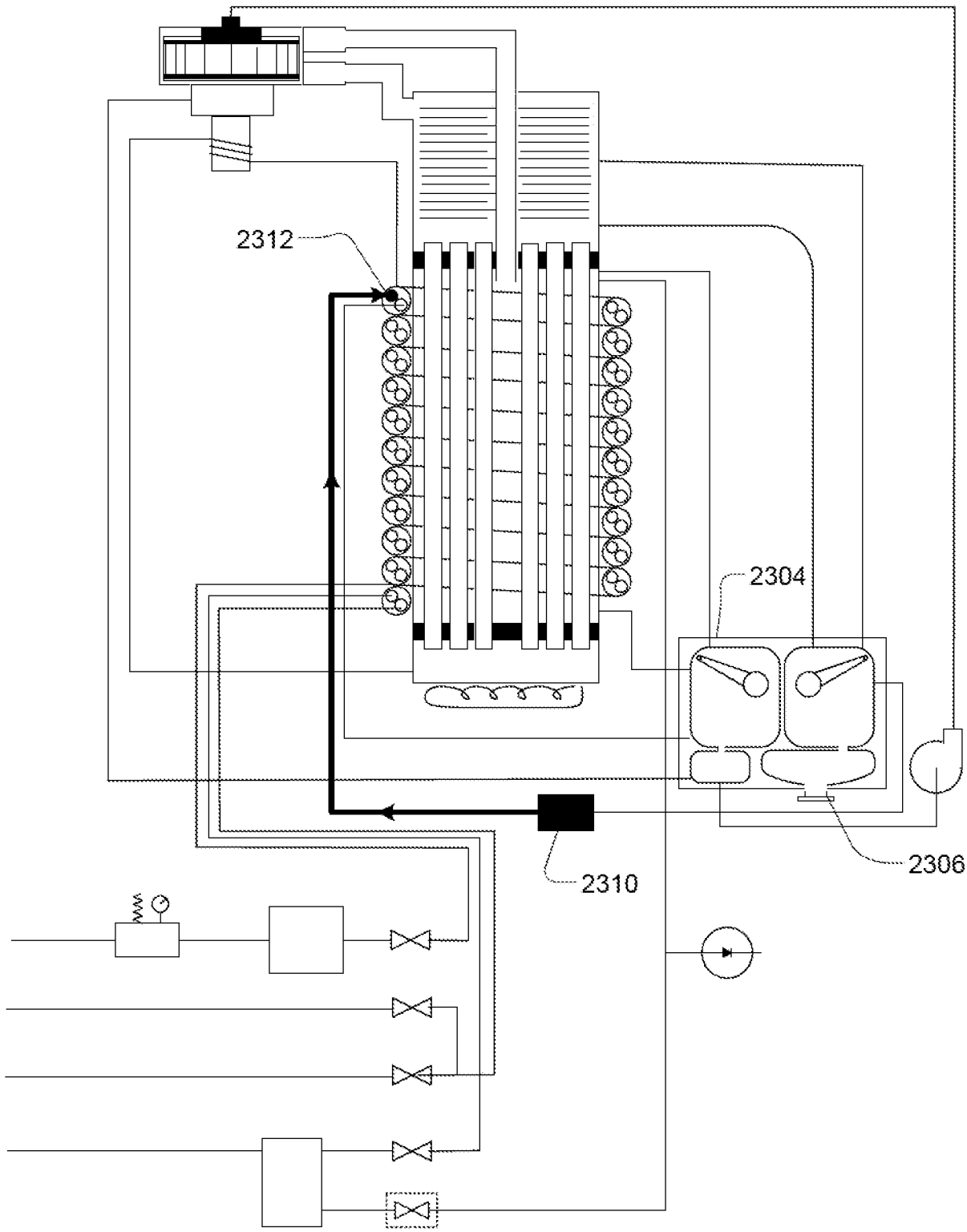



FIG. 23E

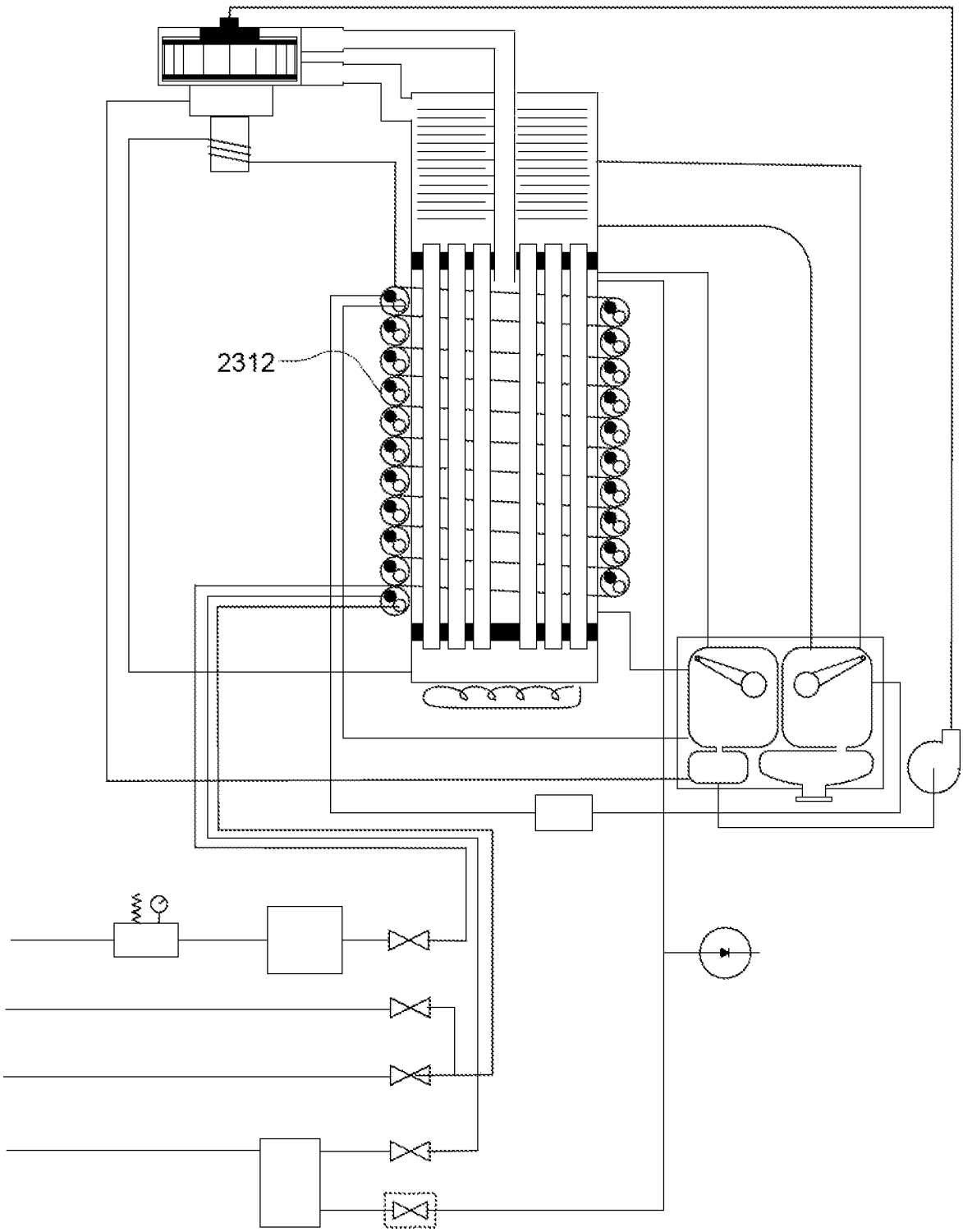



FIG. 23F

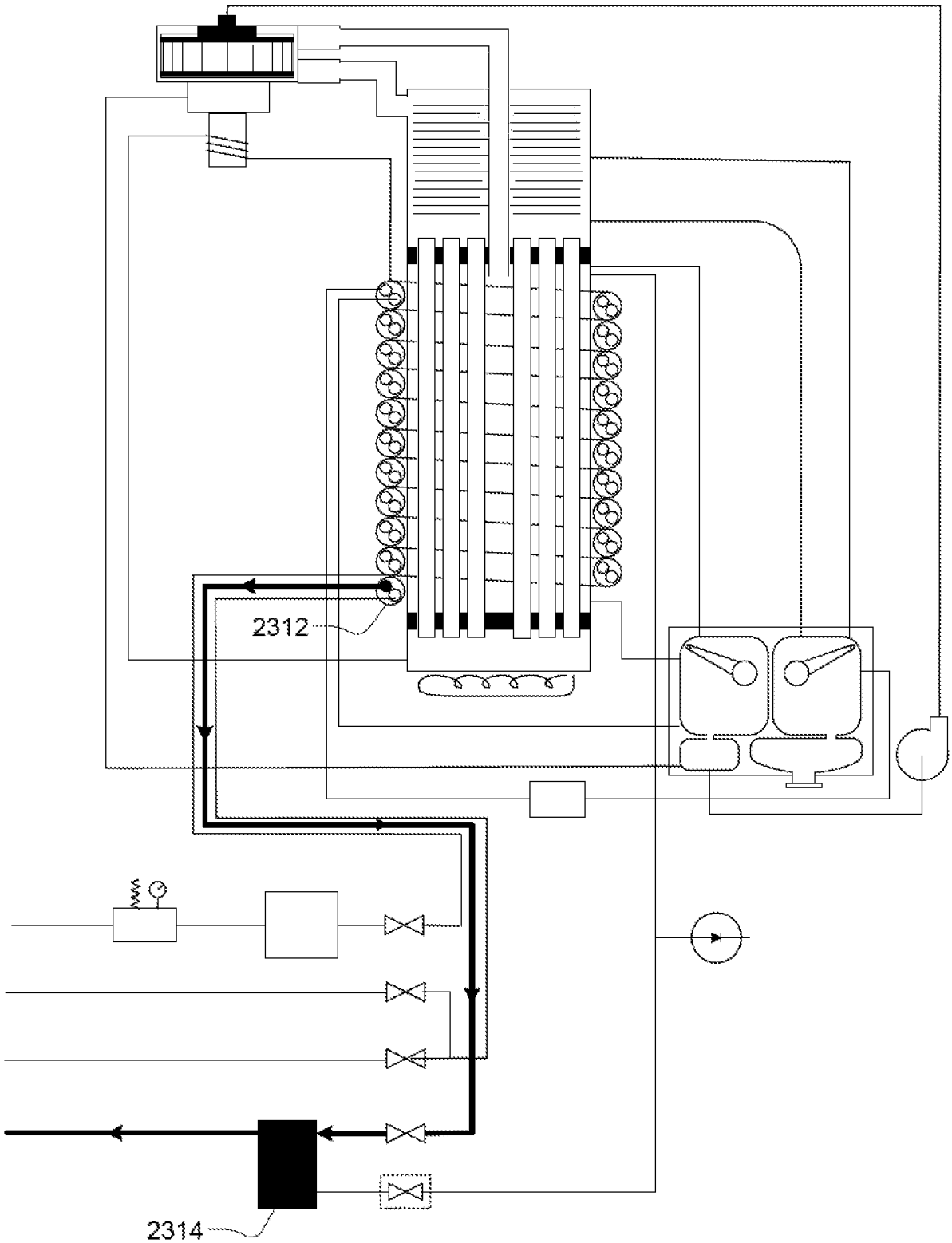



FIG. 23G

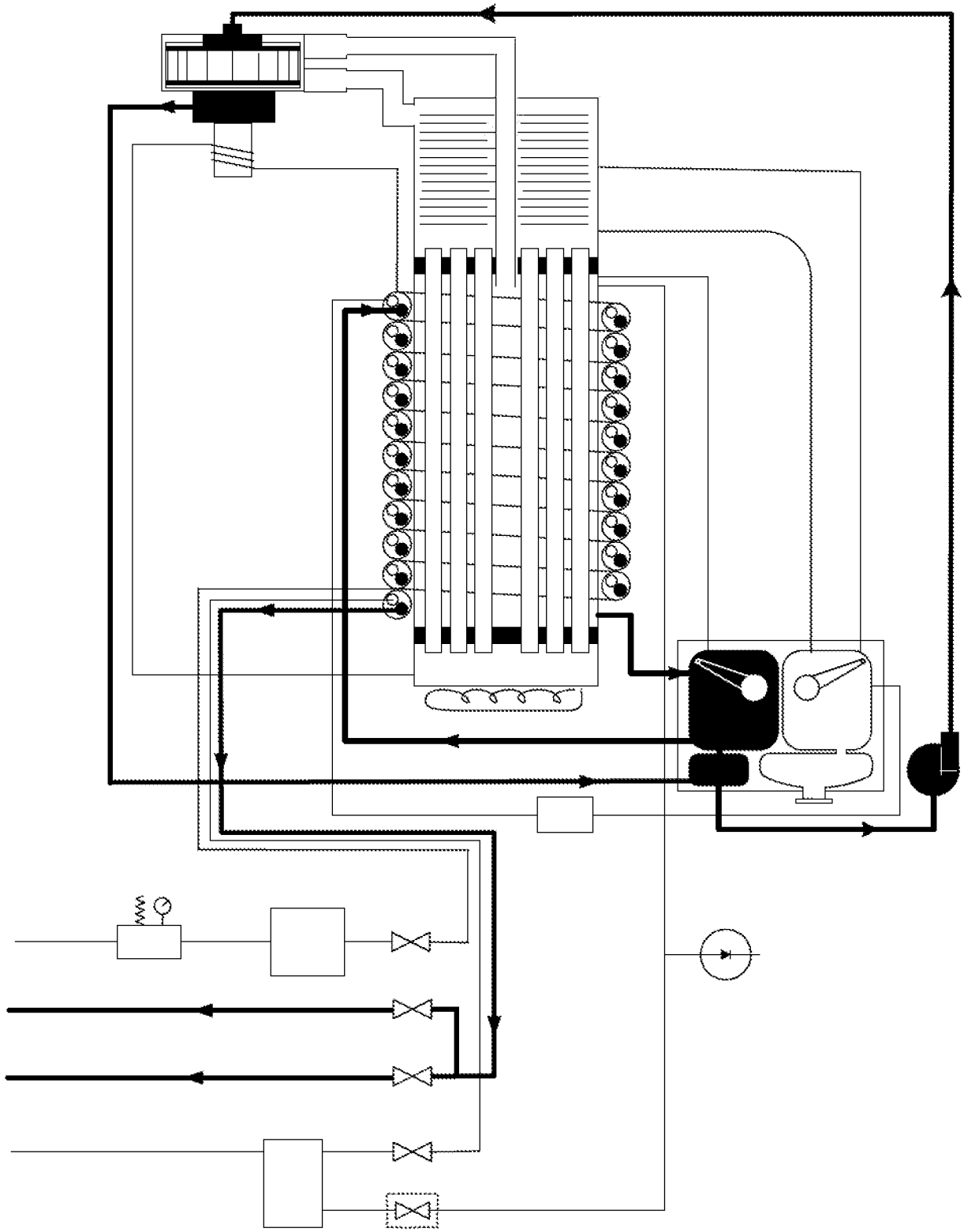


FIG. 24

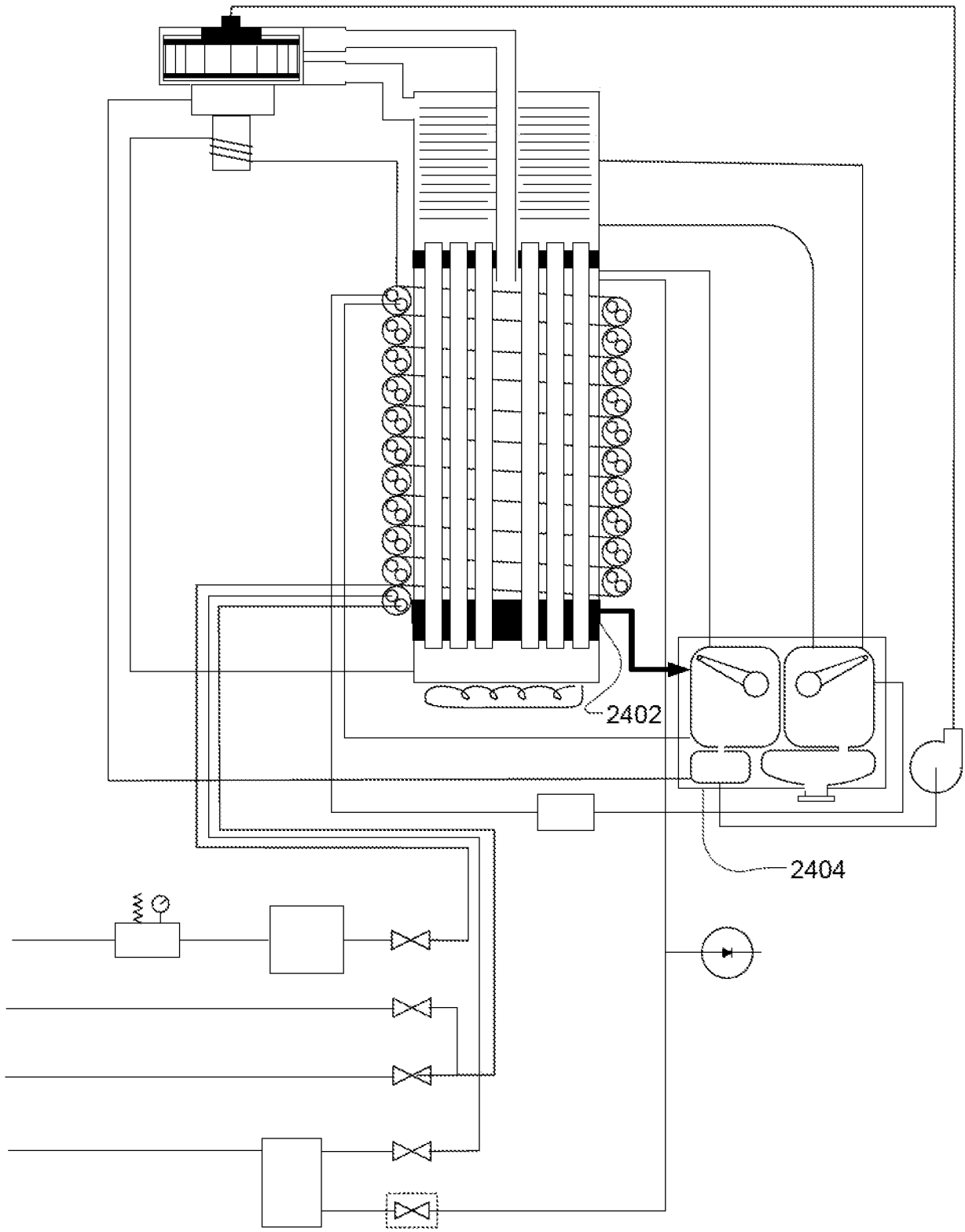



FIG. 24A

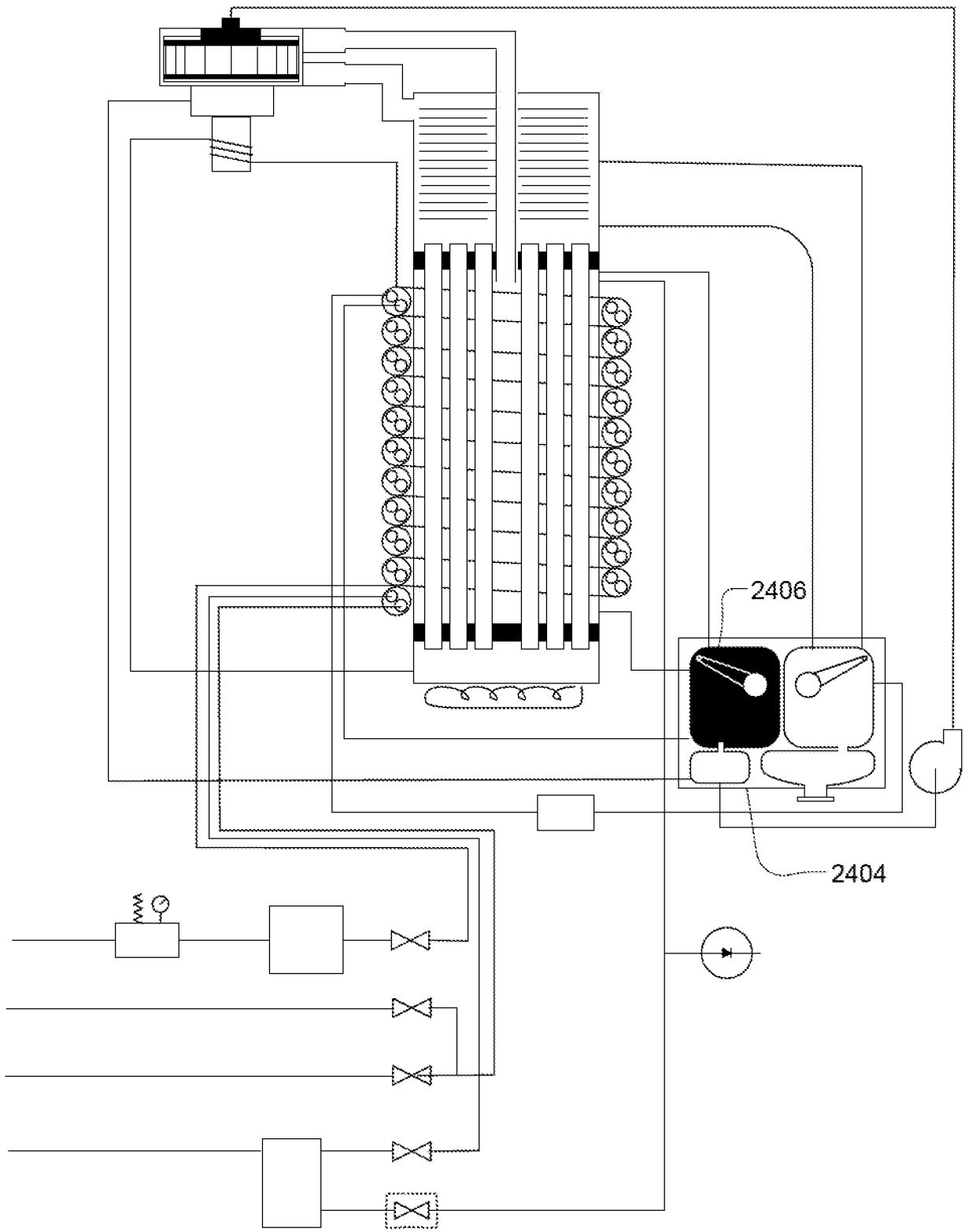



FIG. 24B

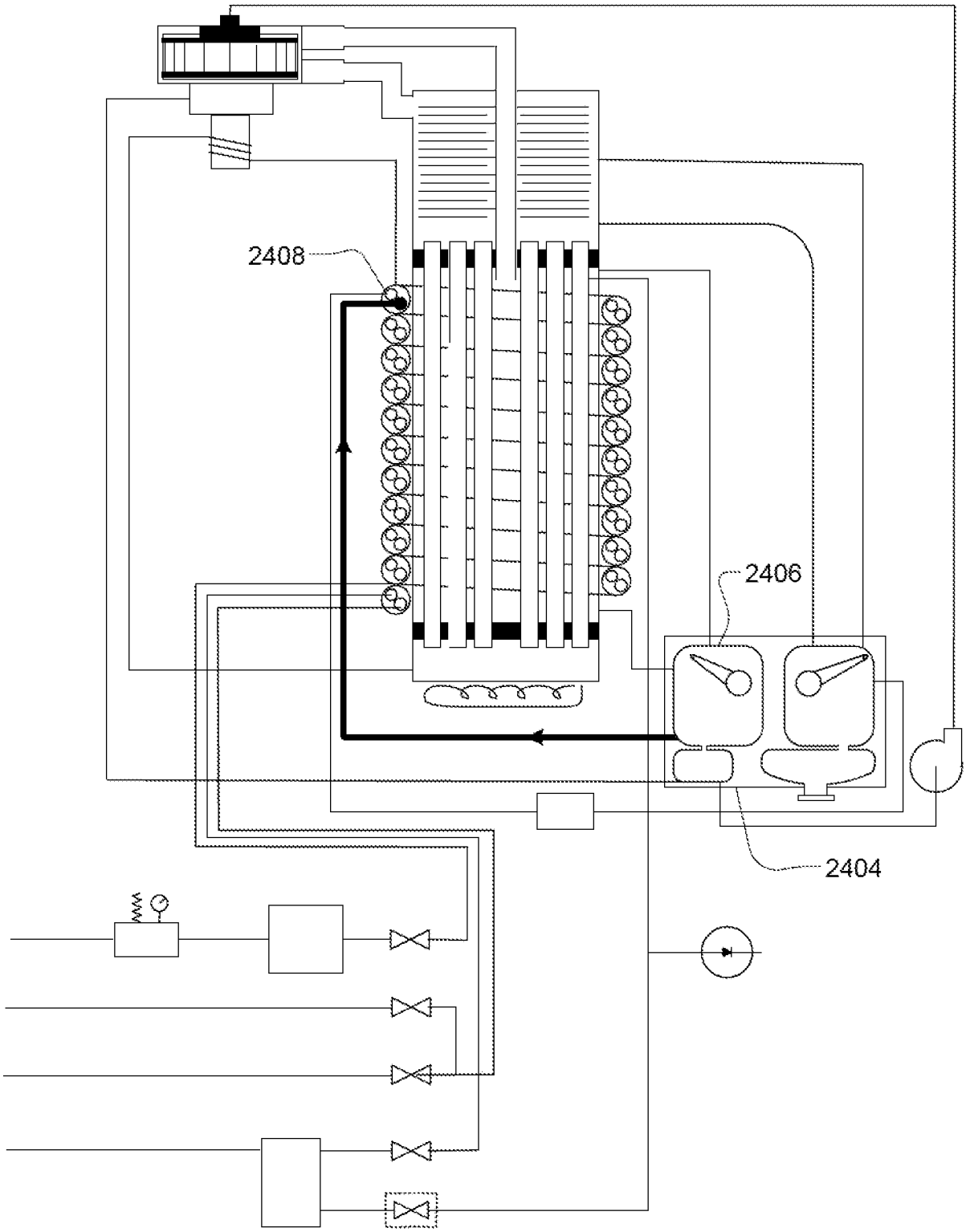



FIG. 24C

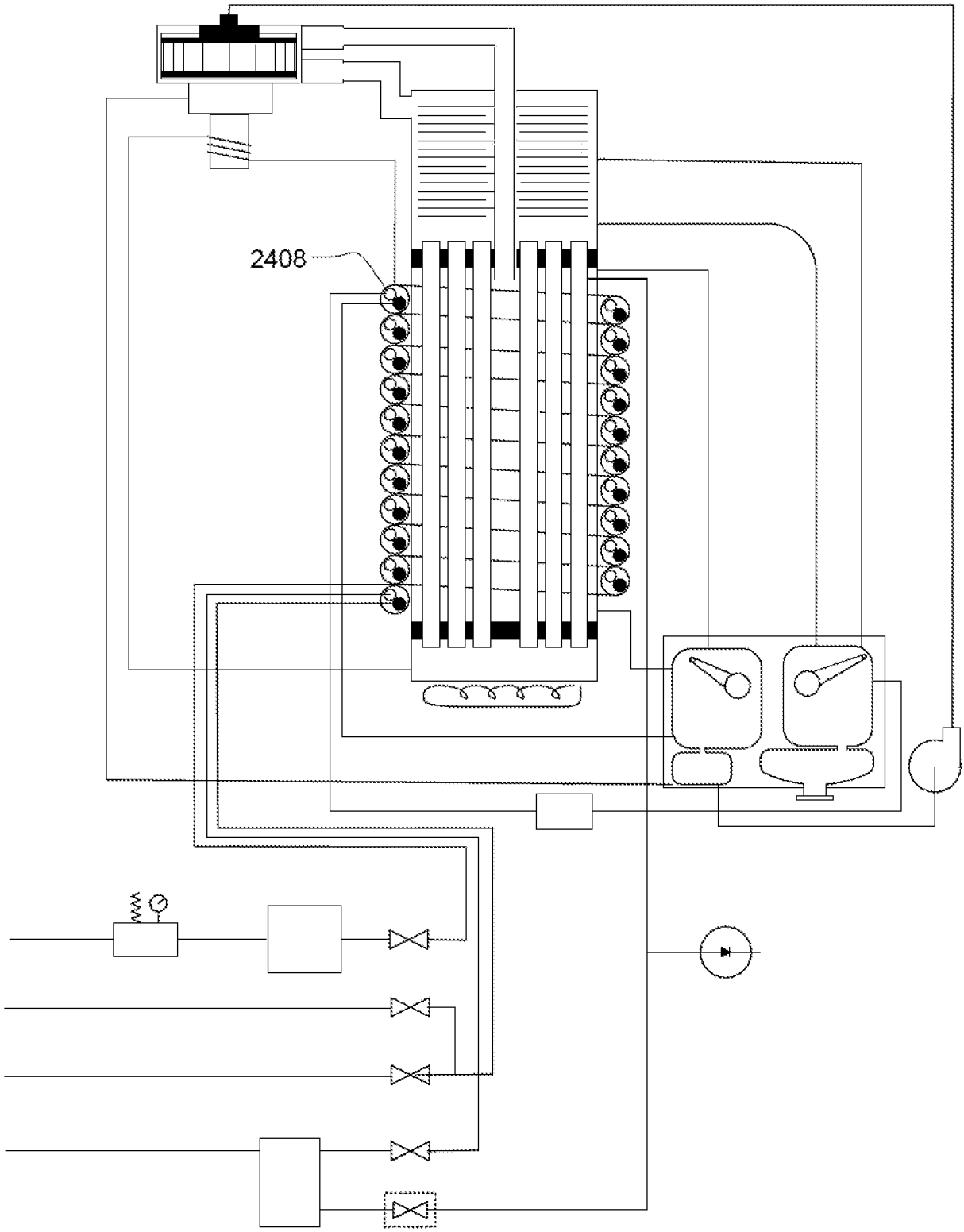



FIG. 24D

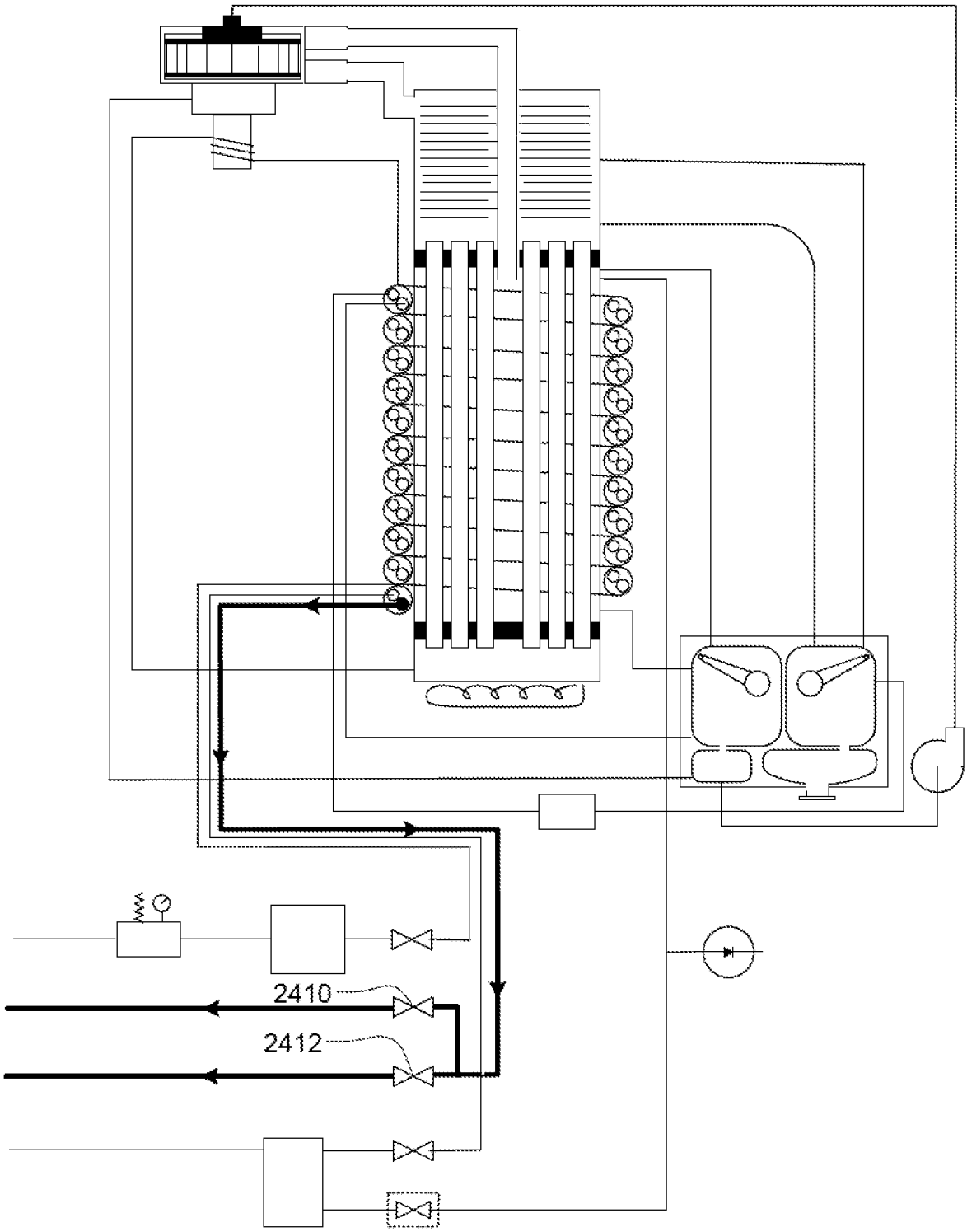



FIG. 24E

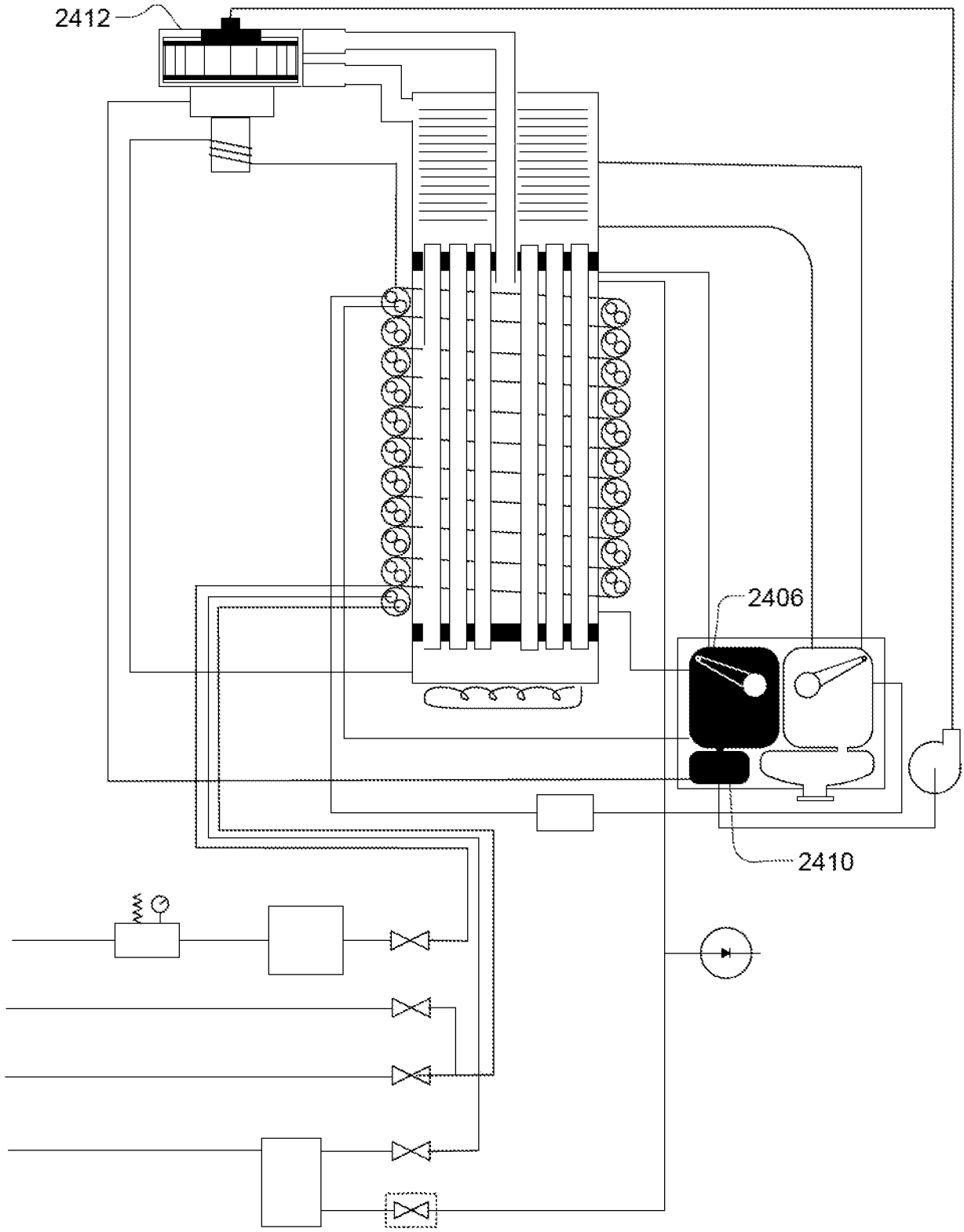



FIG. 24F

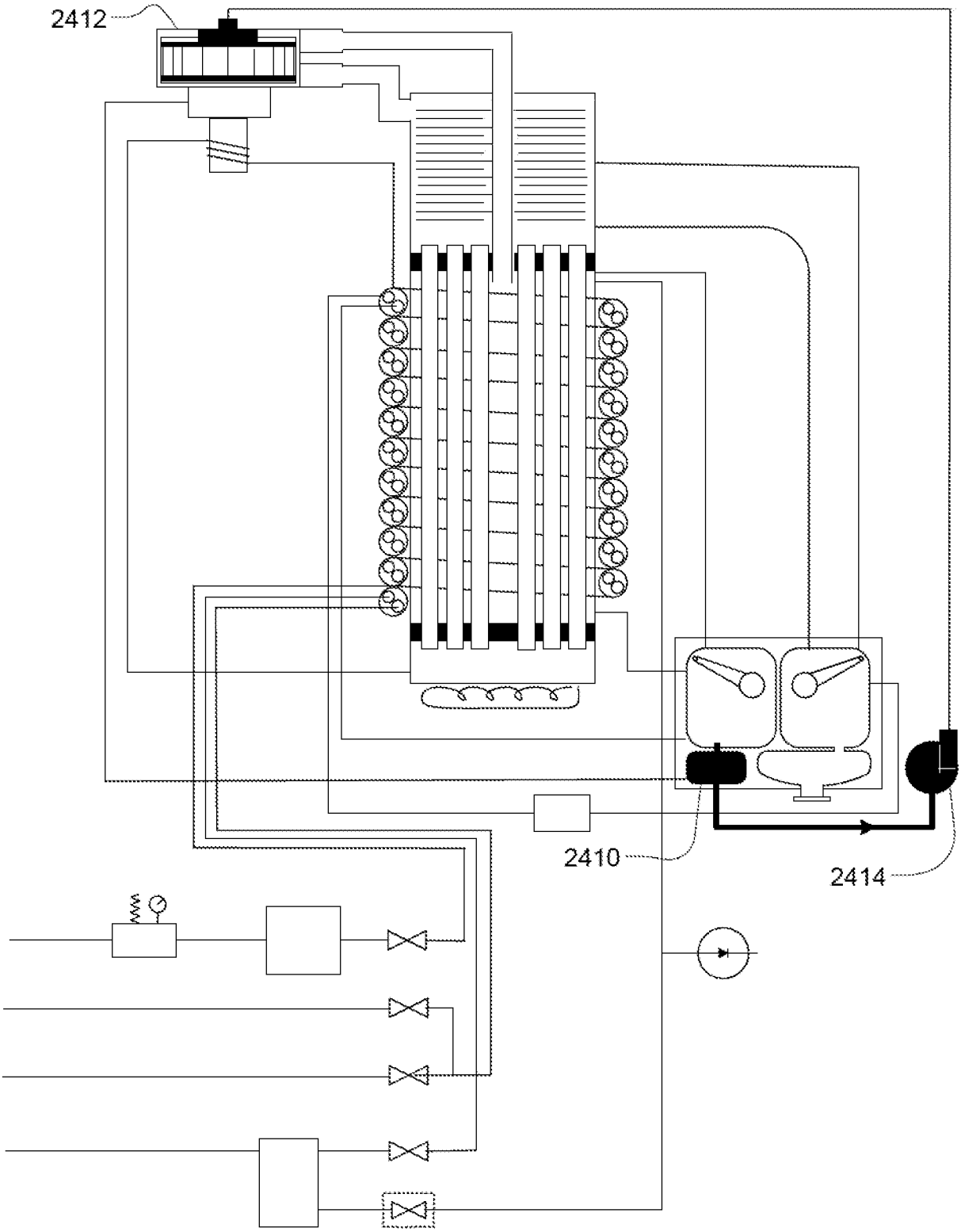



FIG. 24G

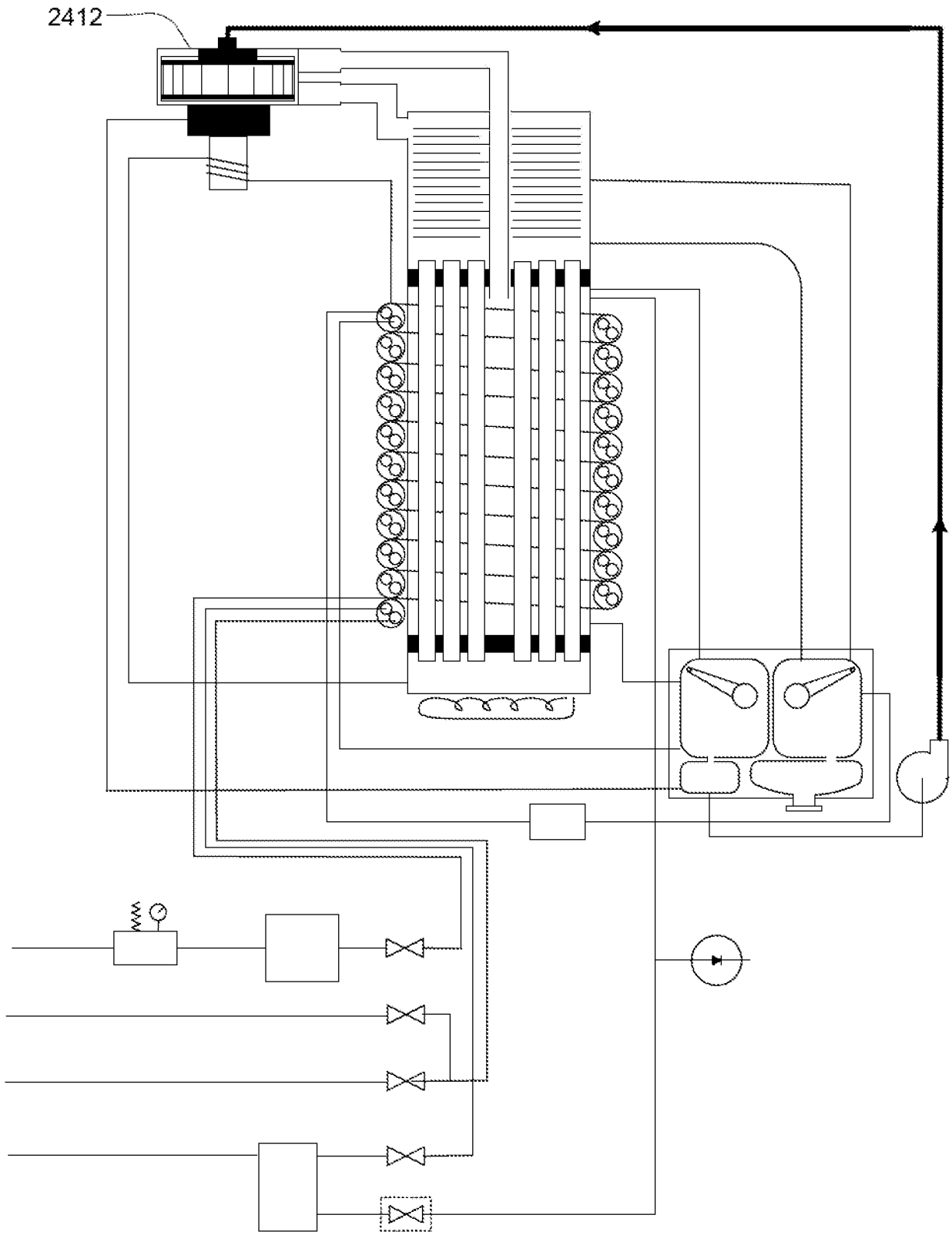



FIG. 24H

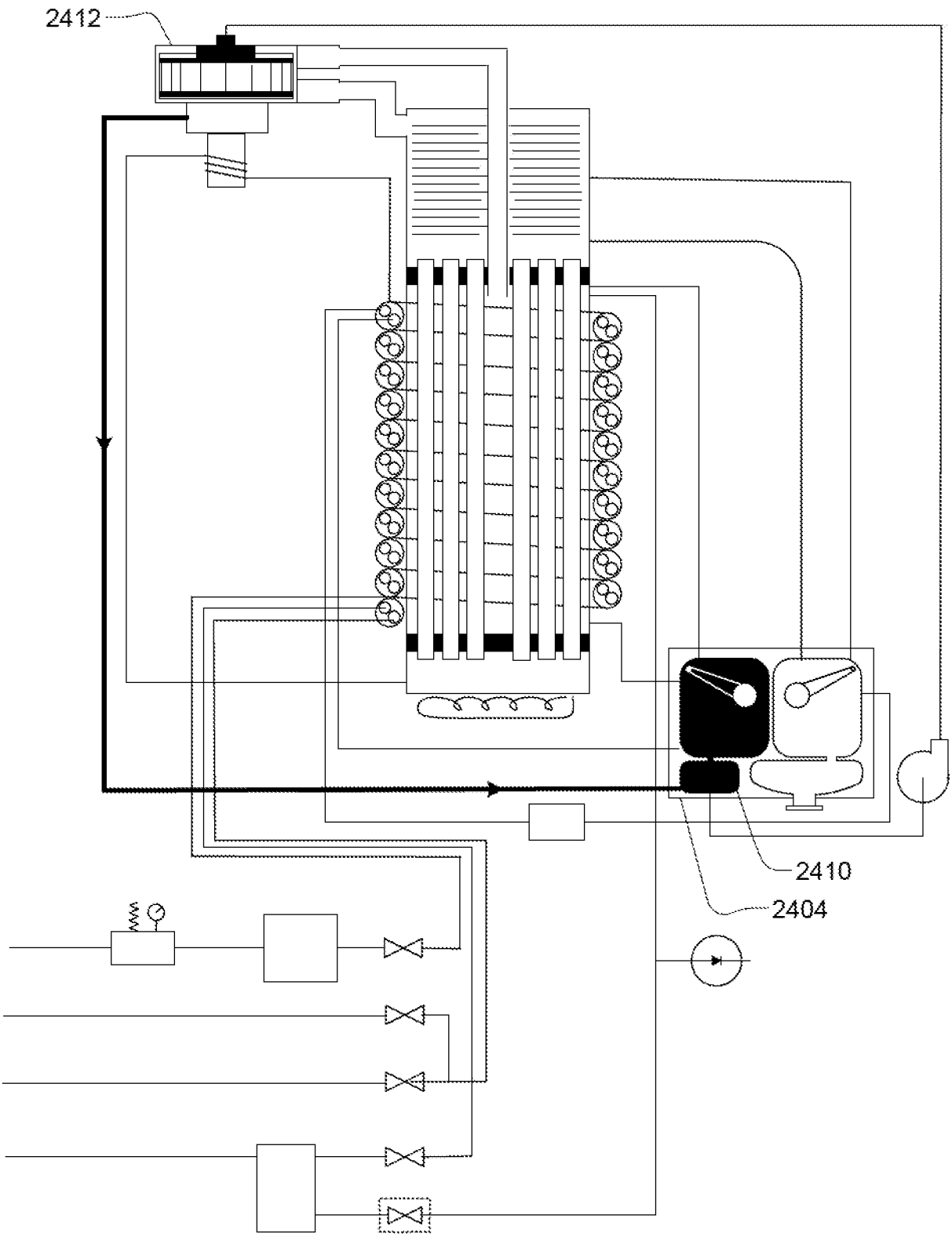



FIG. 24I

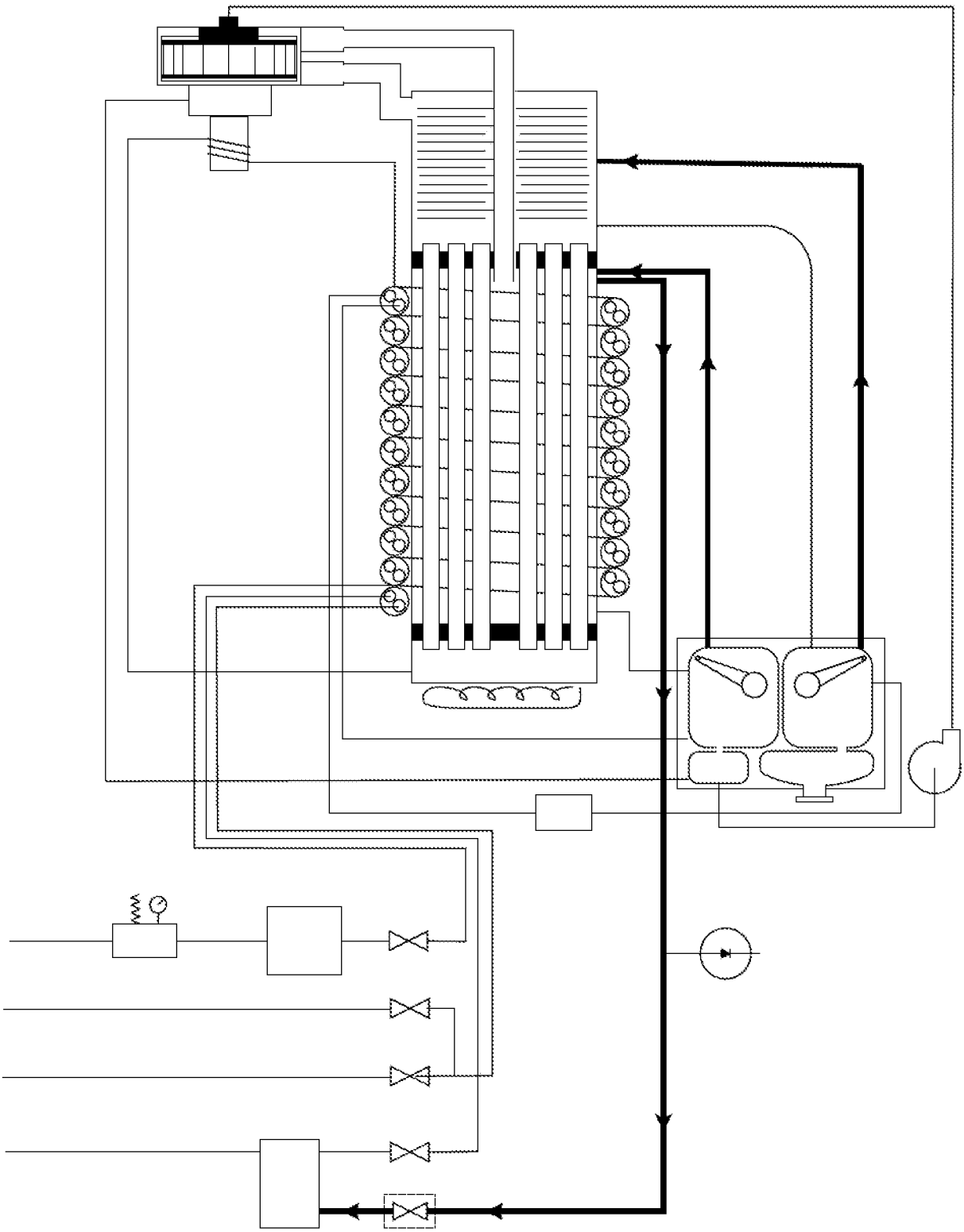


FIG. 25

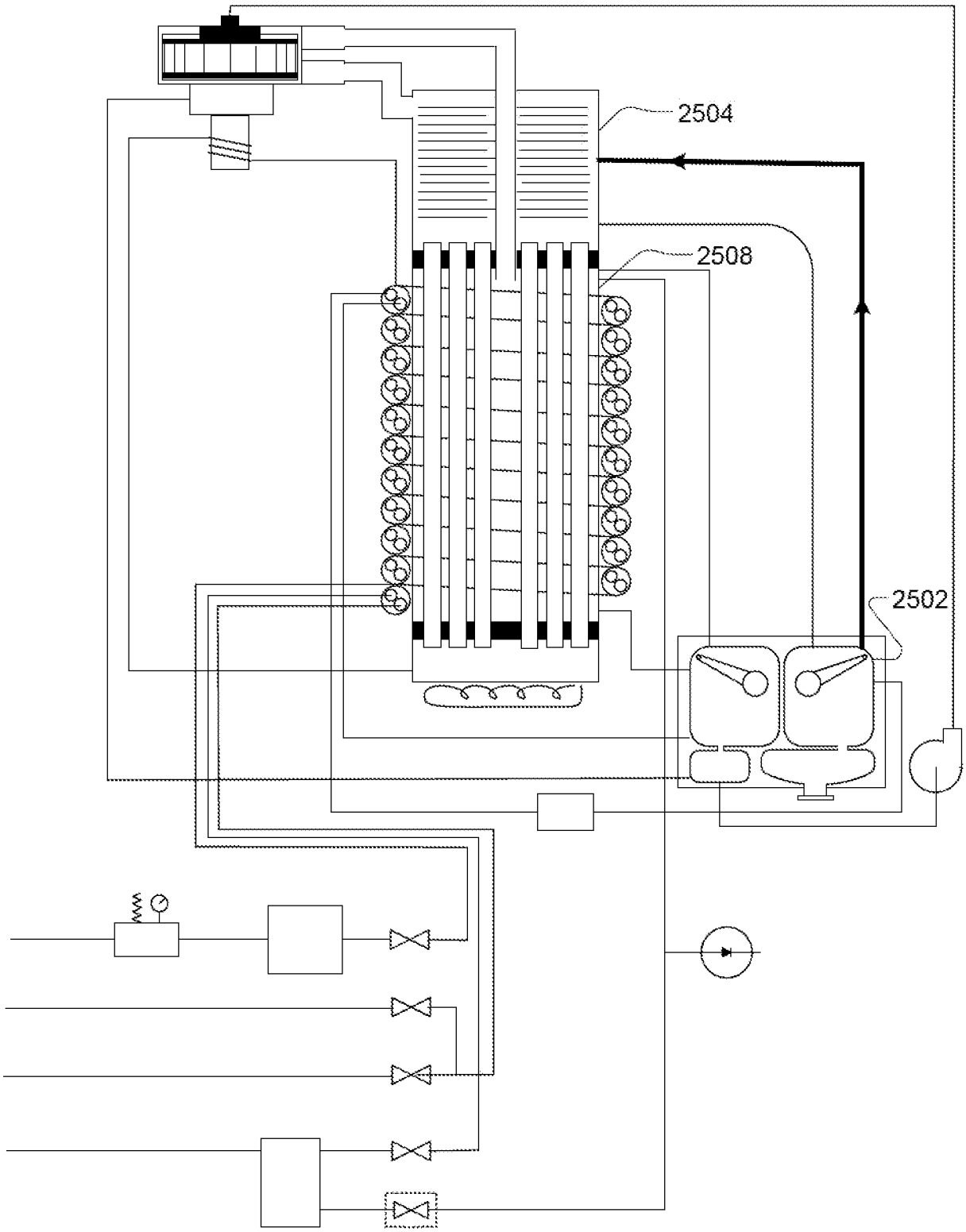



FIG. 25A

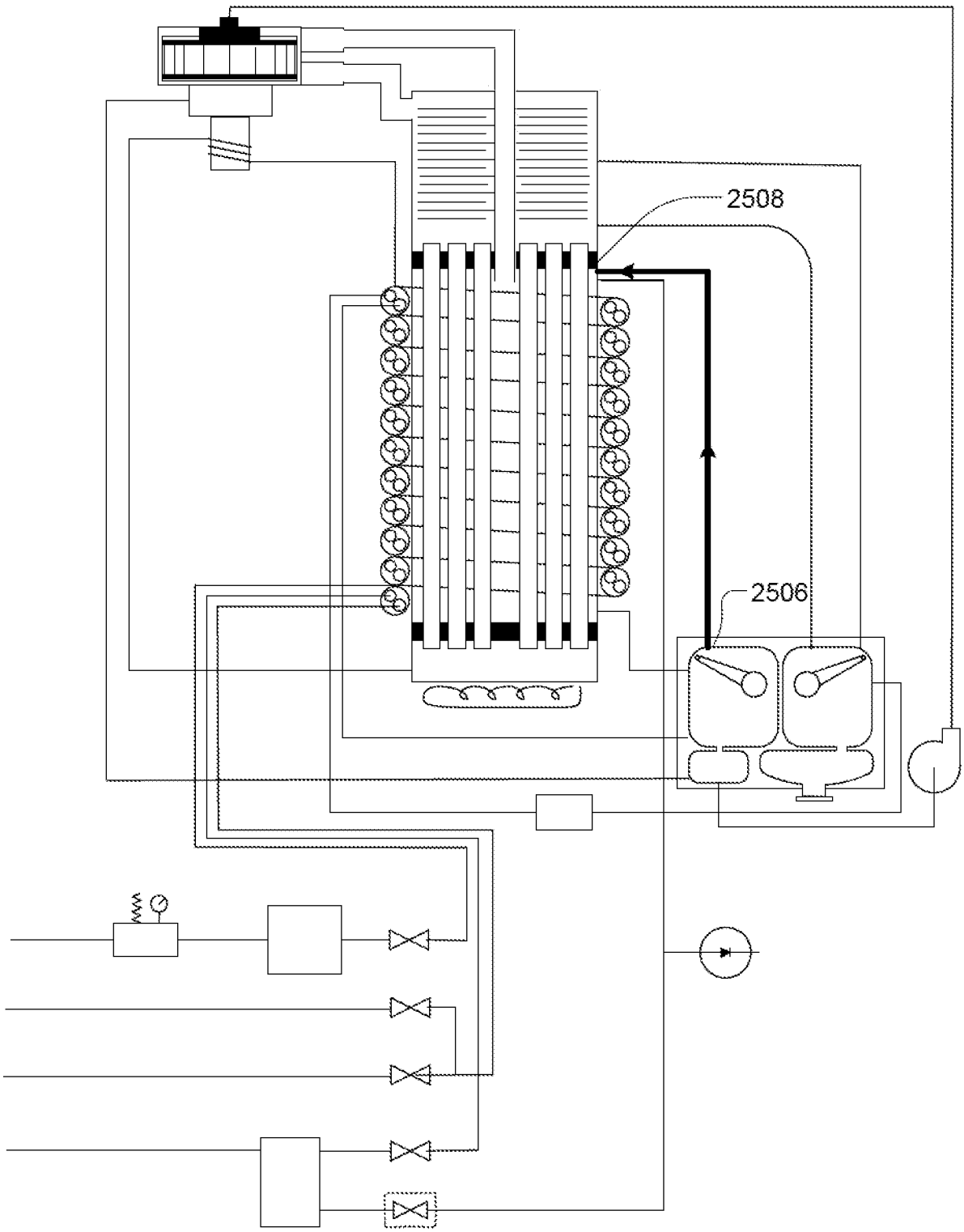



FIG. 25B

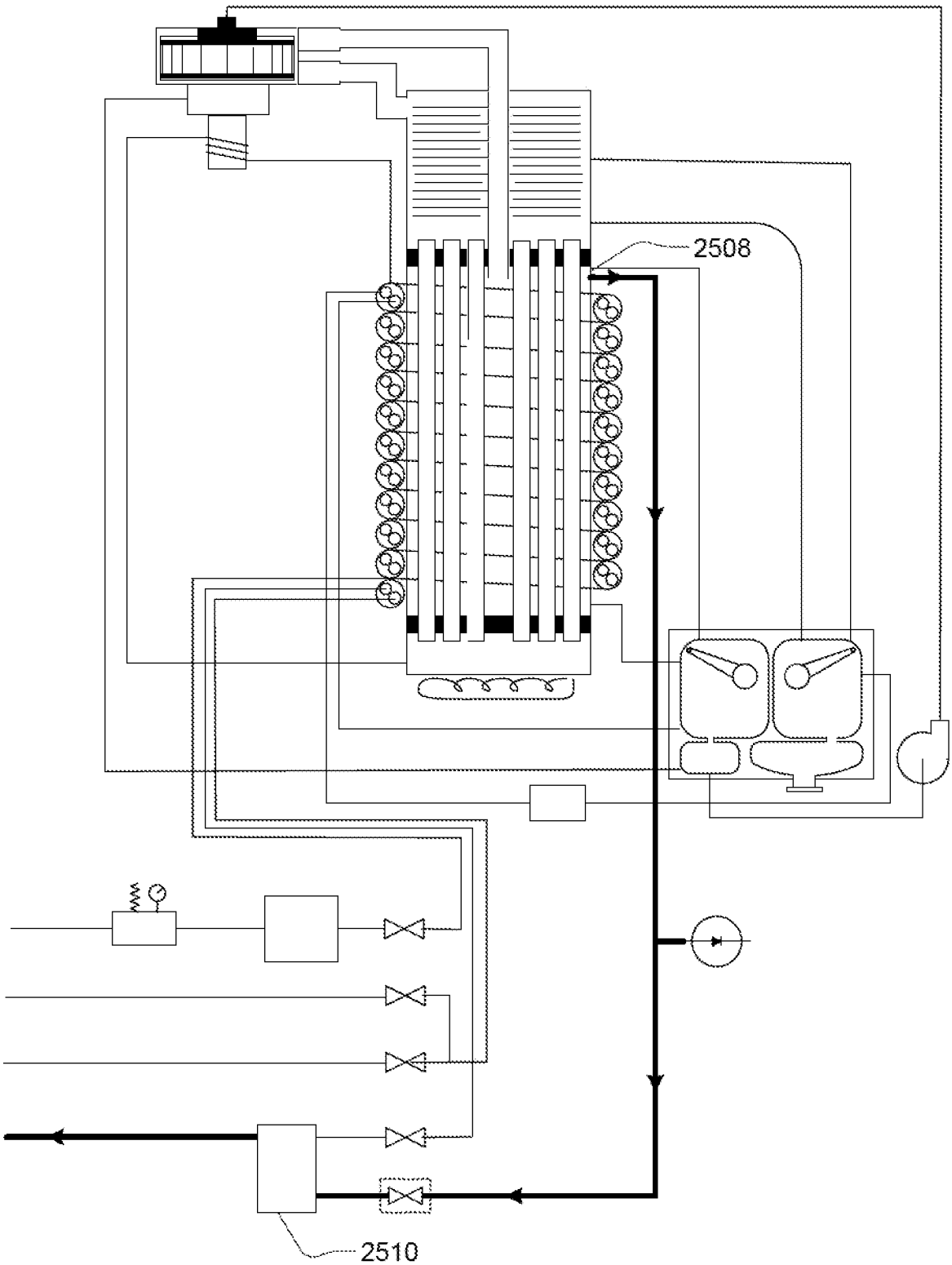



FIG. 25C

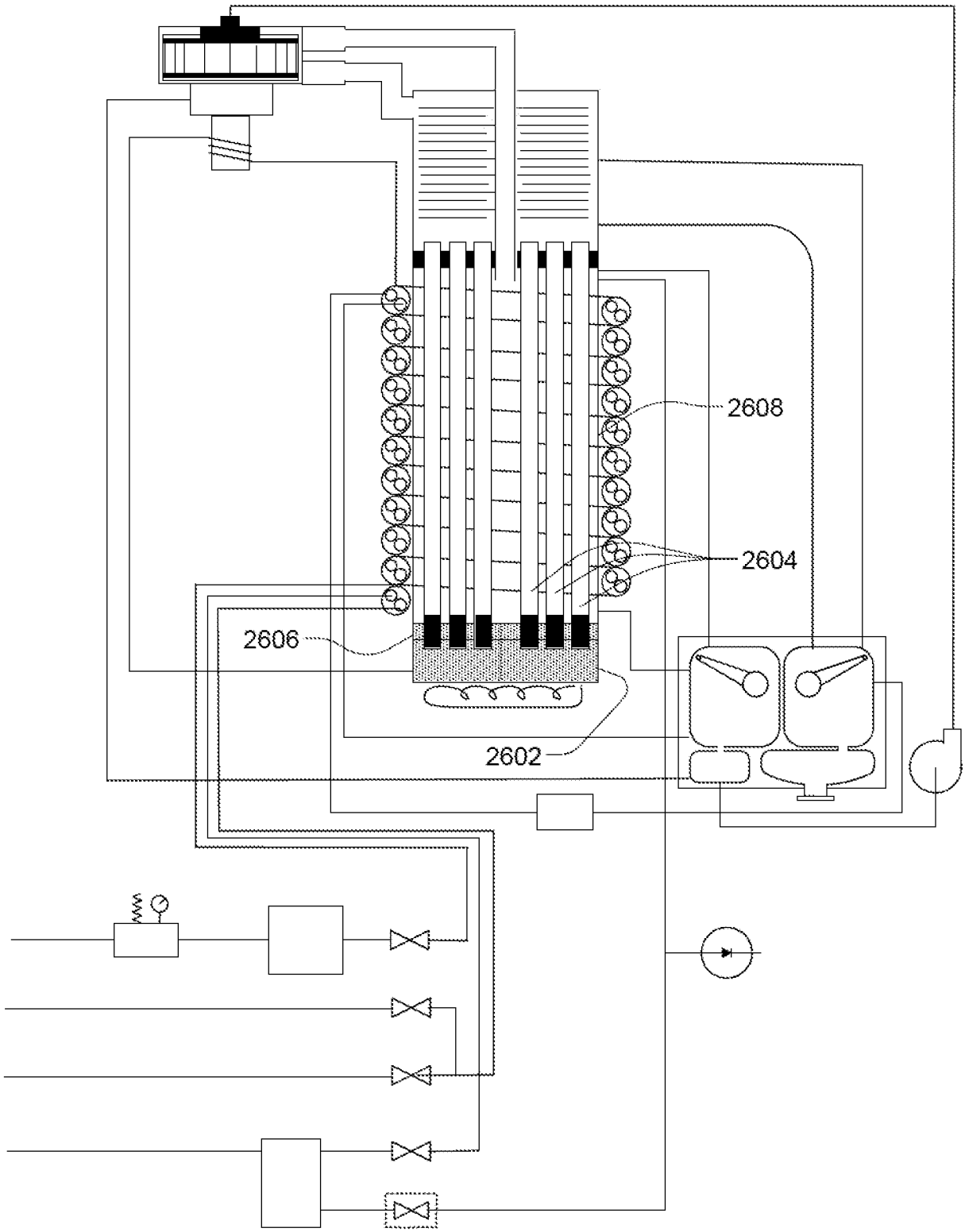



FIG. 26

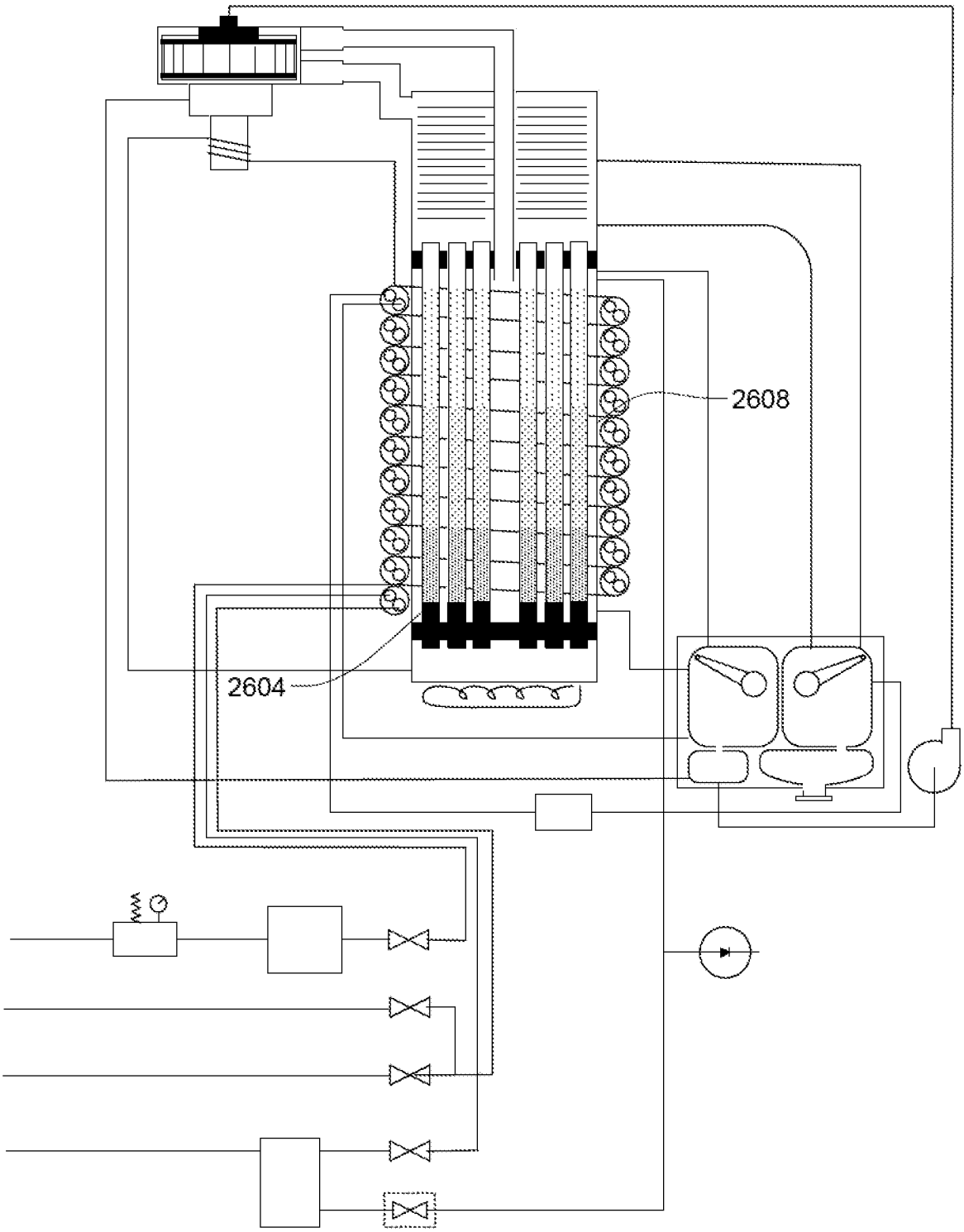



FIG. 26A

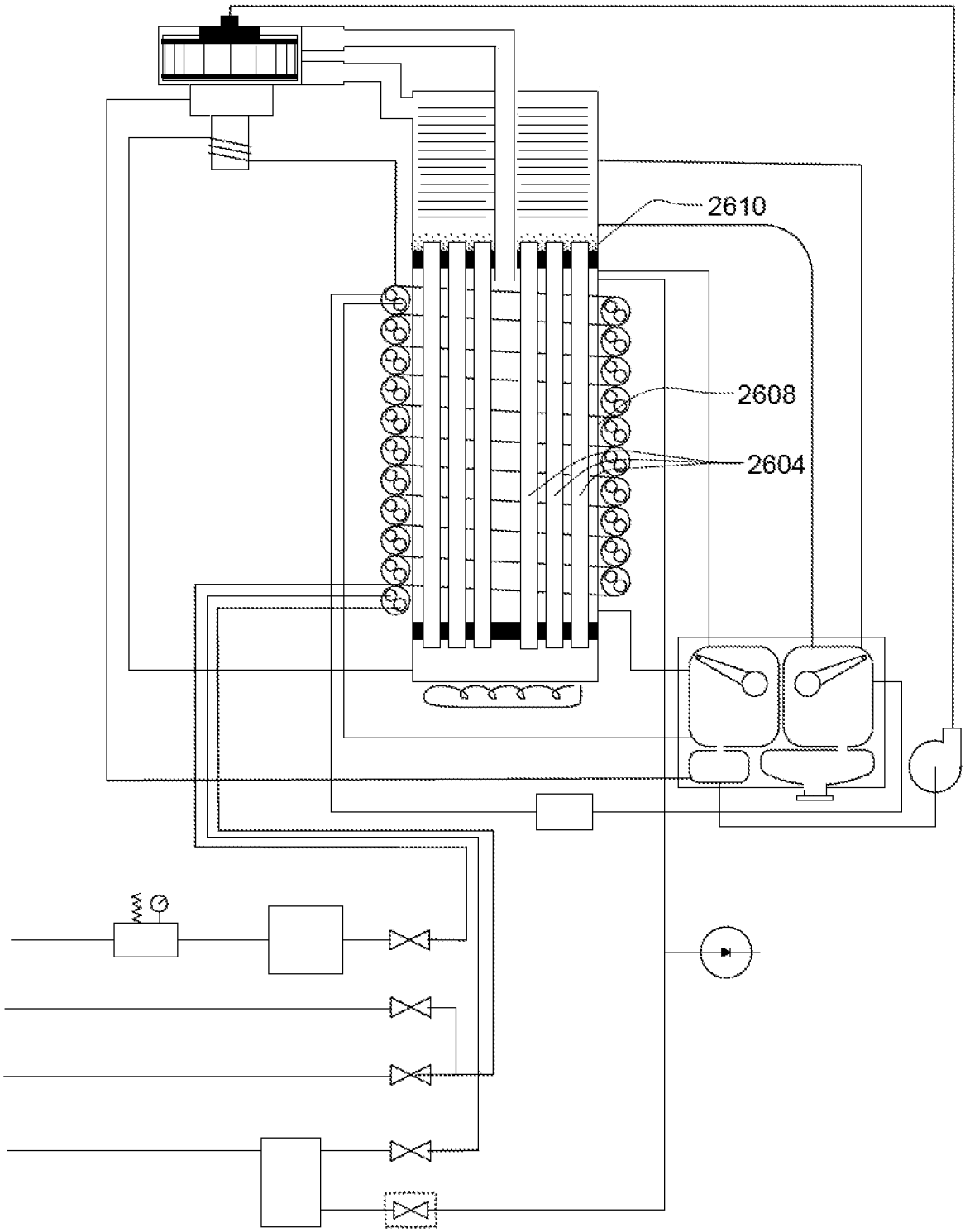



FIG. 26B

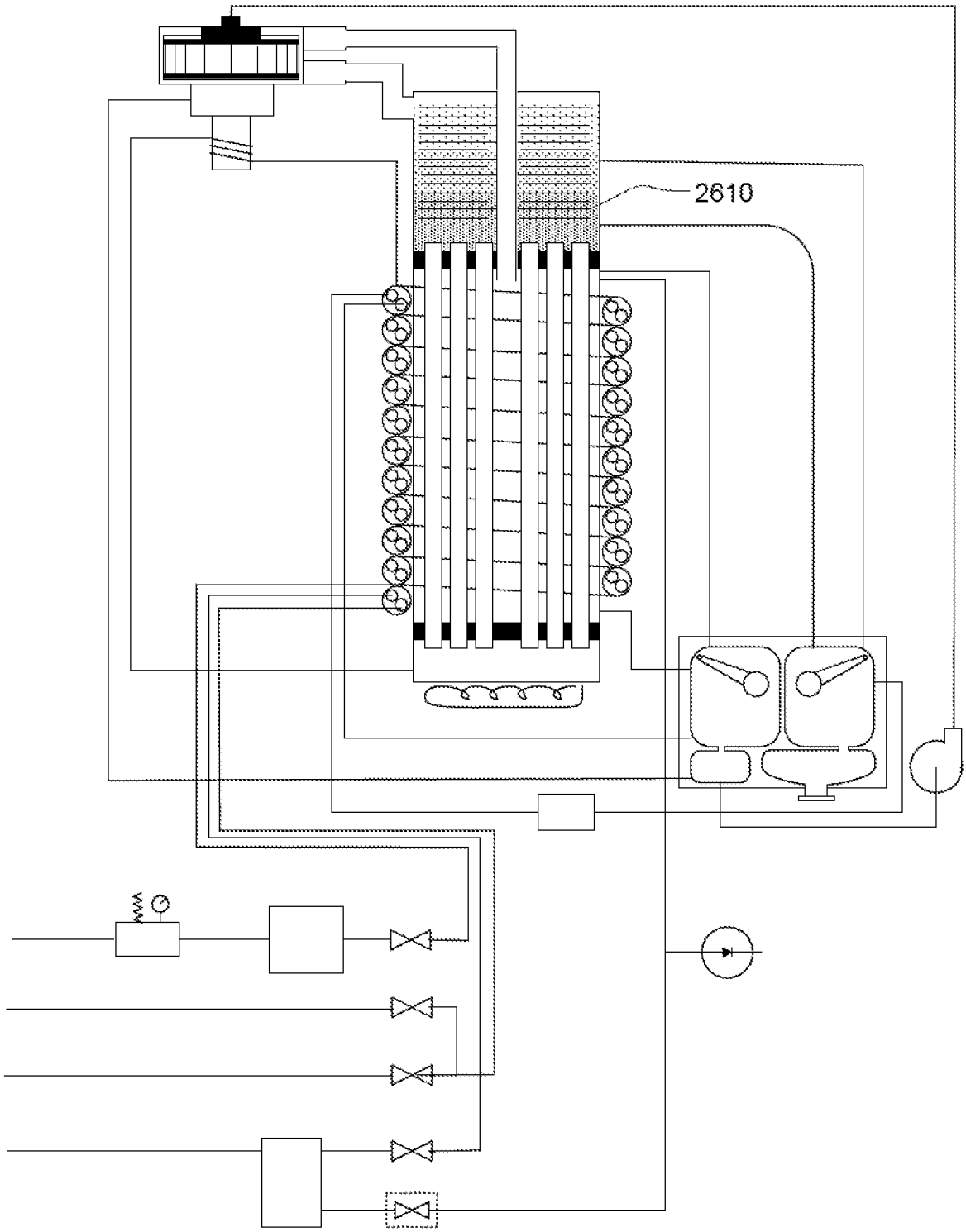



FIG. 26C

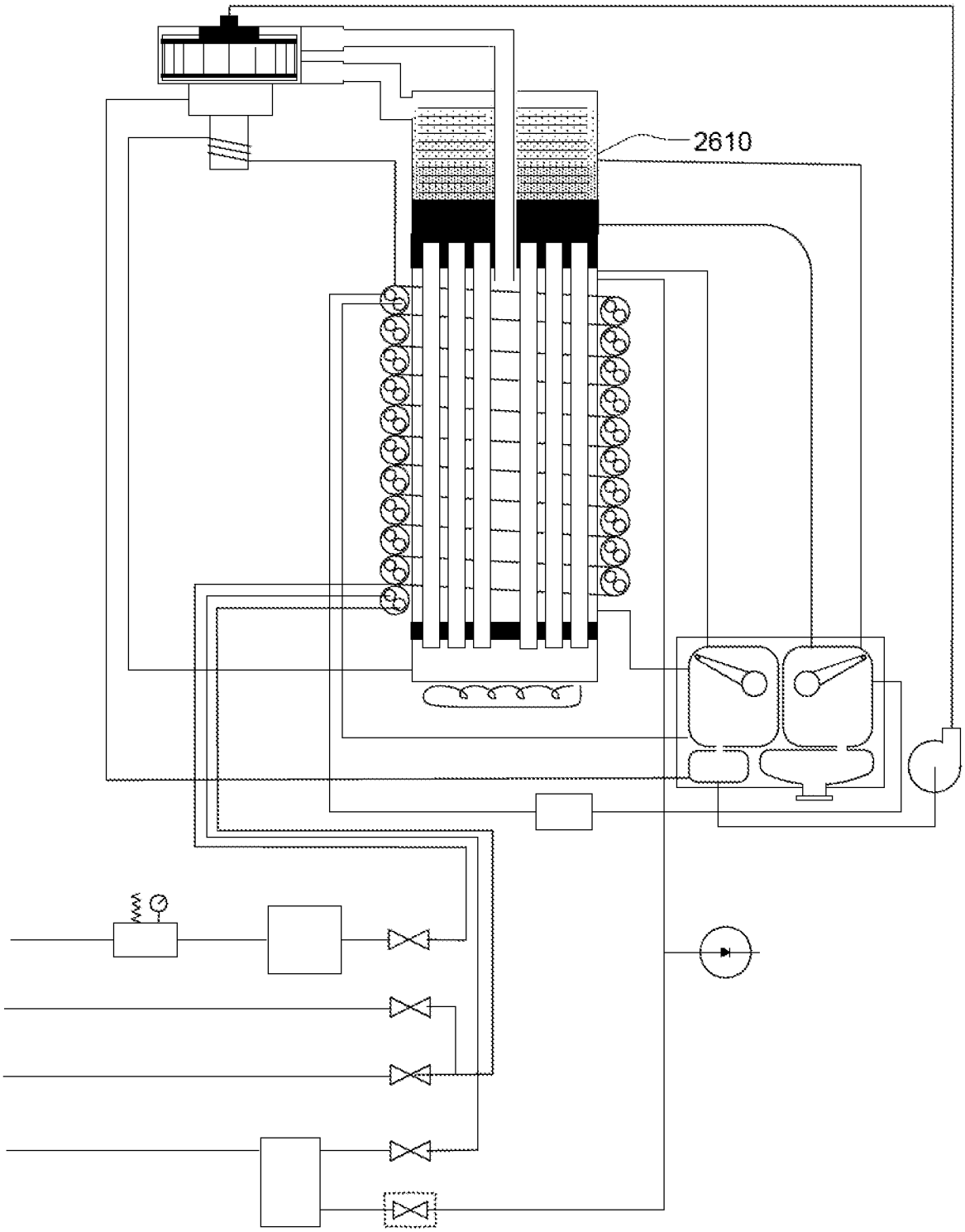



FIG. 26D

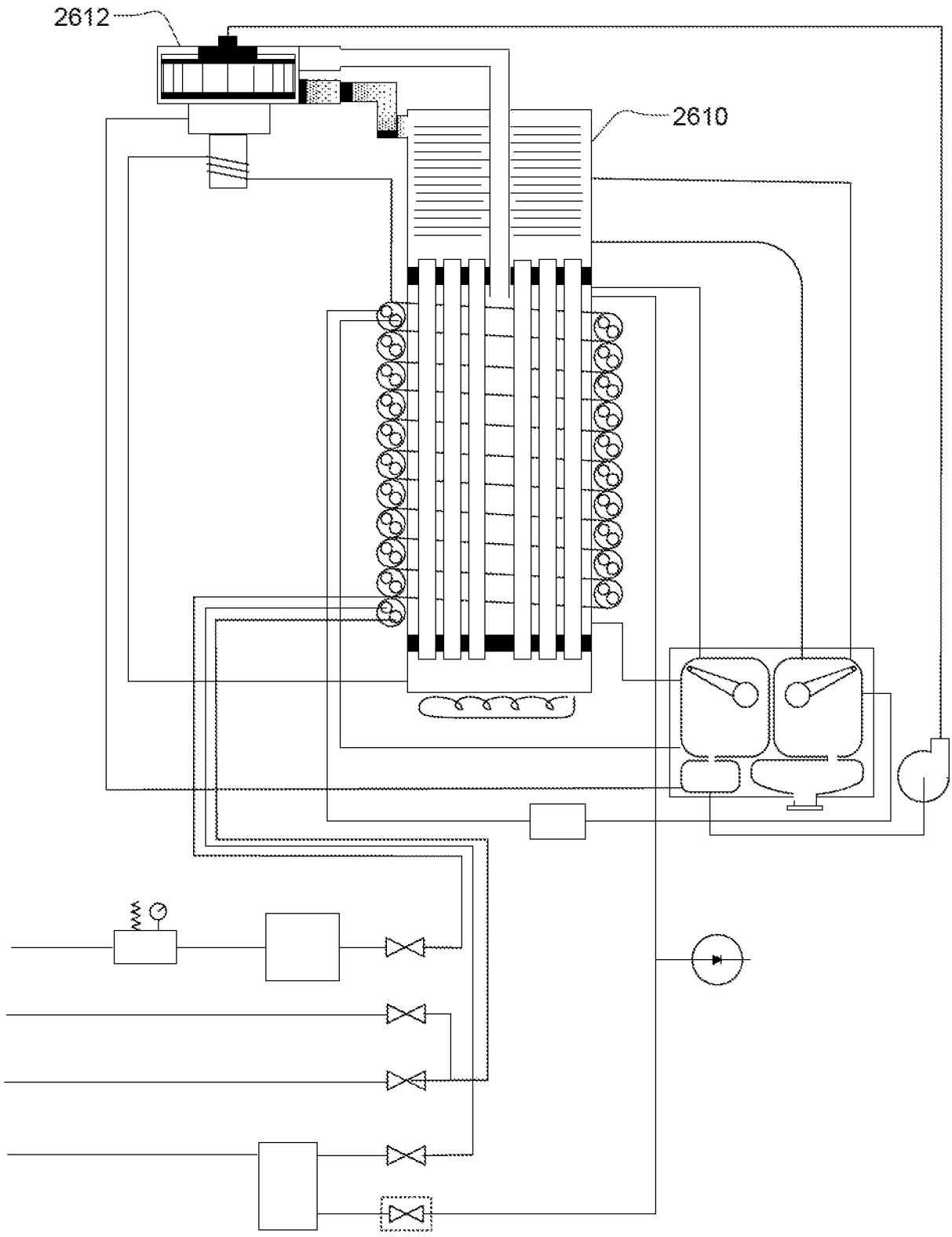



FIG. 26E

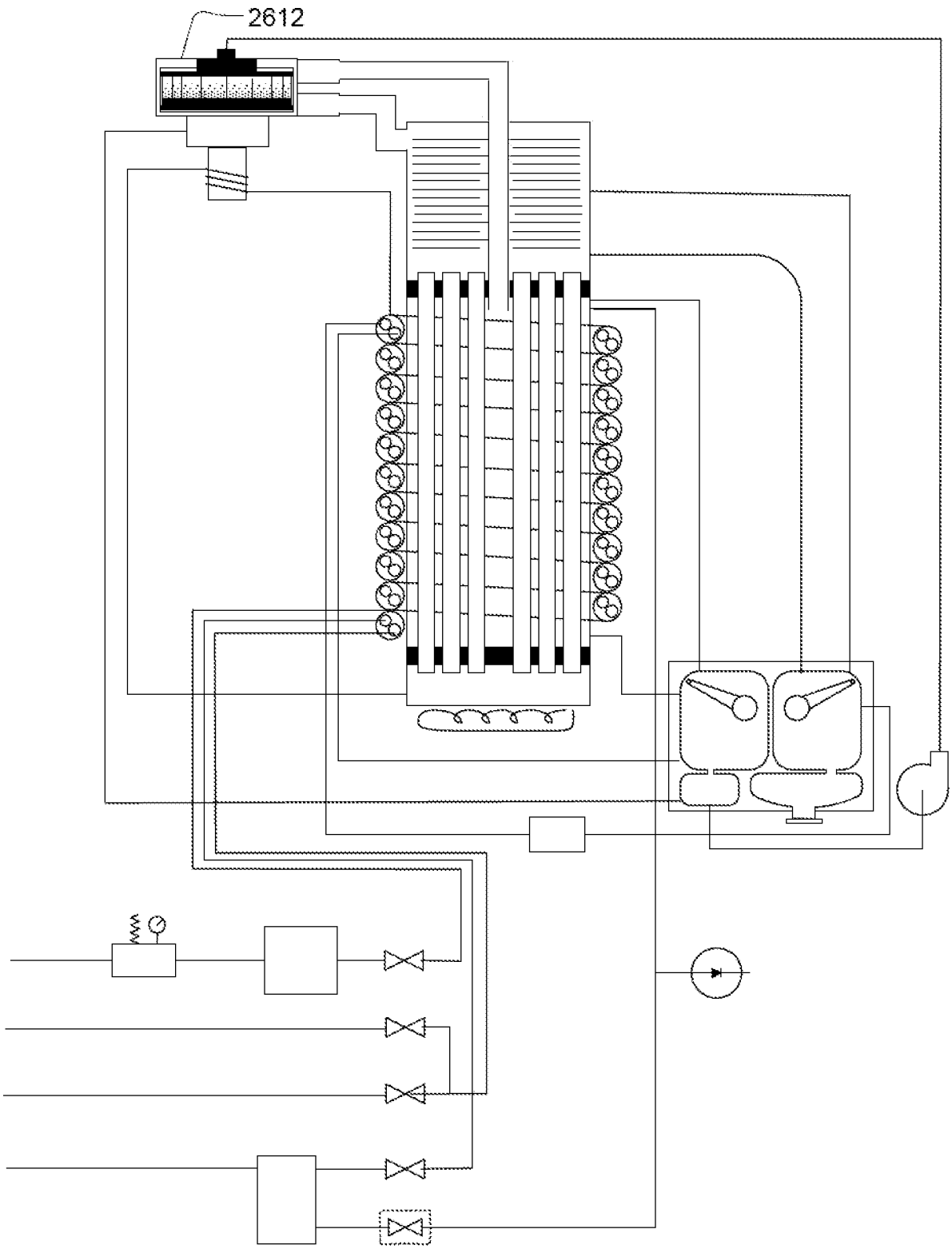



FIG. 26F

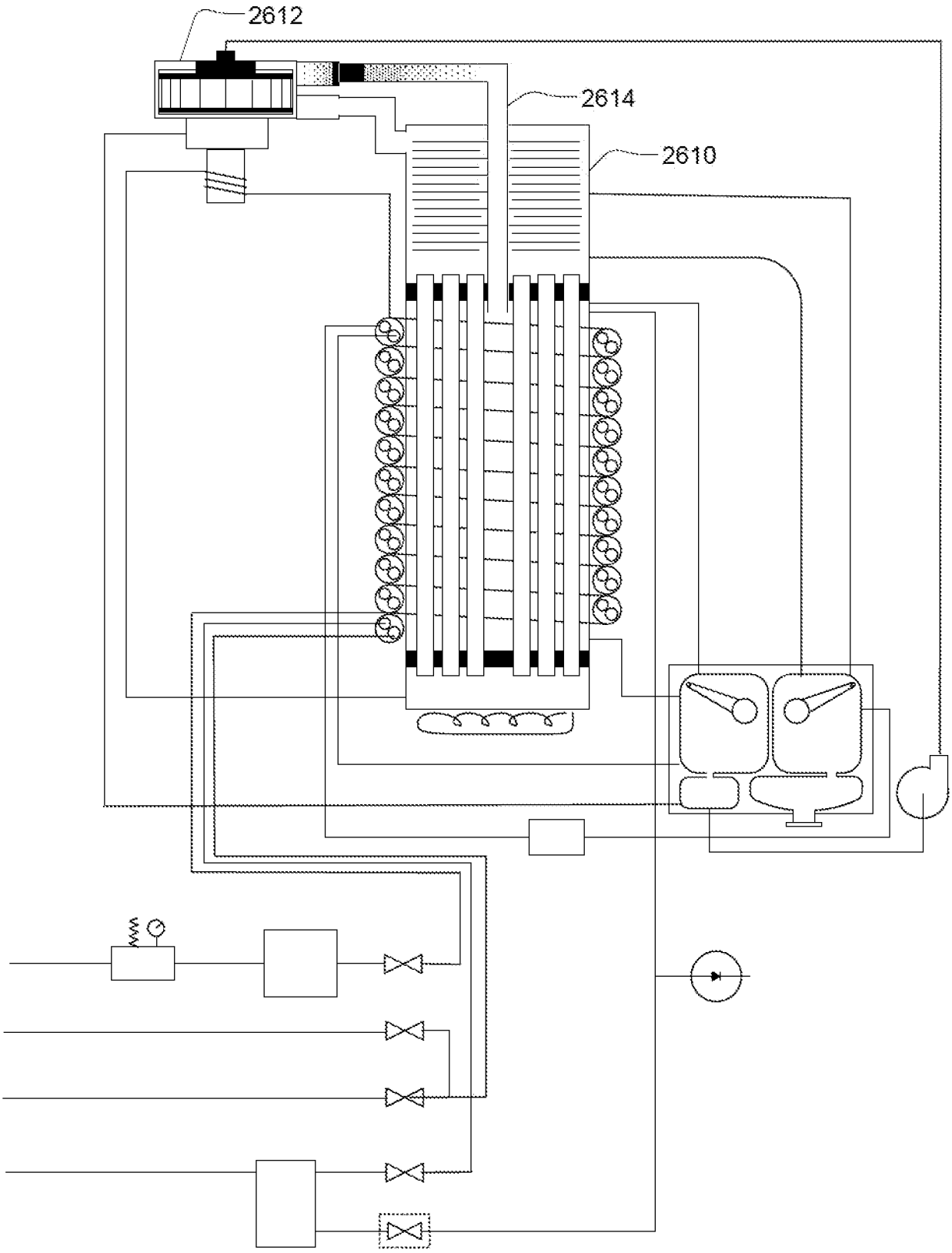



FIG. 26G

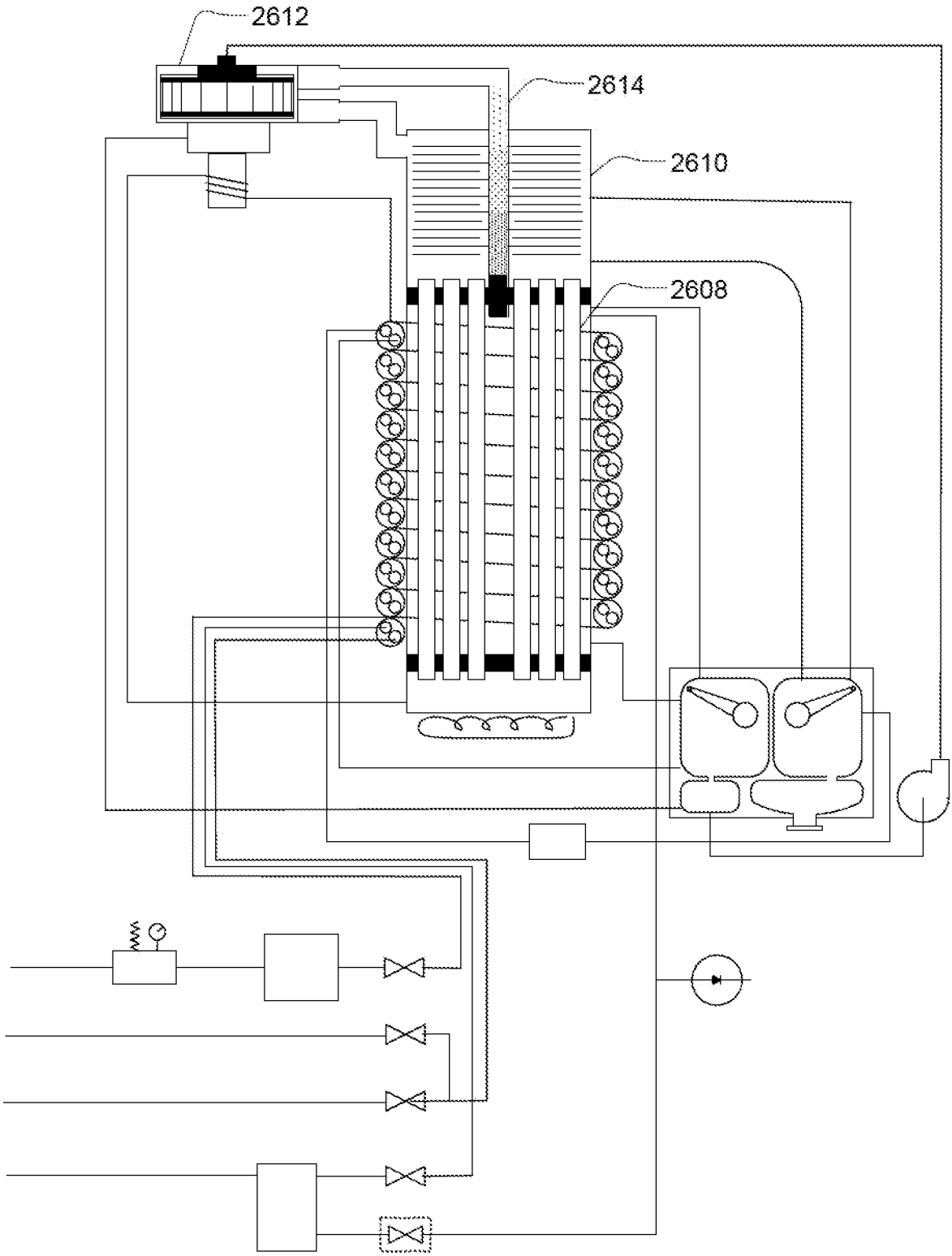



FIG. 26H

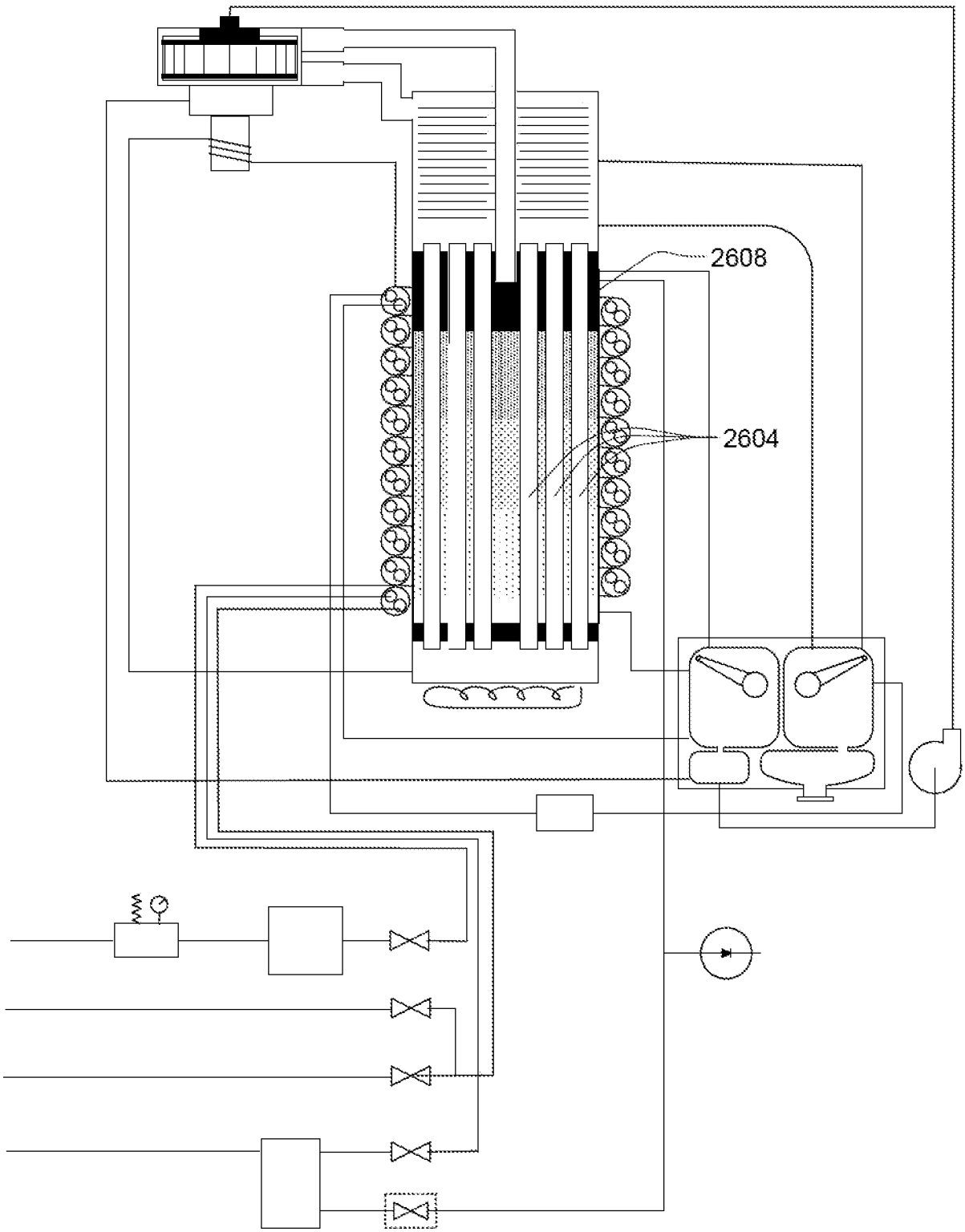



FIG. 26I

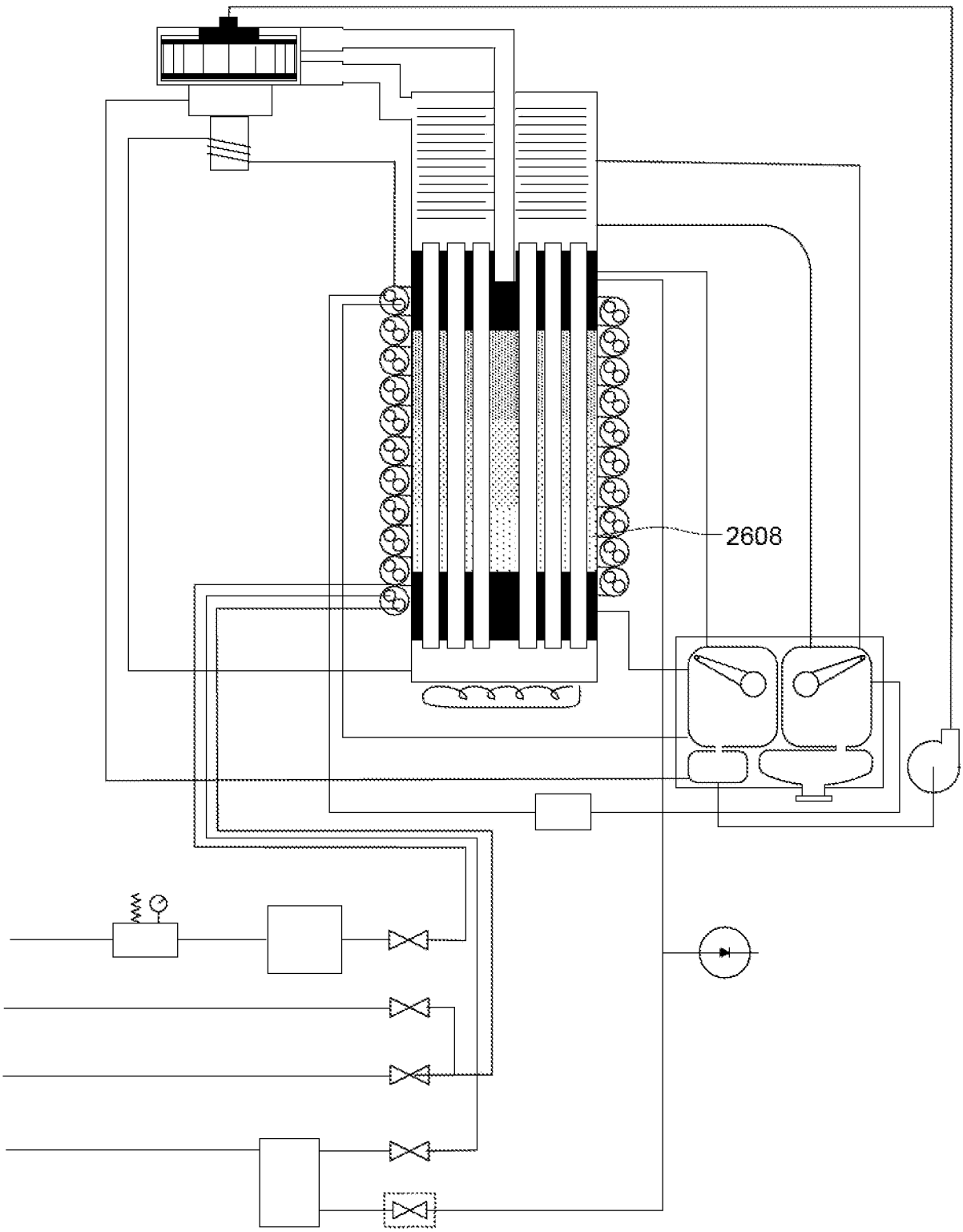



FIG. 26J

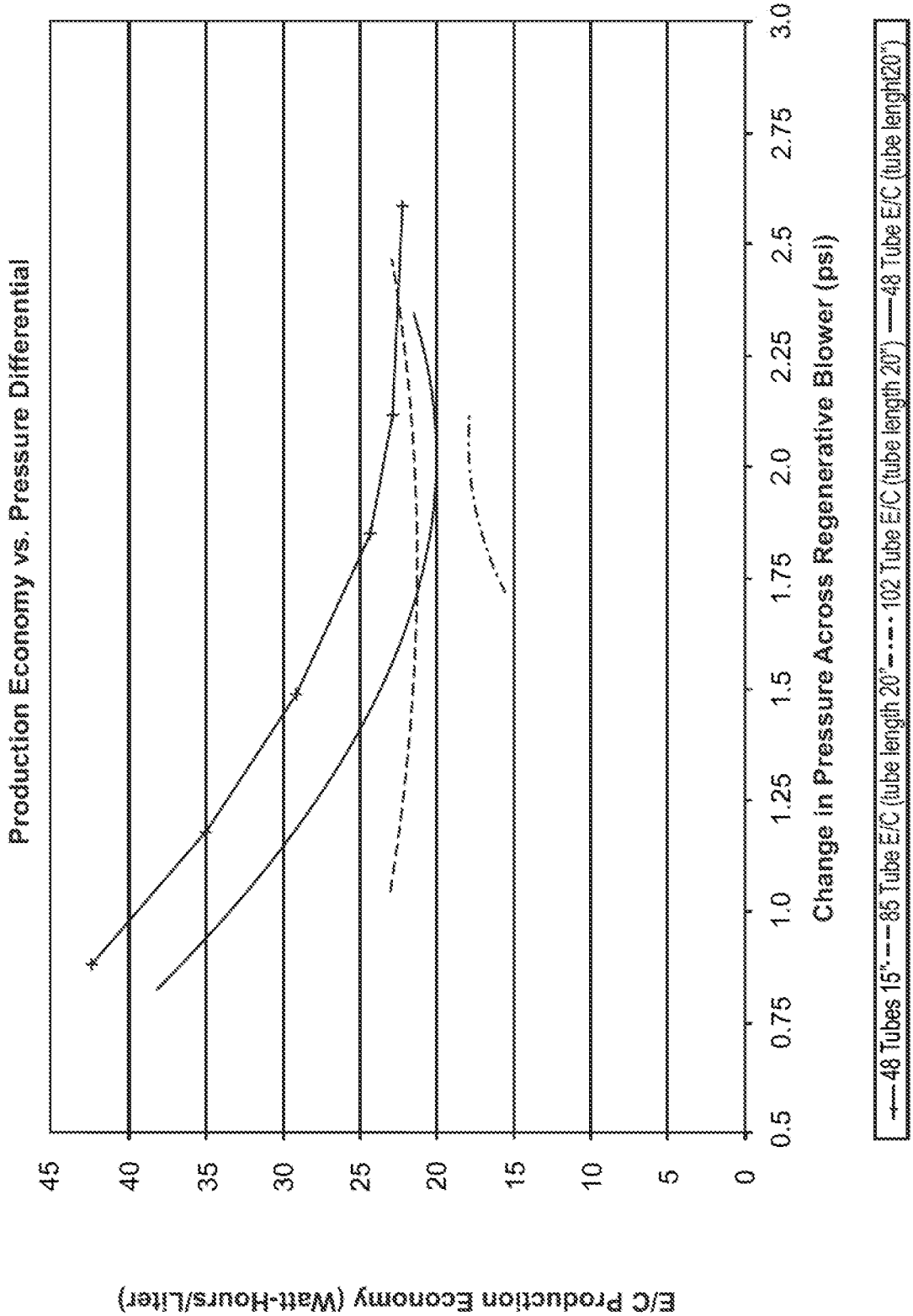

Production Economy vs. Pressure Differential
E/C Production Economy (Watt-Hours/Liter)
Change in Pressure Across Regenerative Blower (psi)
0
5
10
15
20
25
30
35
40
45
0.5
0.75
1.0
1.25
1.5
1.75
2.0
2.25
2.5
2.75
3.0
48 Tubes 15"
85 Tube E/C (tube length 20")
102 Tube E/C (tube length 20")
48 Tube E/C (tube lenght20")

FIG. 27

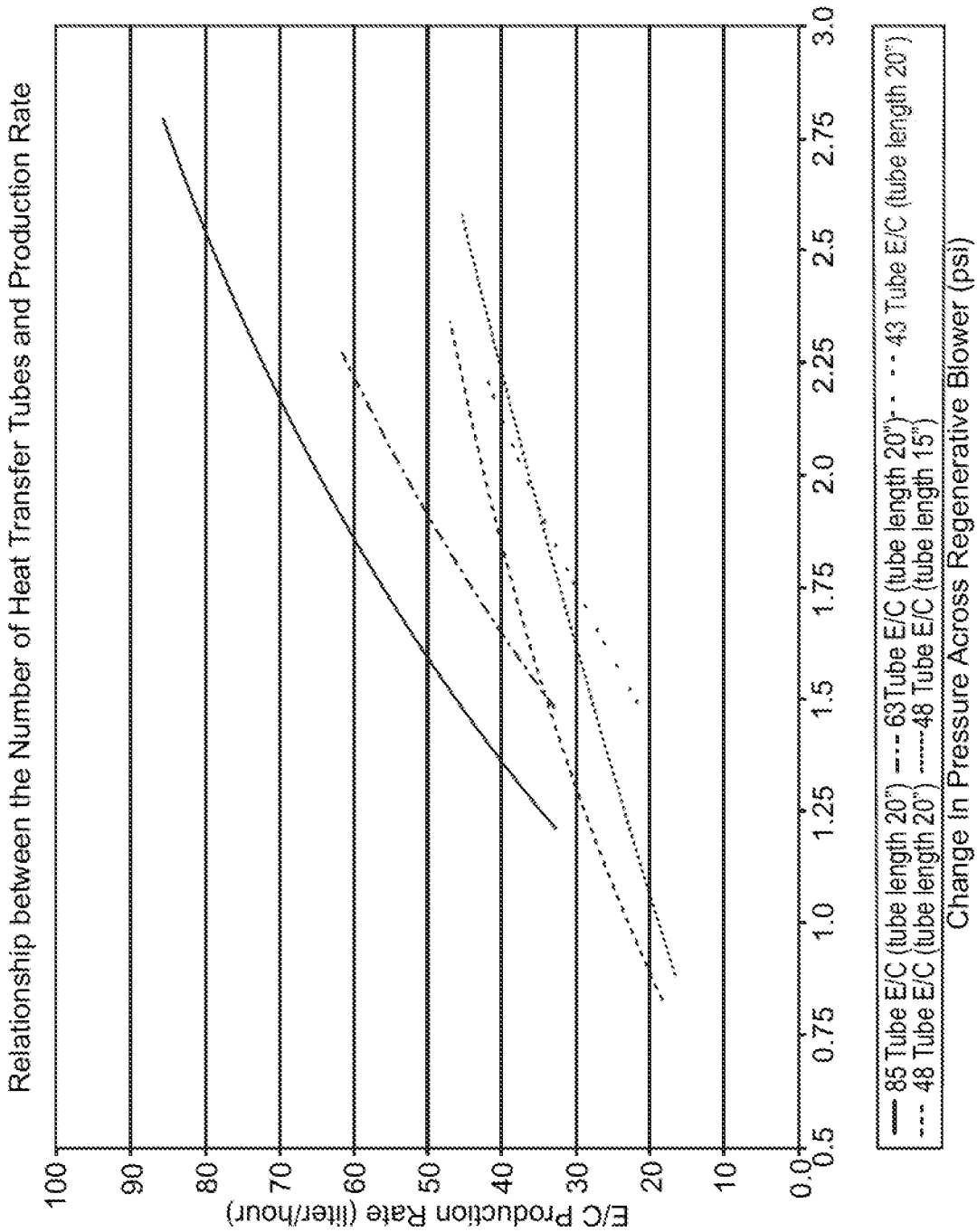

Relationship between the Number of Heat Transfer Tubes and Production Rate
E/C Production Rate (liter/hour)
100
90
80
70
60
50
40
30
20
10
0.0
0.5
0.75
1.0
1.25
1.5
1.75
2.0
2.25
2.5
2.75
3.0
85 Tube E/C (tube length 20")
63Tube E/C (tube length 20")
43 Tube E/C (tube length 20")
48 Tube E/C (tube length 20")
48 Tube E/C (tube length 15")
Change In Pressure Across Regenerative Blower (psi)

FIG. 28

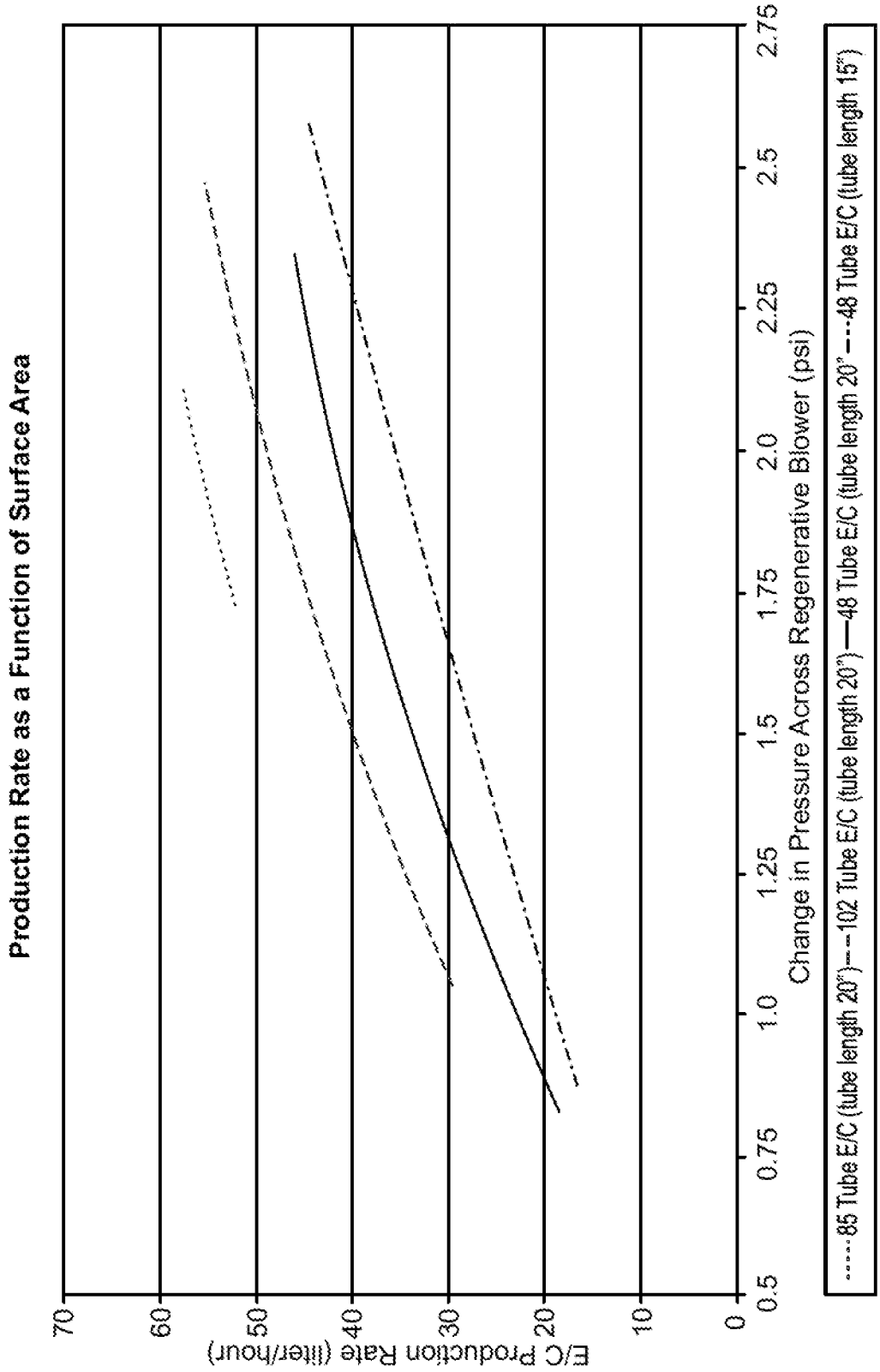

Production Rate as a Function of Surface Area
E/C Production Rate (liter/hour)
70
60
50
40
30
20
10
0
0.5
0.75
1.0
1.25
1.5
1.75
2.0
2.25
2.5
2.75
Change in Pressure Across Regenerative Blower (psi)
85 Tube E/C (tube length 20") — 102 Tube E/C (tube length 20") — 48 Tube E/C (tube length 20") — 48 Tube E/C (tube length 15")

FIG. 29

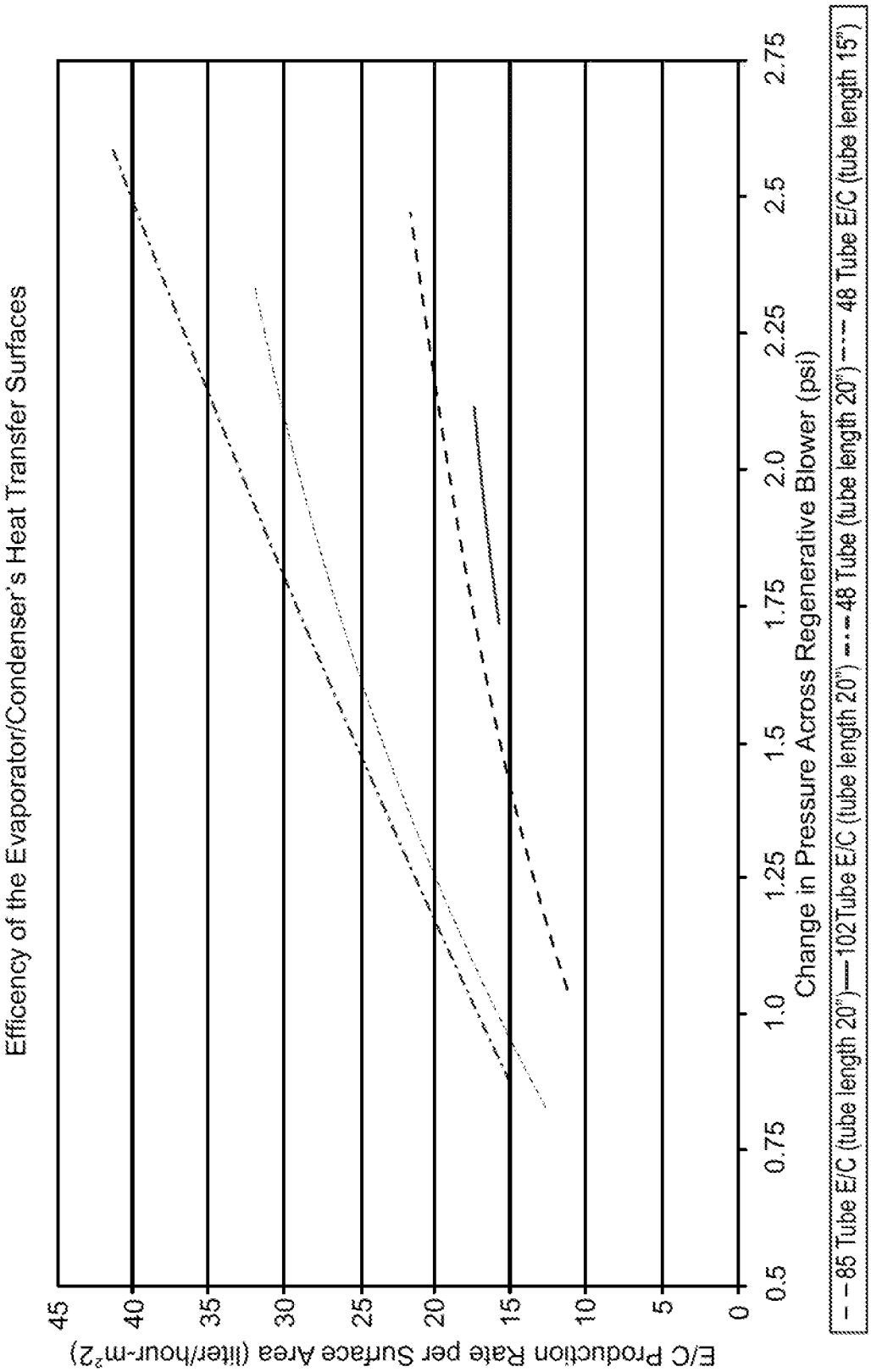

Efficency of the Evaporator/Condenser's Heat Transfer Surfaces
E/C Production Rate per Surface Area (liter/hour-m^2)
0
5
10
15
20
25
30
35
40
45
0.5
0.75
1.0
1.25
1.5
1.75
2.0
2.25
2.5
2.75
Change in Pressure Across Regenerative Blower (psi)
– – 85 Tube E/C (tube length 20")
102Tube E/C (tube length 20")
– · – 48 Tube (tube length 20")
– – – 48 Tube E/C (tube length 15")

FIG. 30

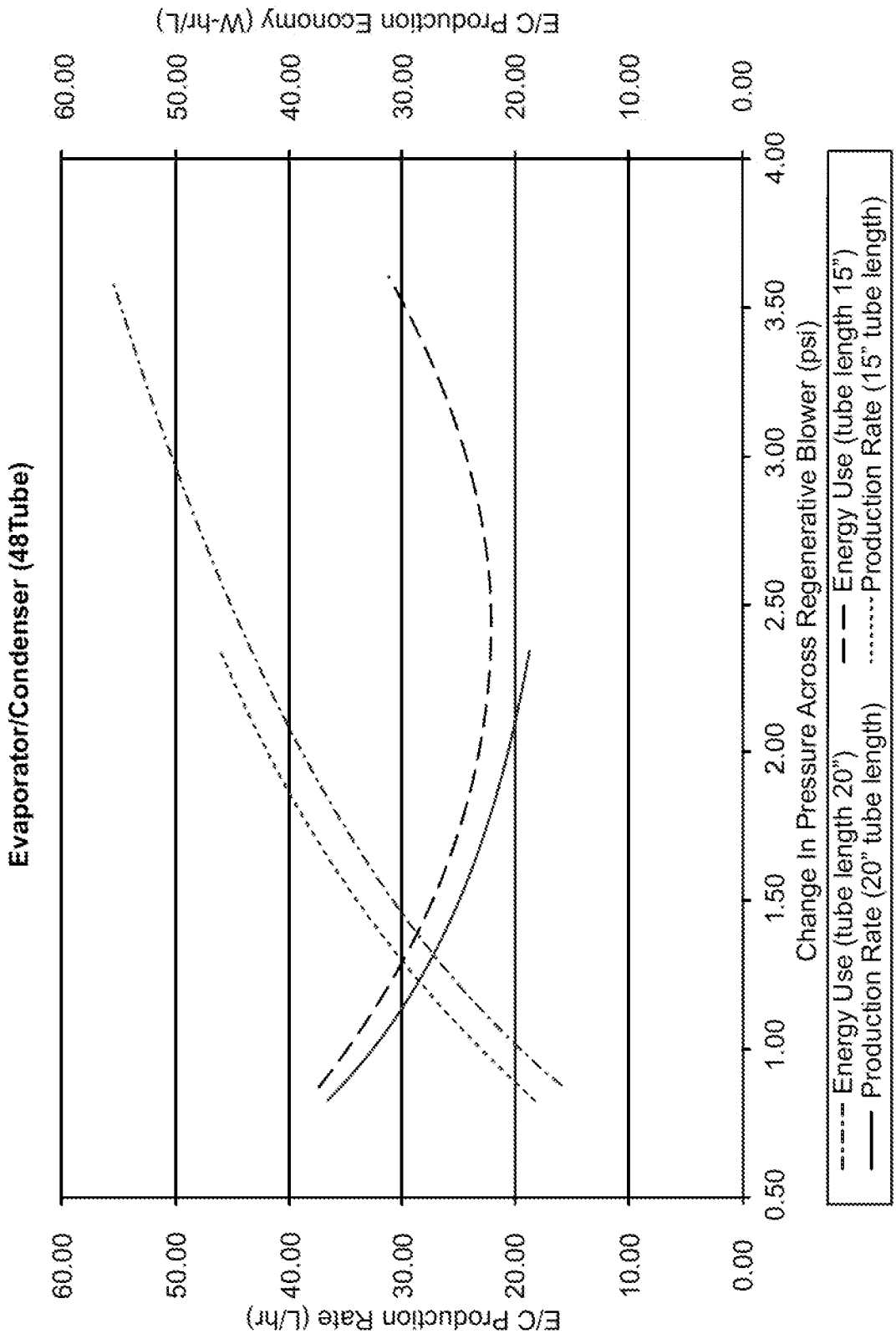

Evaporator/Condenser (48Tube)
E/C Production Economy (W-hr/L)
E/C Production Rate (L/hr)
Change In Pressure Across Regenerative Blower (psi)
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
Energy Use (tube length 20")
Production Rate (20" tube length)
Energy Use (tube length 15")
Production Rate (15" tube length)

FIG. 31

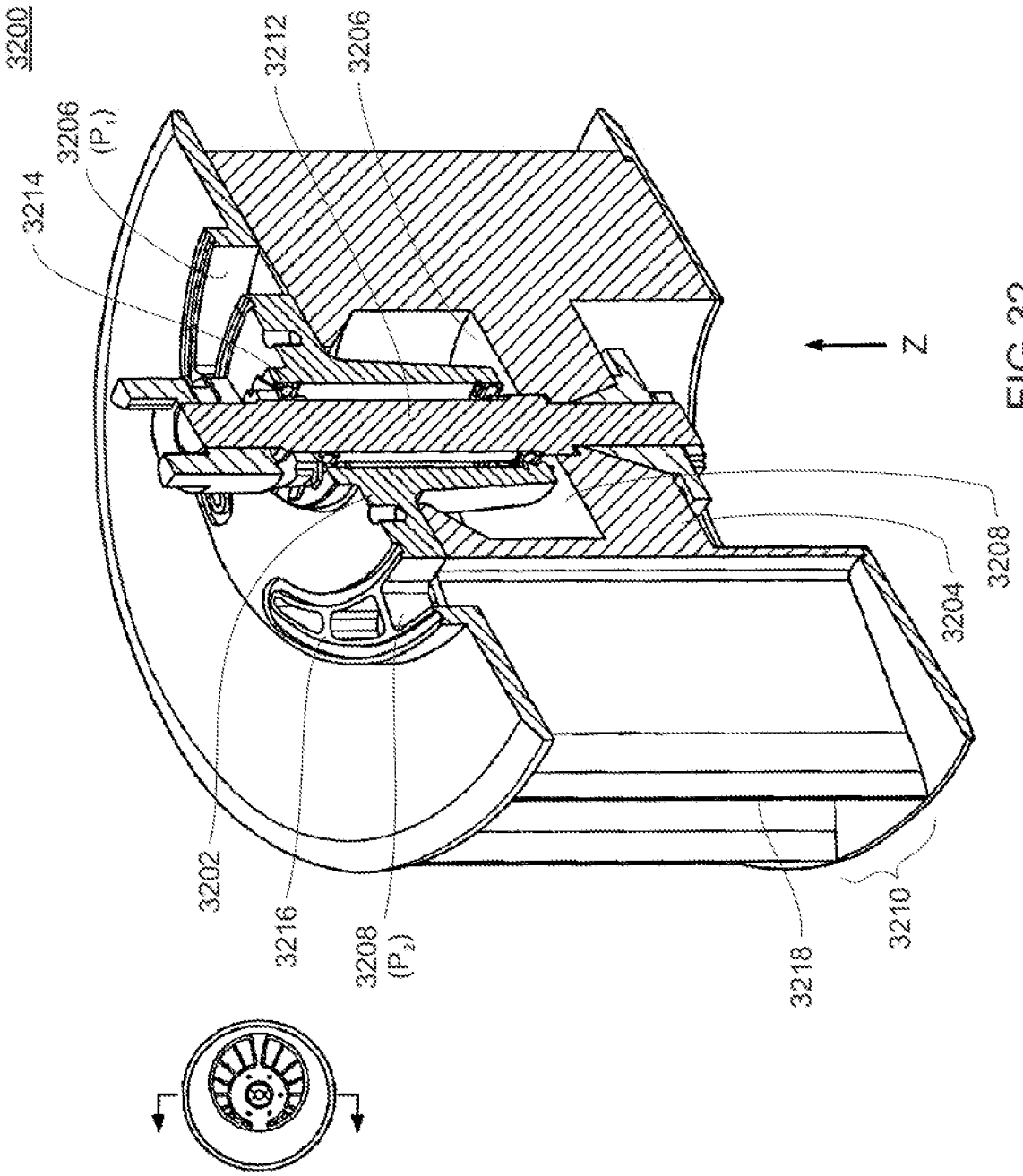

3200
3212
3206
3206 (P1)
3214
Z
3208
3204
3202
3216
3208 (P2)
3218
3210

FIG.32

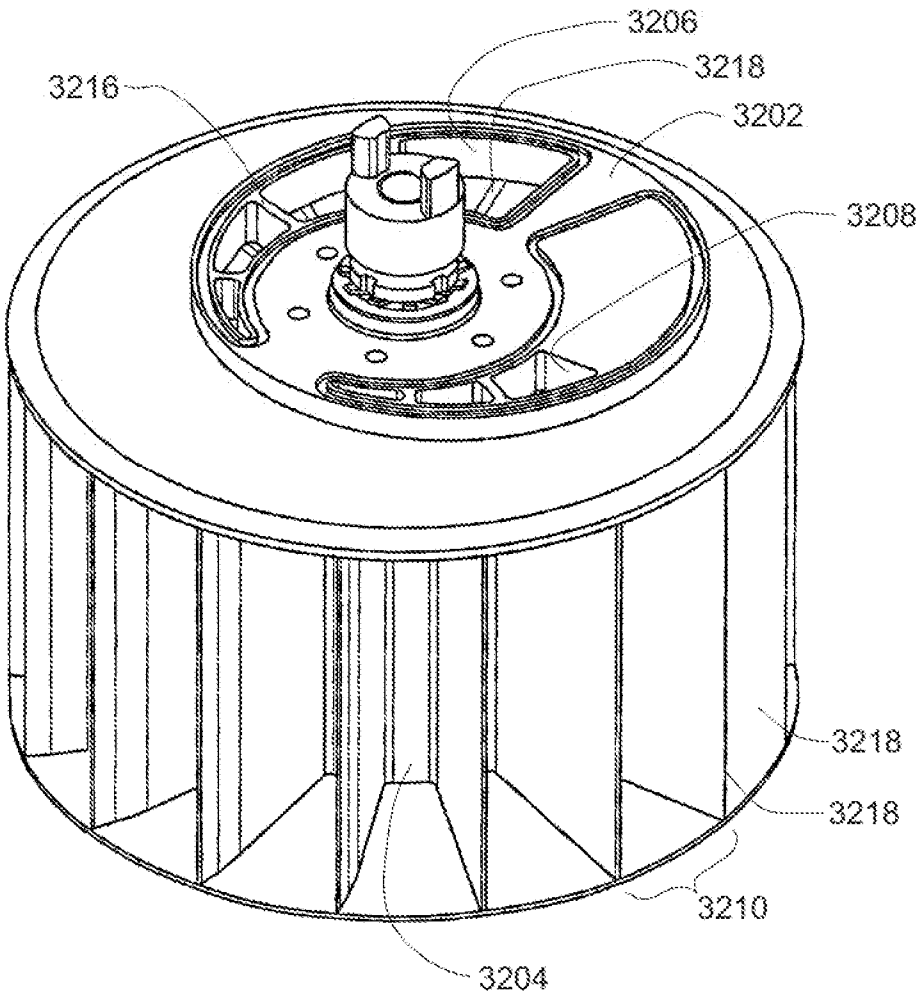



FIG.32A

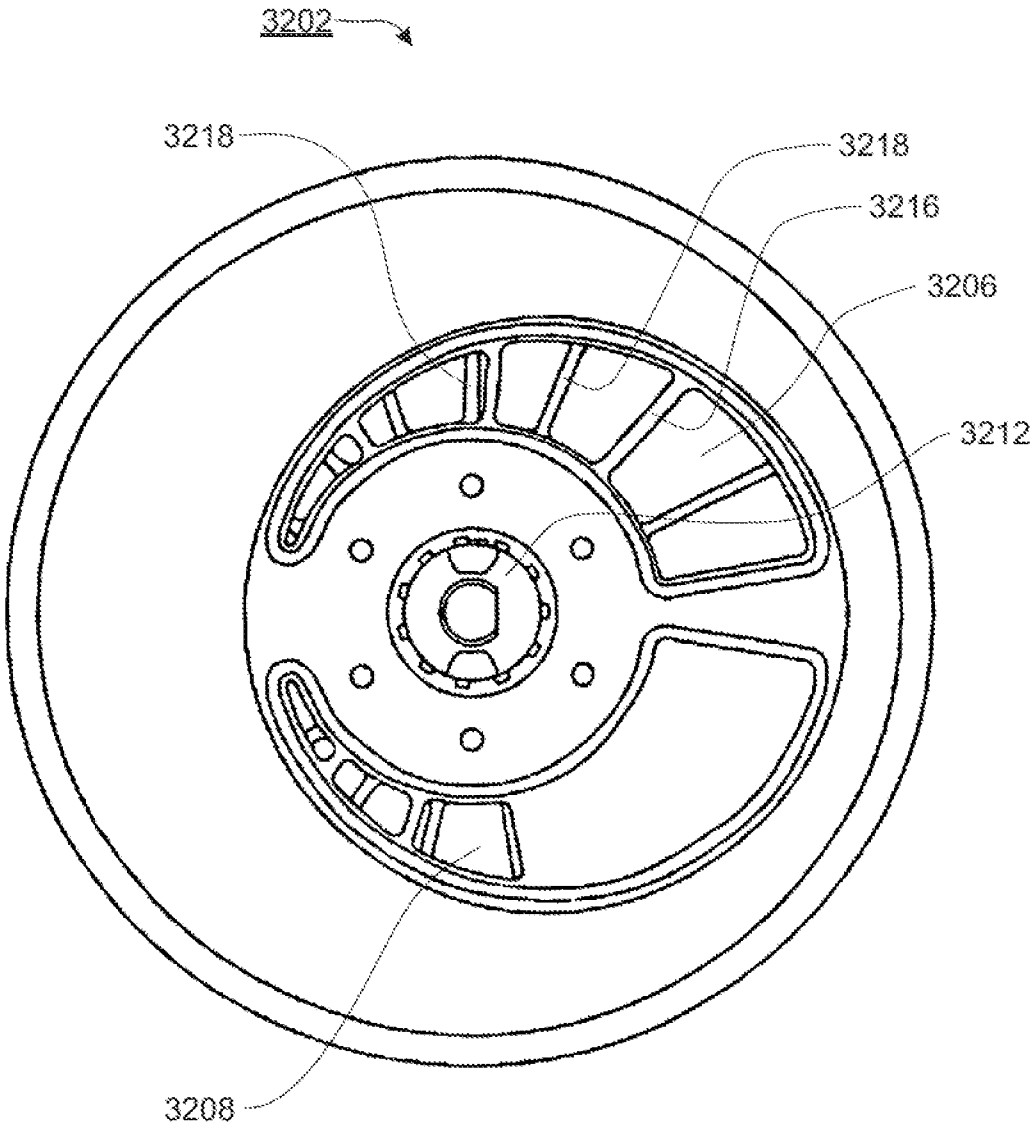



FIG.32B

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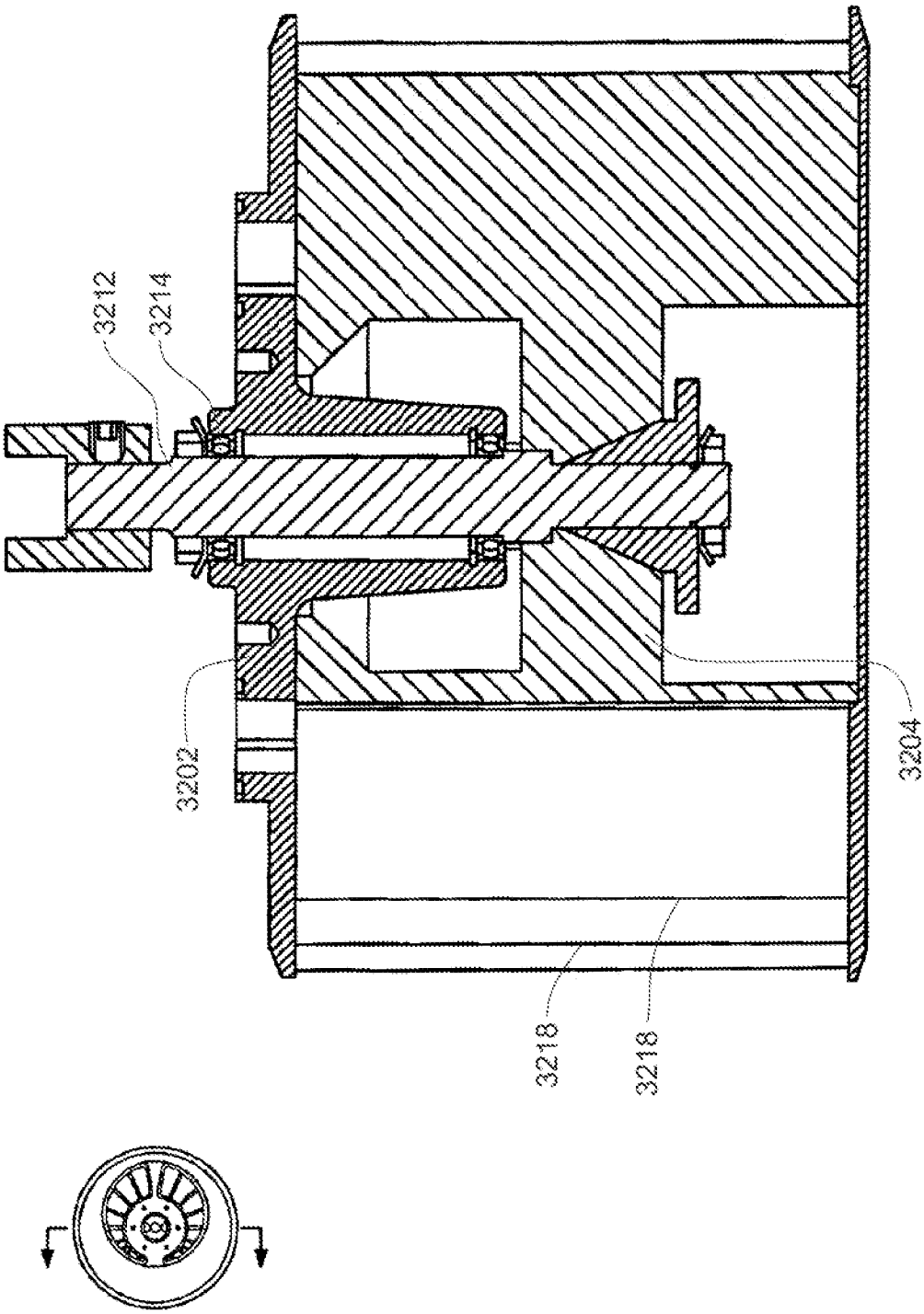
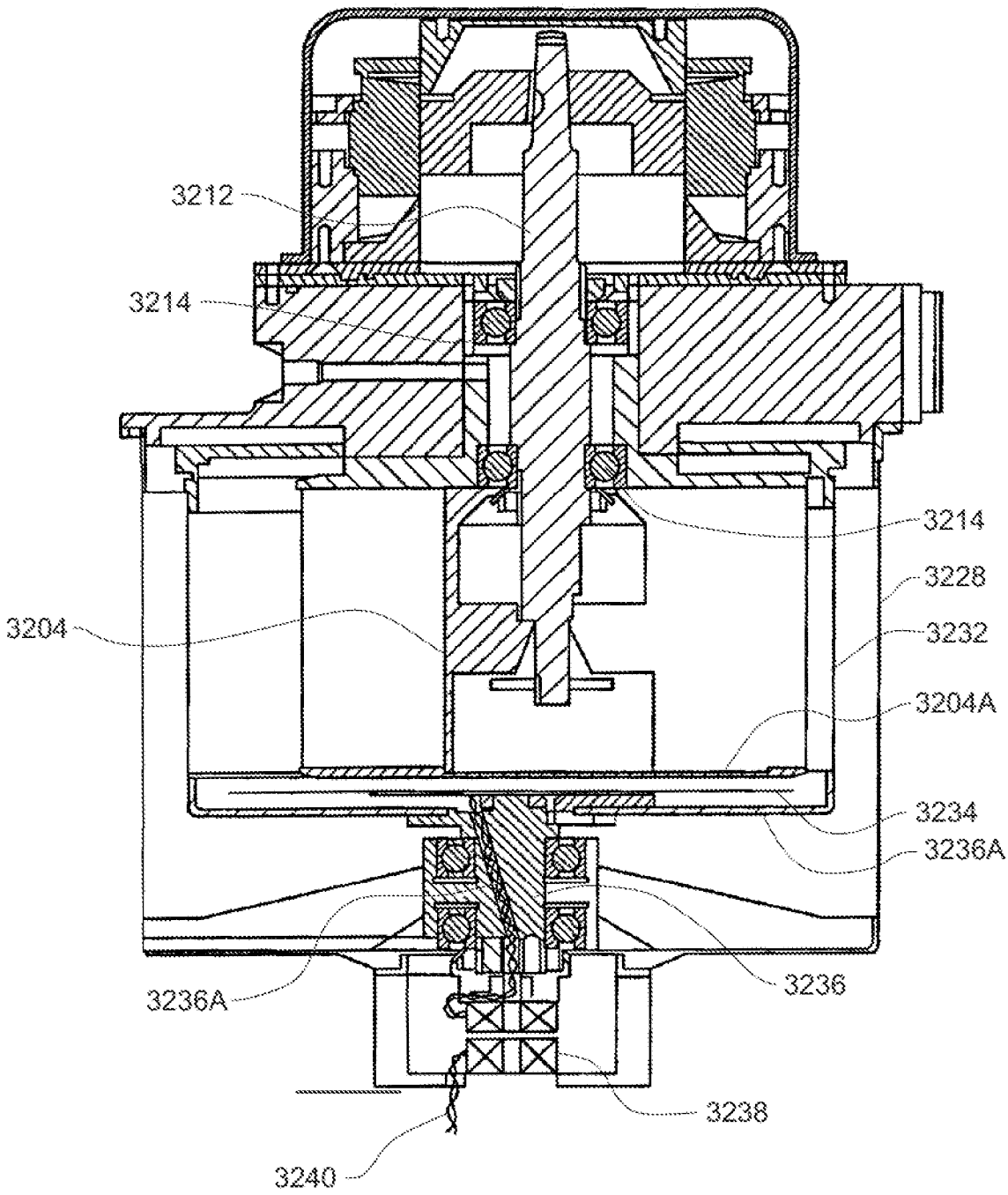



FIG.32C


3212
3214
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3228
3204
3232
3204A
3234
3236A
3236A
3236
3238
3240

FIG.32D

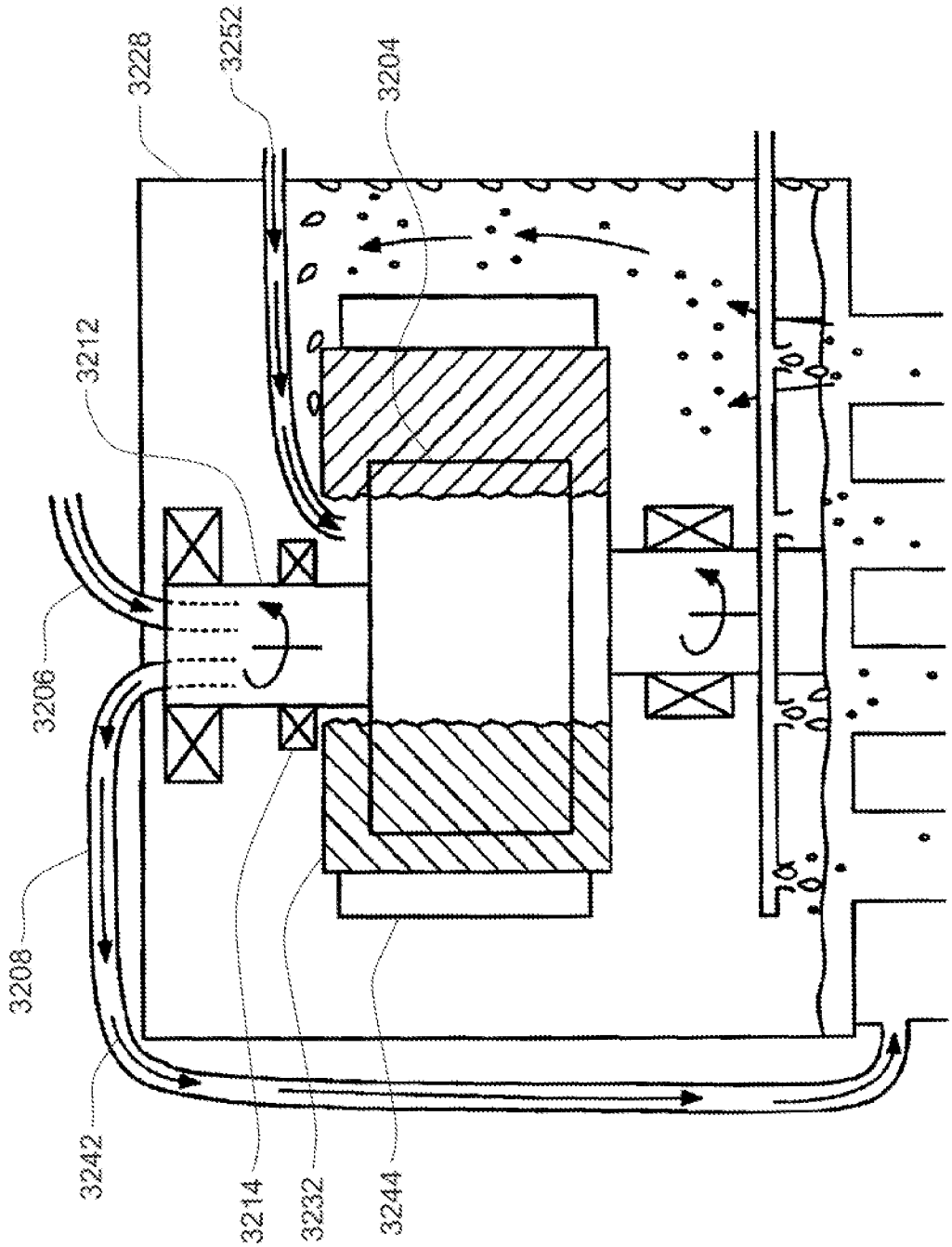


FIG.32E

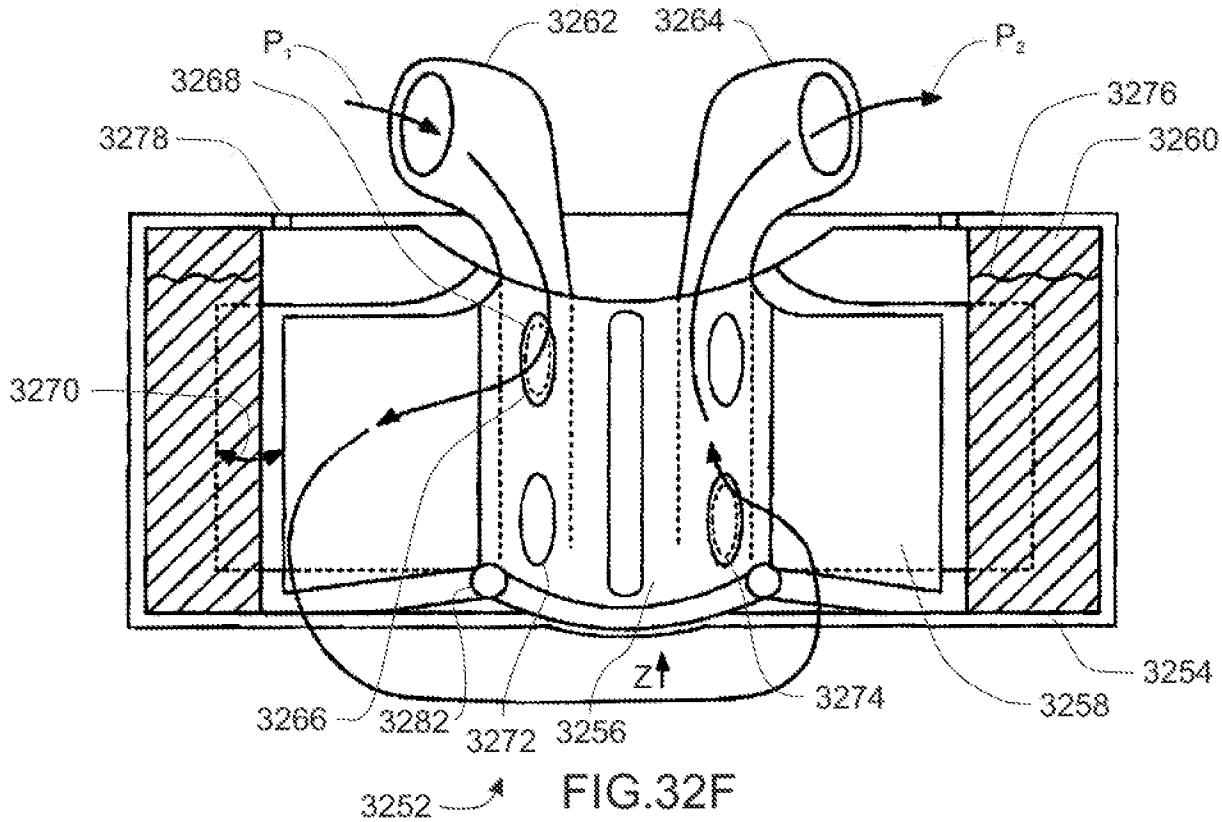


FIG.32F

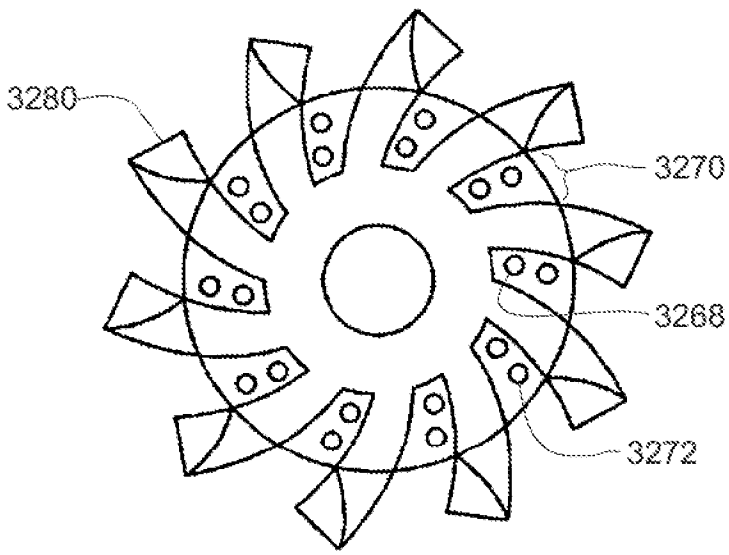


FIG.32G

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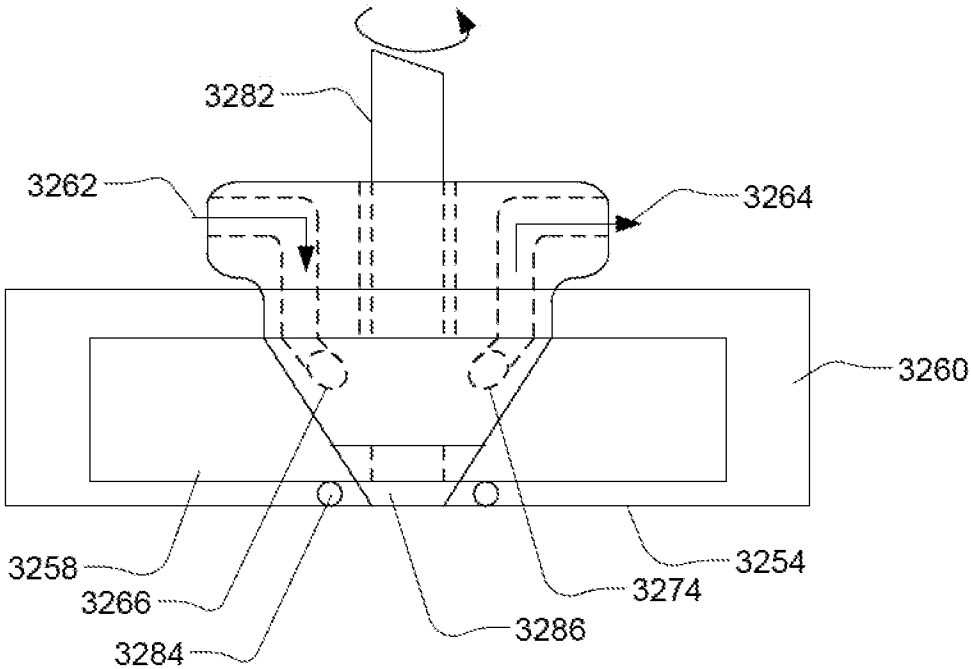


FIG. 32H

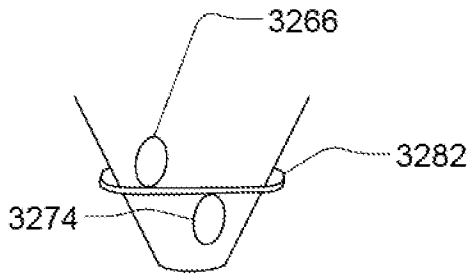


FIG. 32I

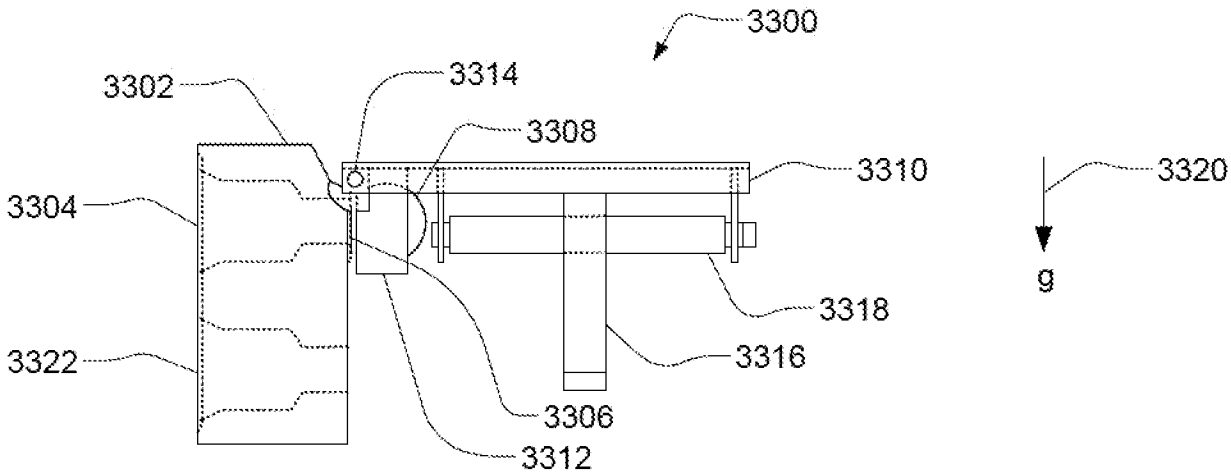


FIG. 33

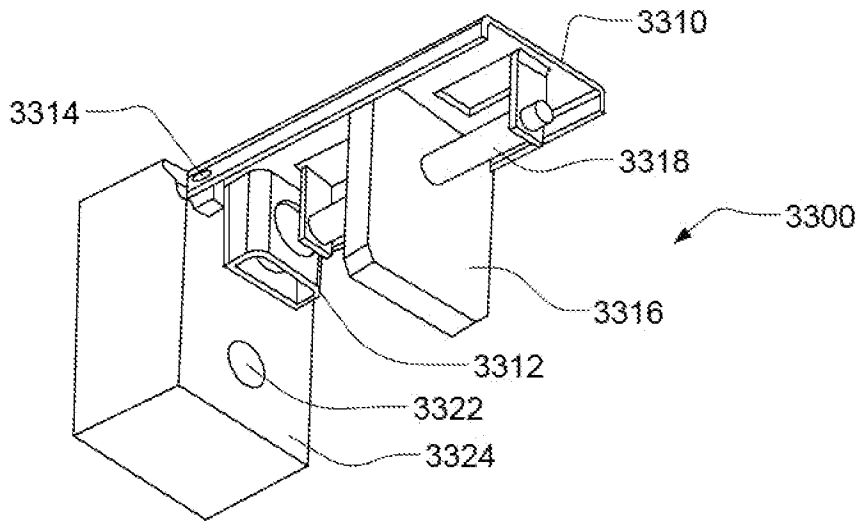


FIG. 33A

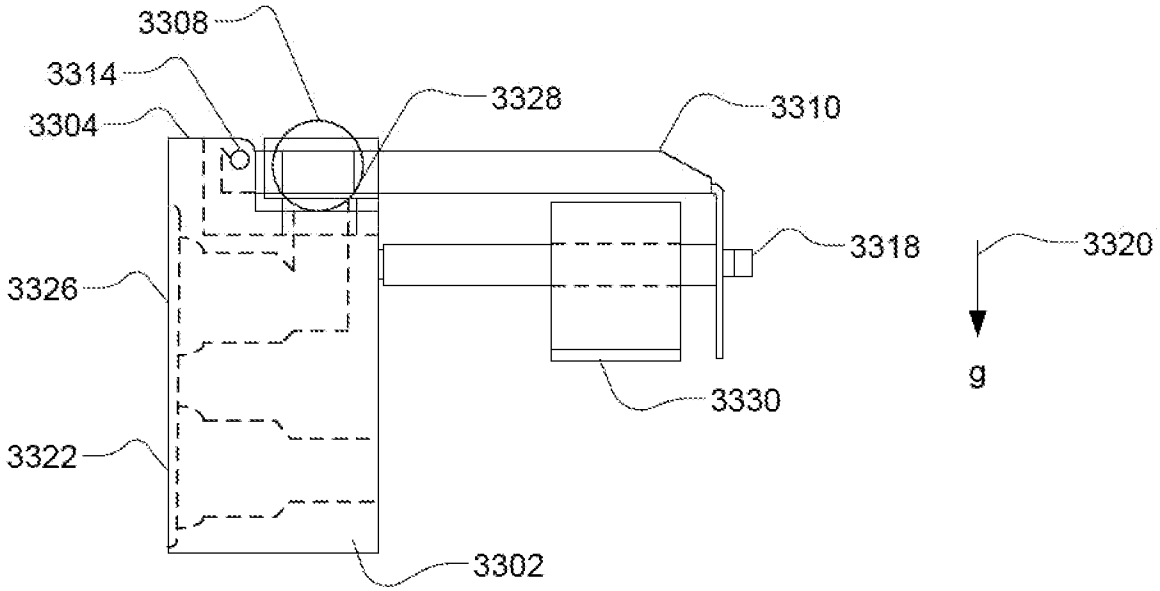


FIG. 33B

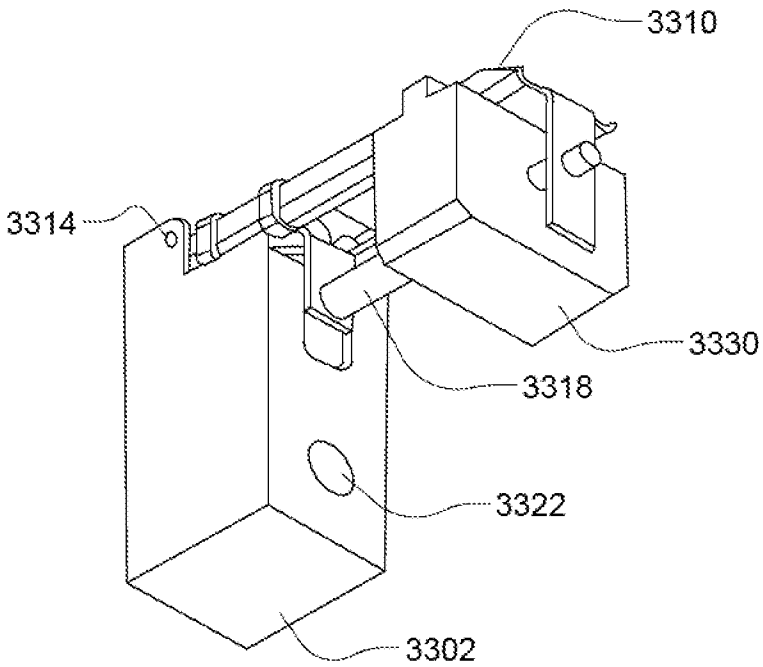


FIG. 33C

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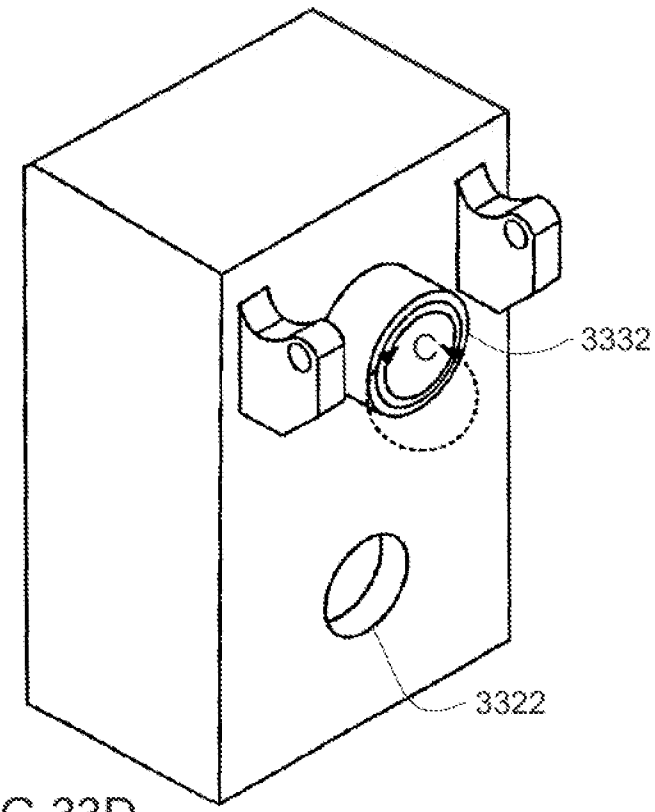



FIG.33D

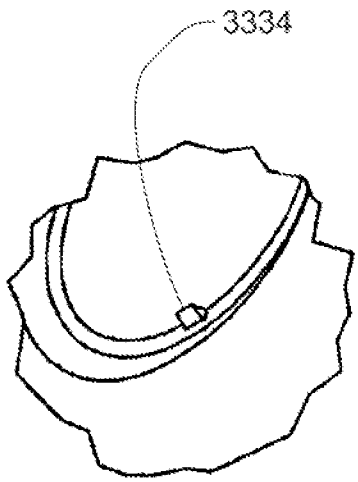



FIG.33E

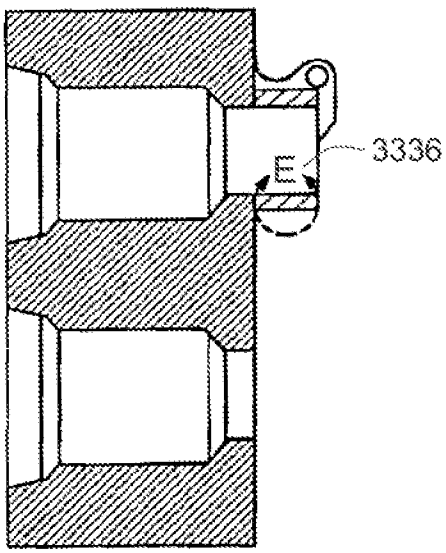



FIG.33F

FIG.33G

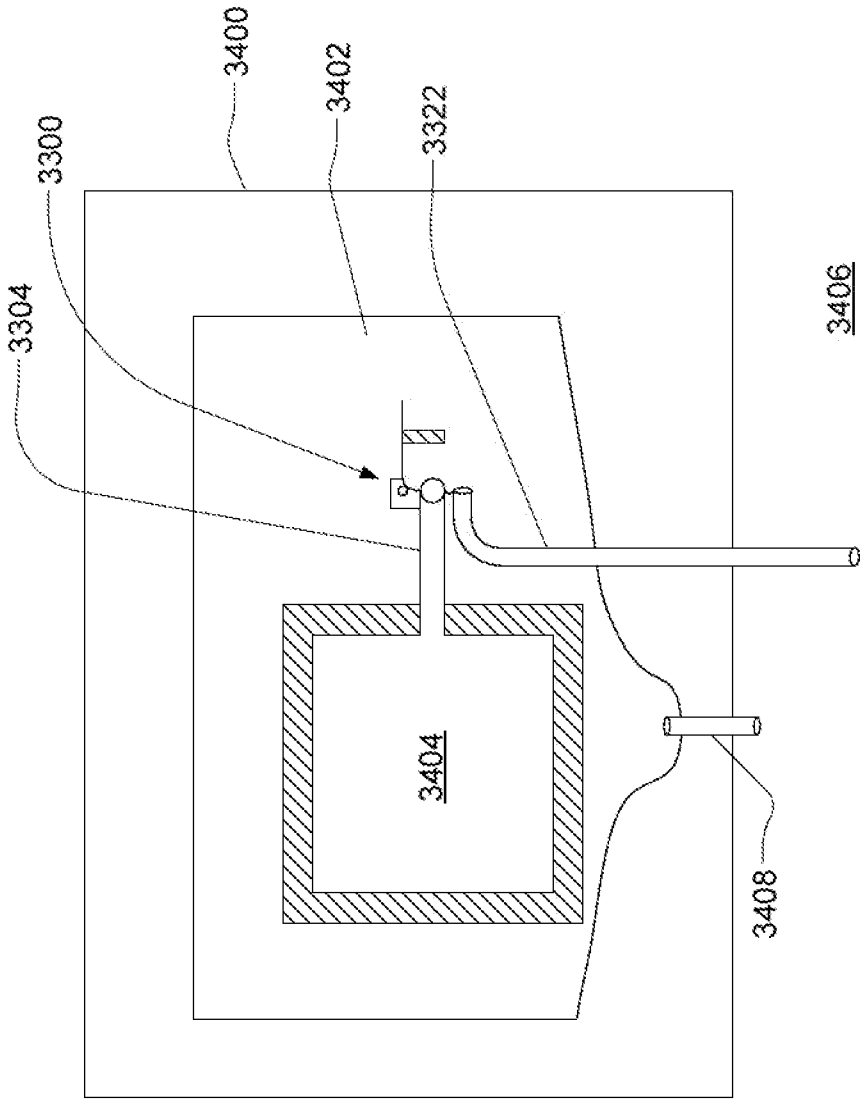
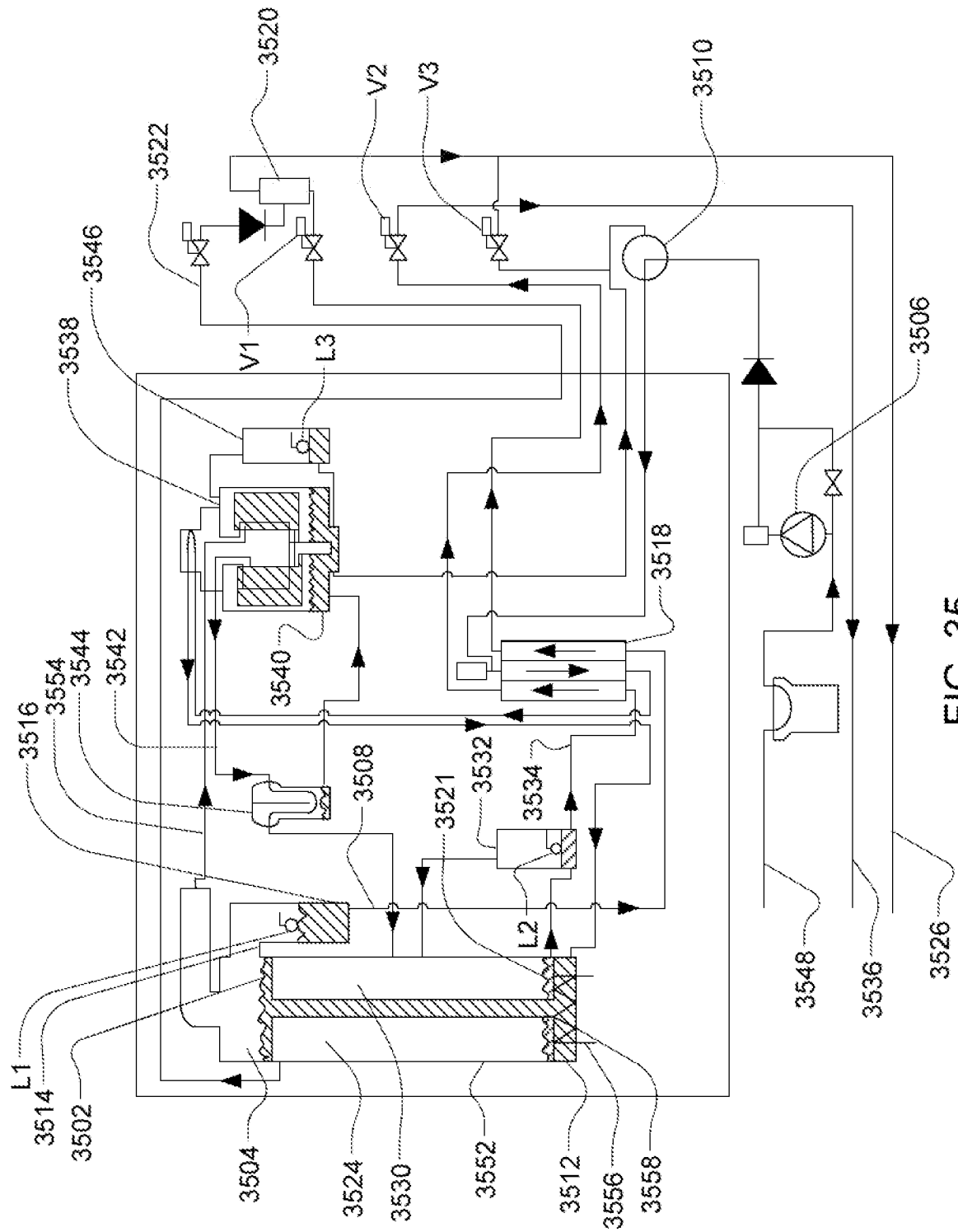



FIG. 34


3520
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V3
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3546
3538
V1
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3554
3516
3508
3521
3532
3534
L2
L1
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FIG. 35

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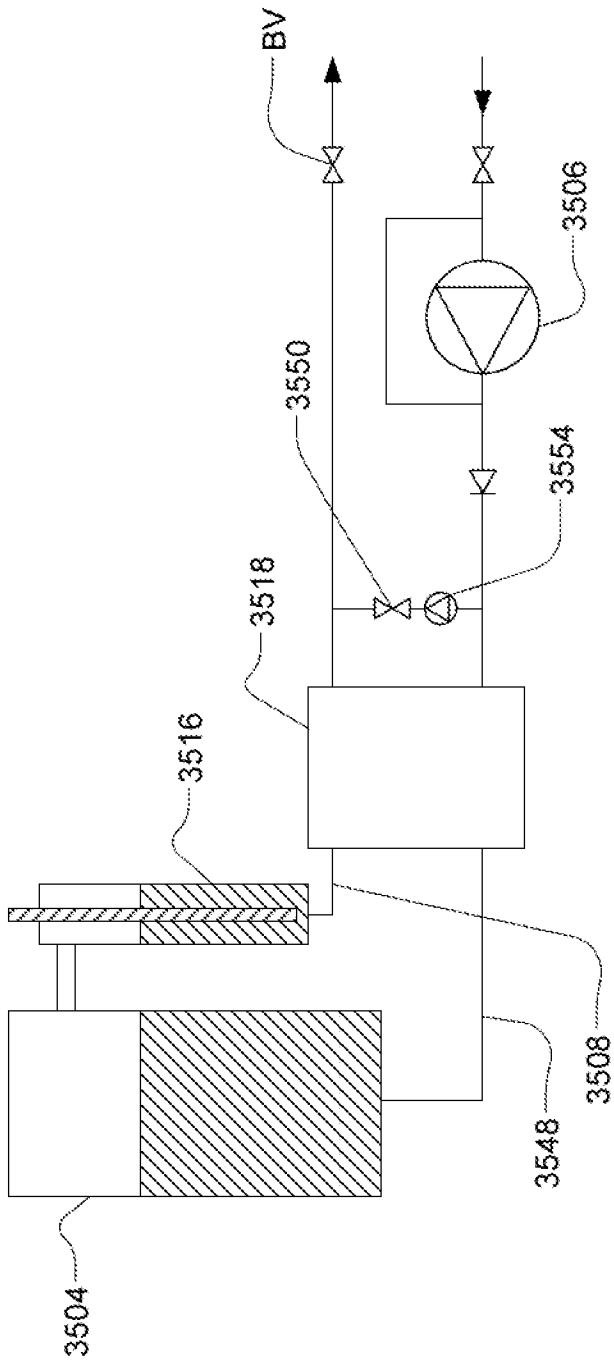


FIG. 35A

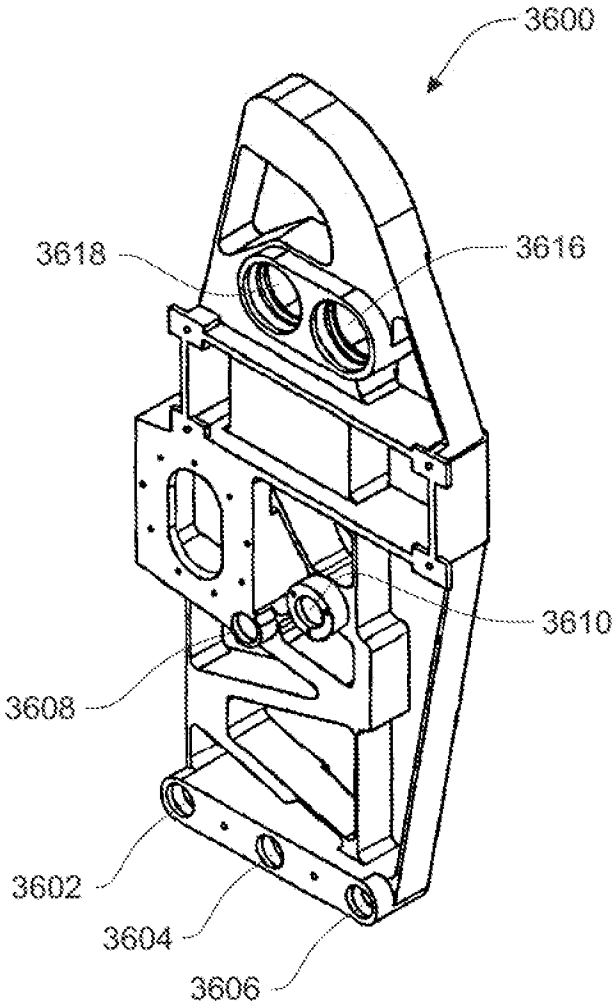


FIG.36

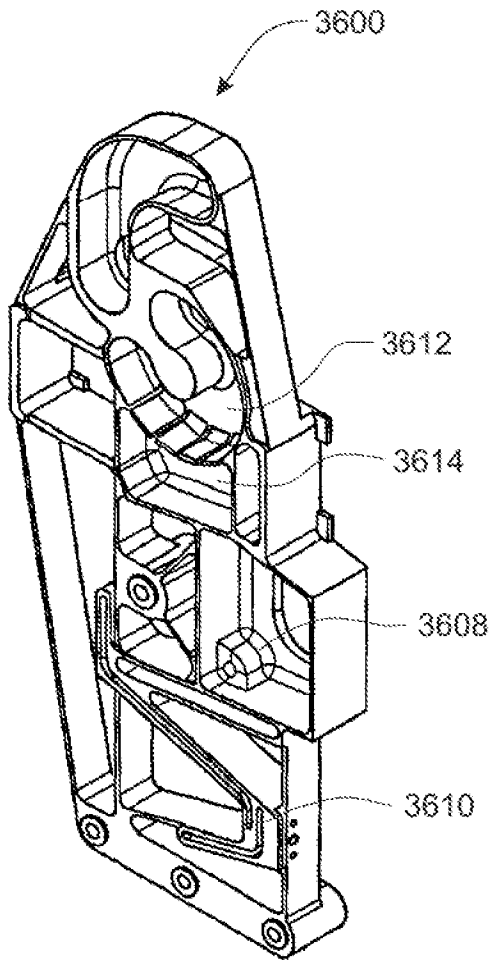


FIG.36A

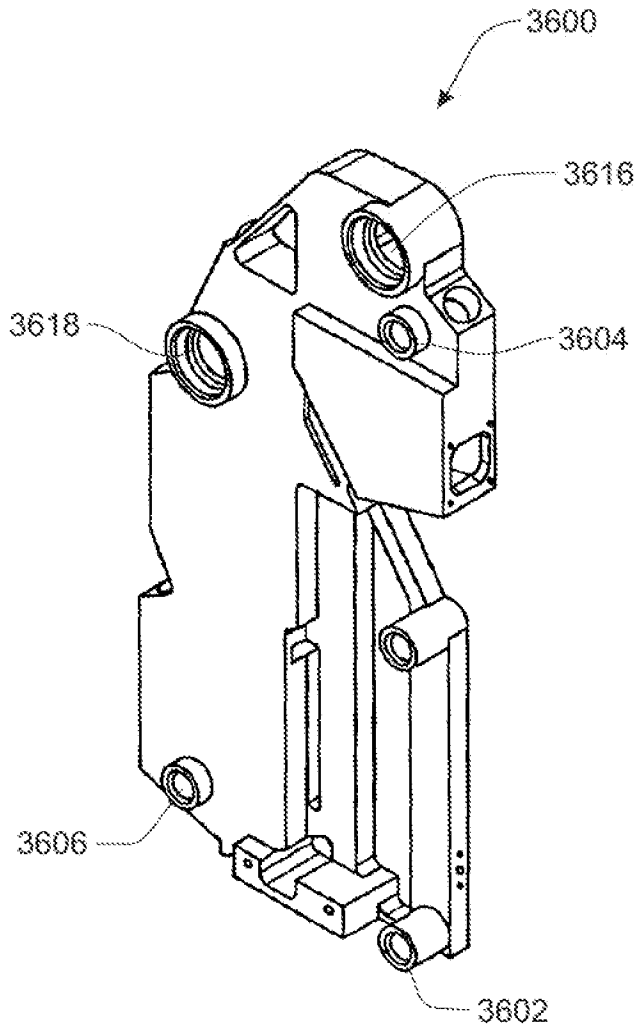


FIG.36B

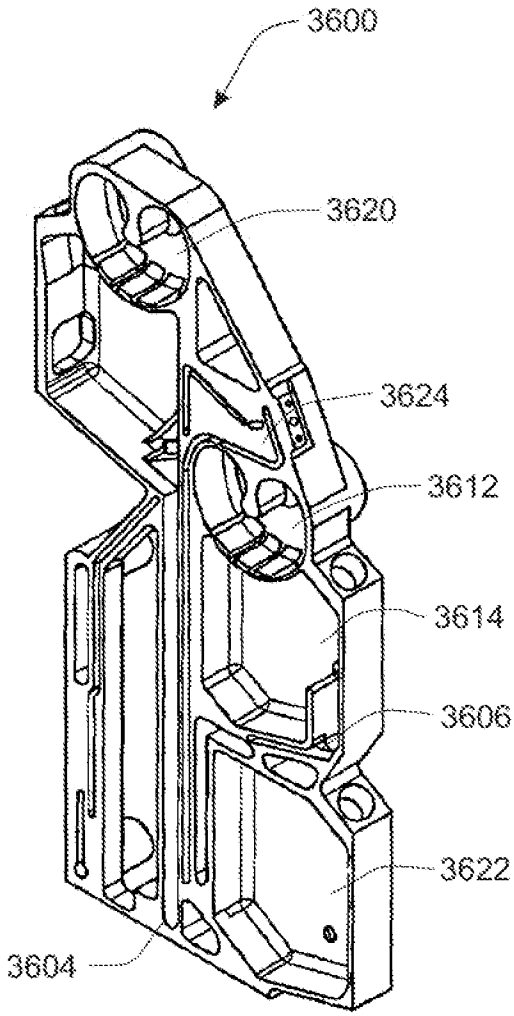


FIG.36C

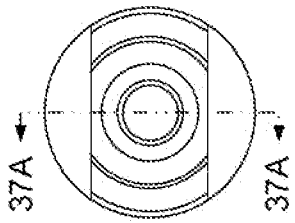


FIG. 37

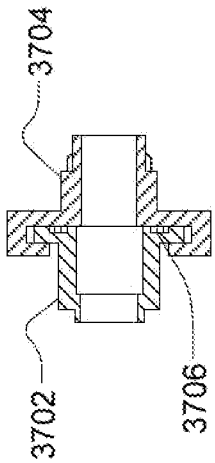


FIG. 37A

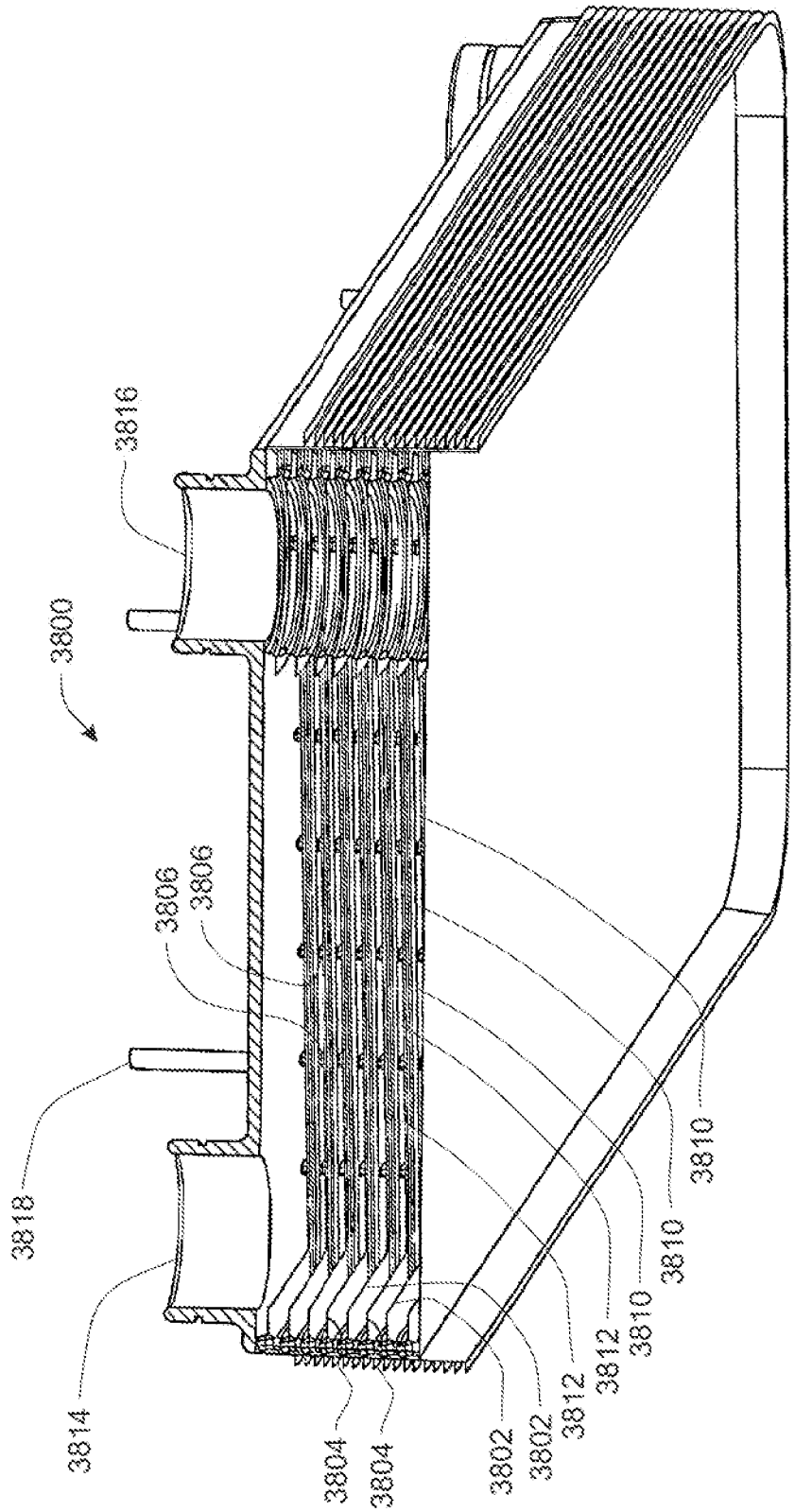
3800
3816
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FIG.38

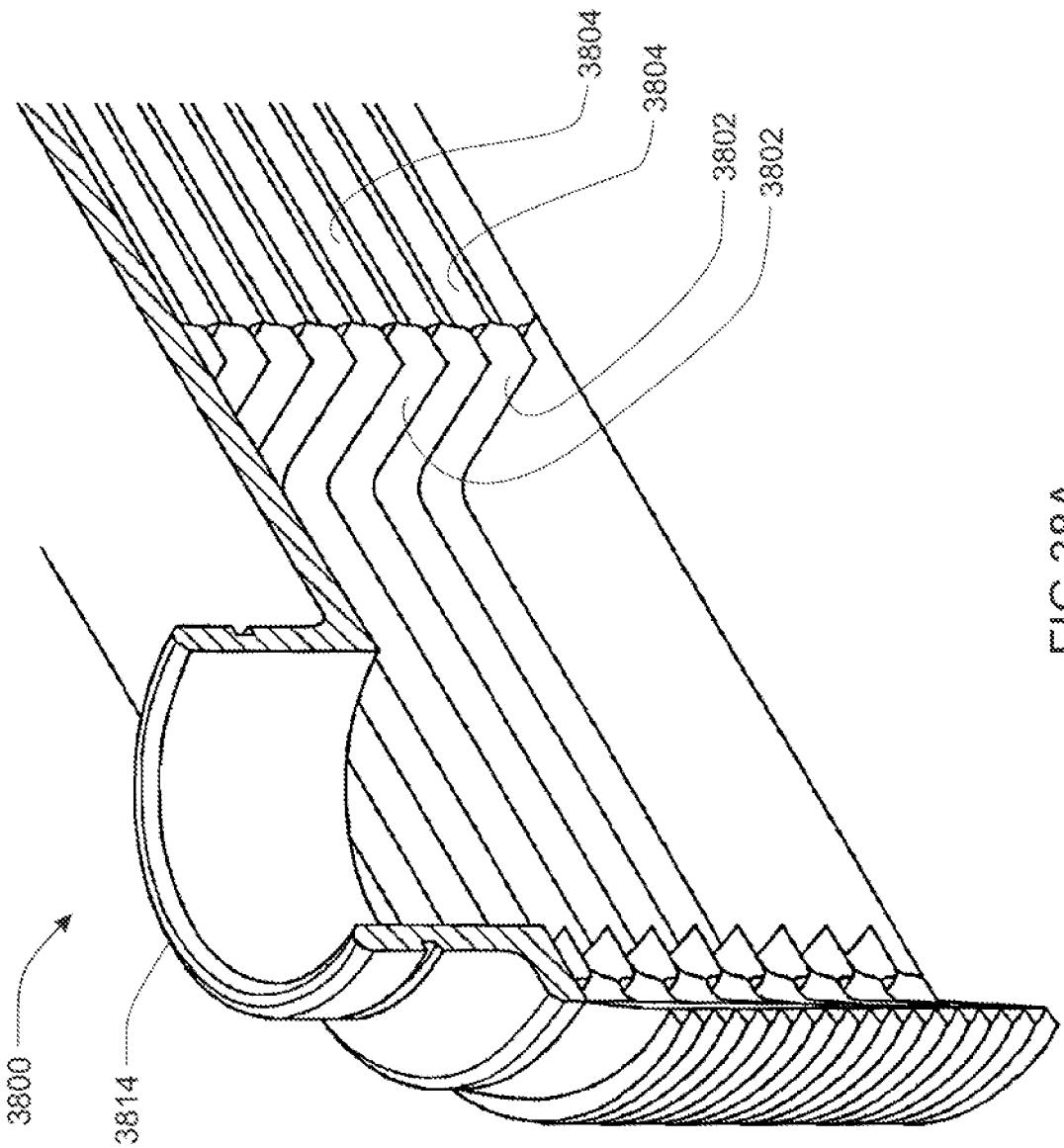



FIG.38A

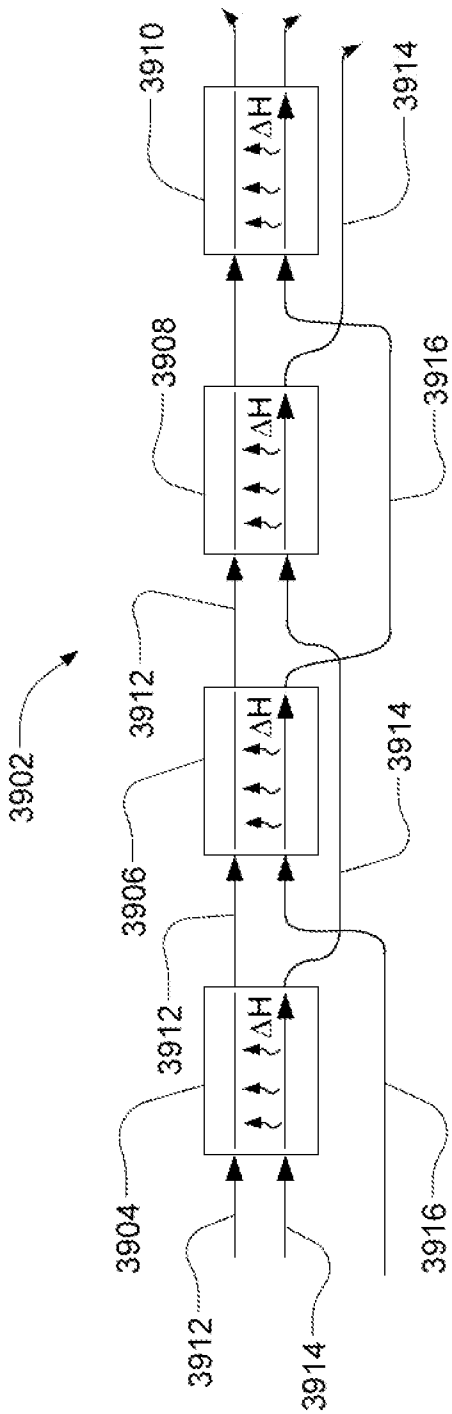



FIG. 39

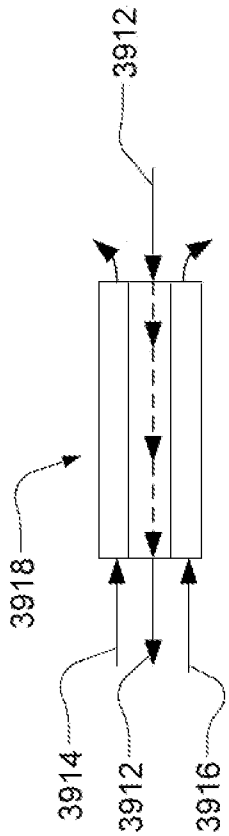



FIG. 39A

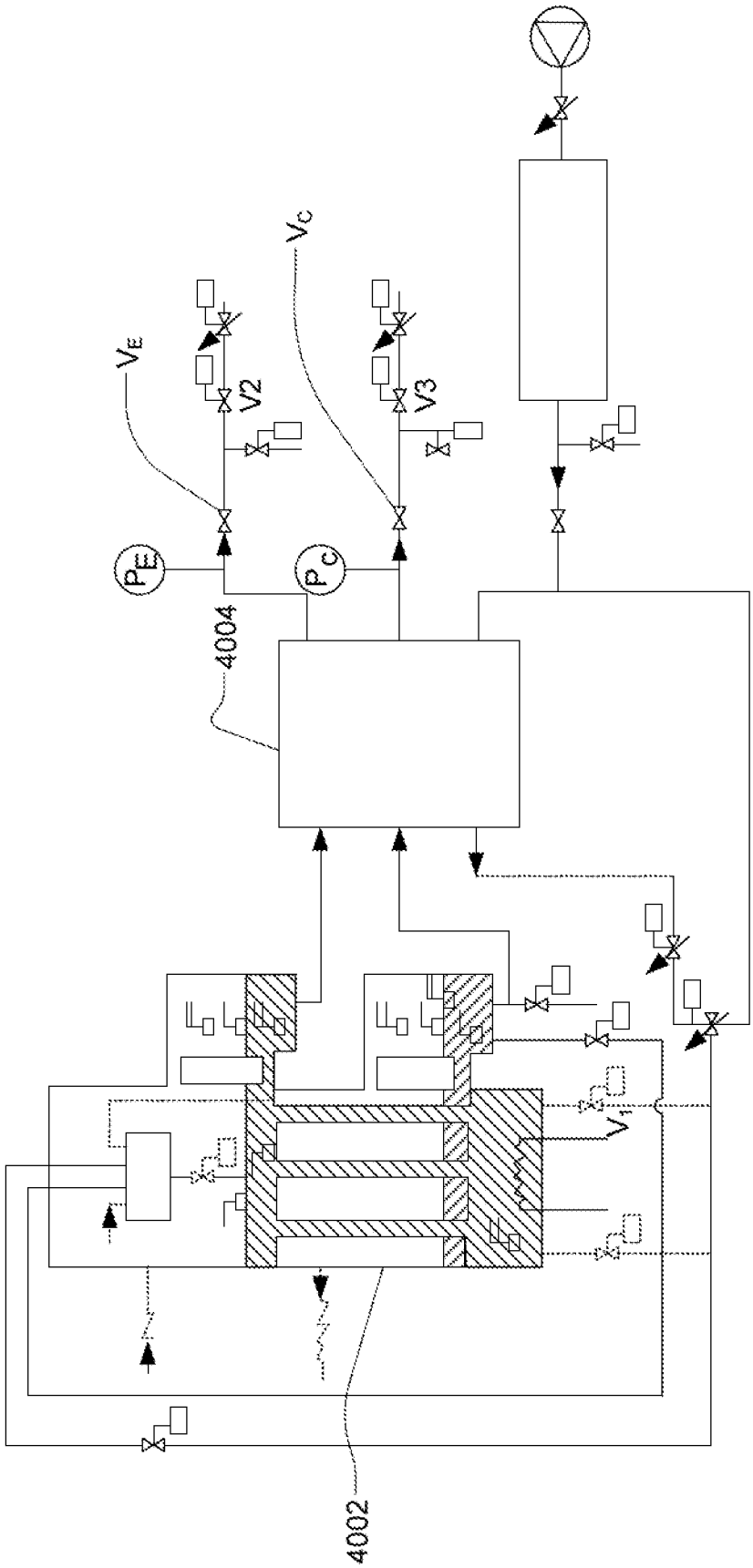



FIG. 40

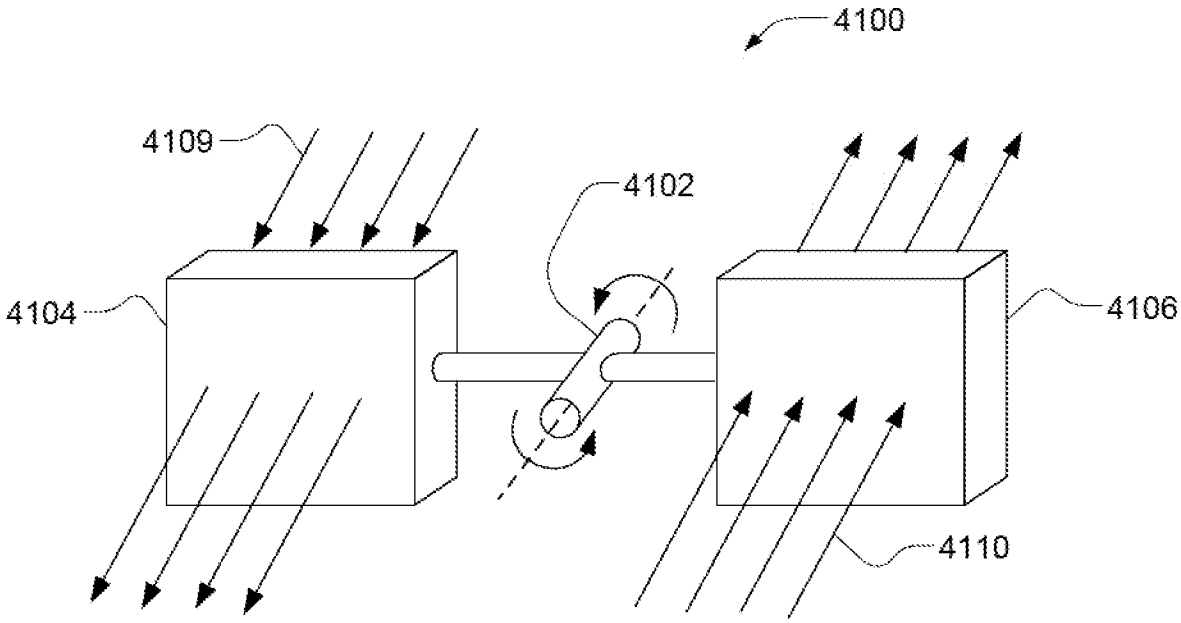



FIG. 41

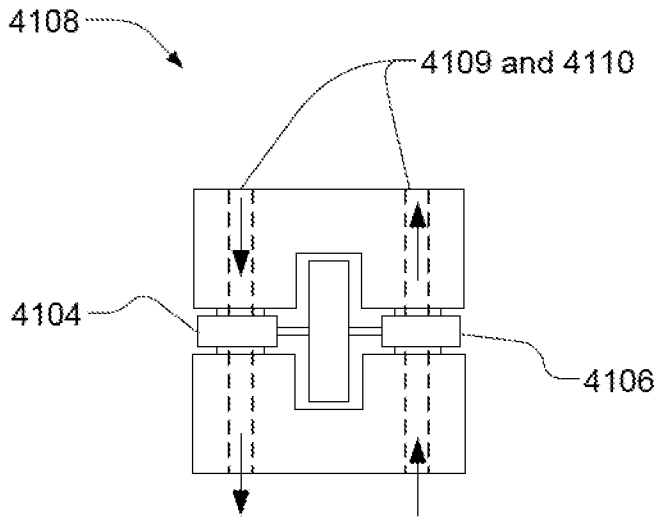



FIG. 41A

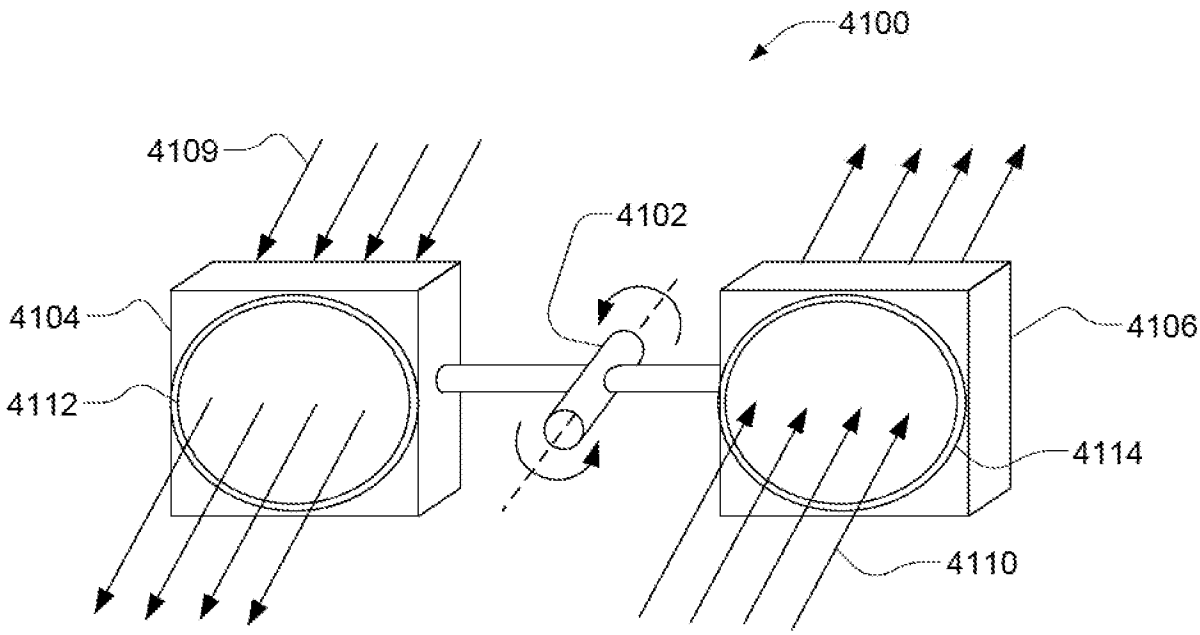



FIG. 41B

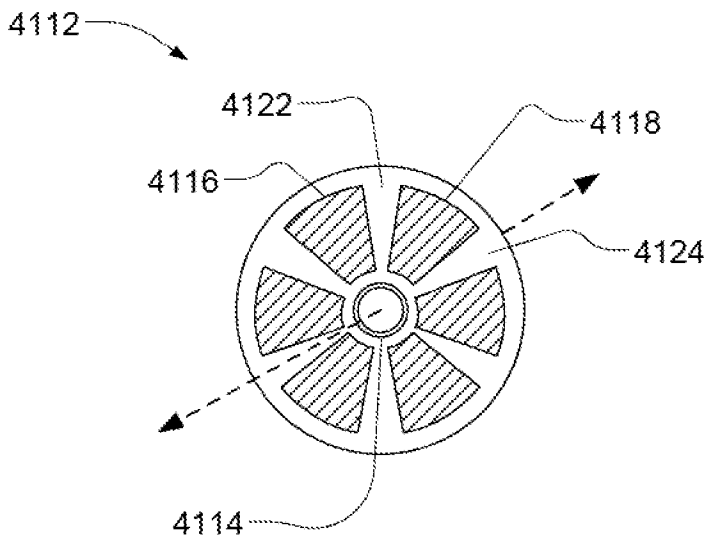



FIG. 41C

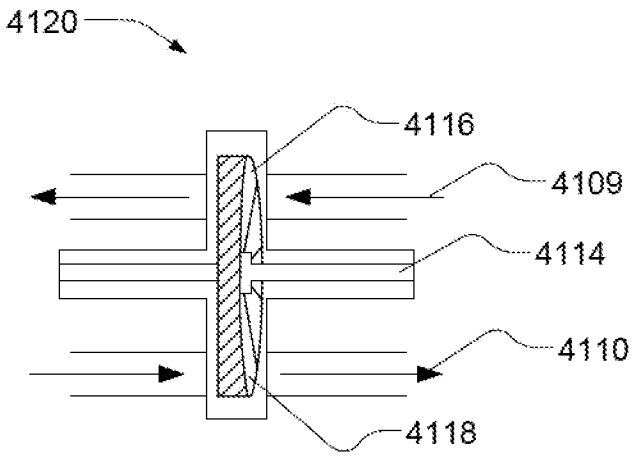



FIG. 41D

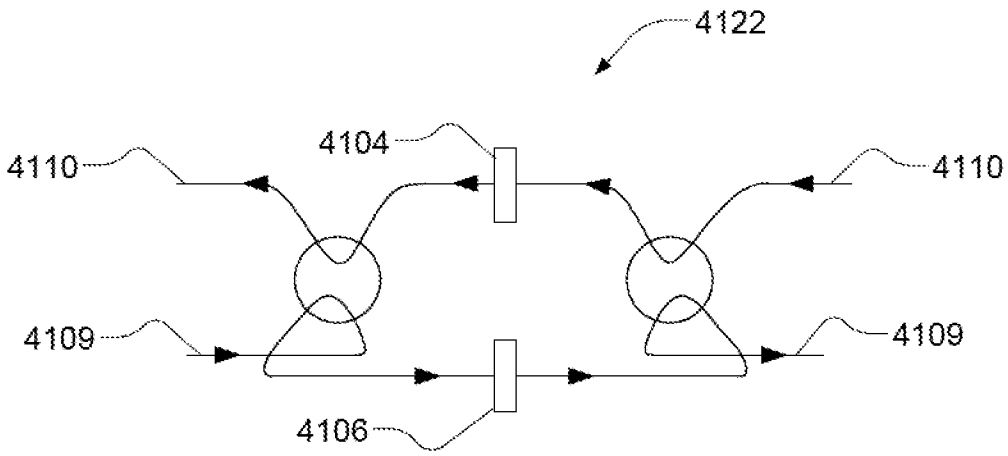



FIG. 41E

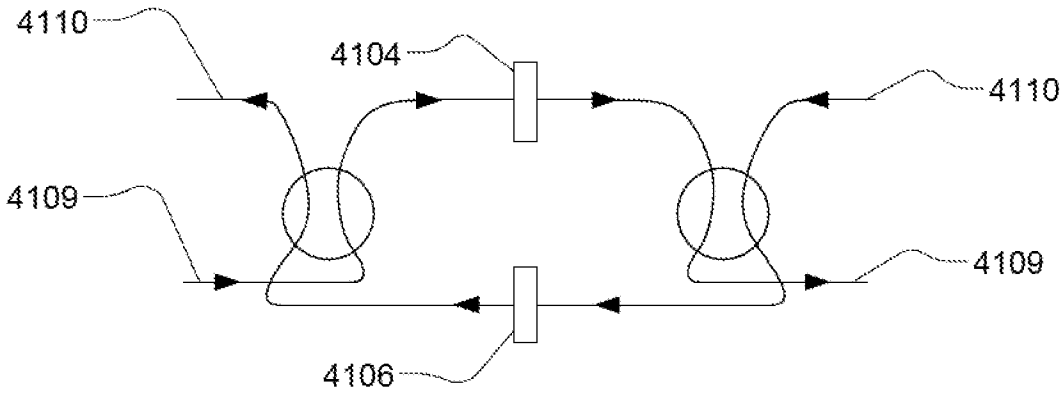



FIG. 41F

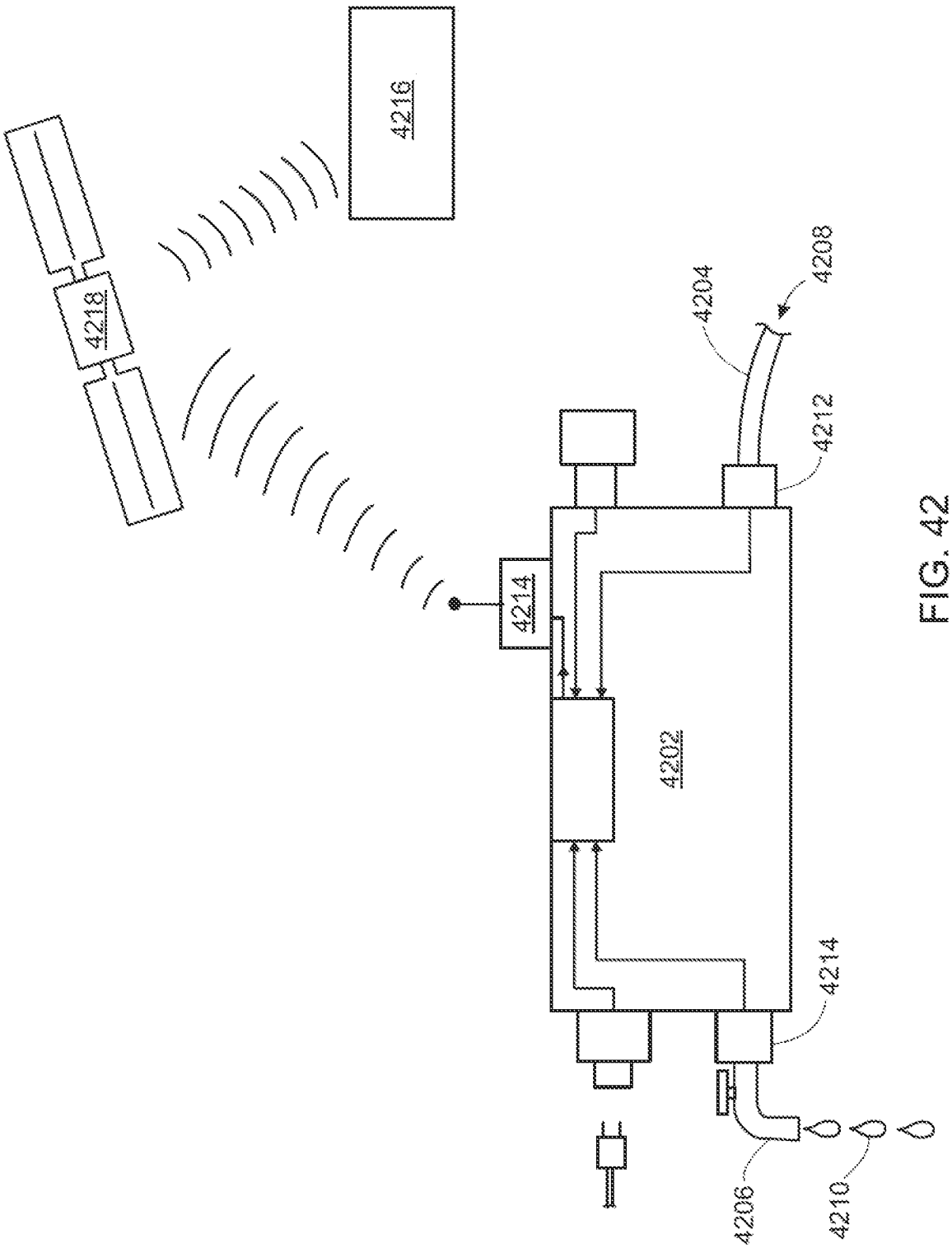
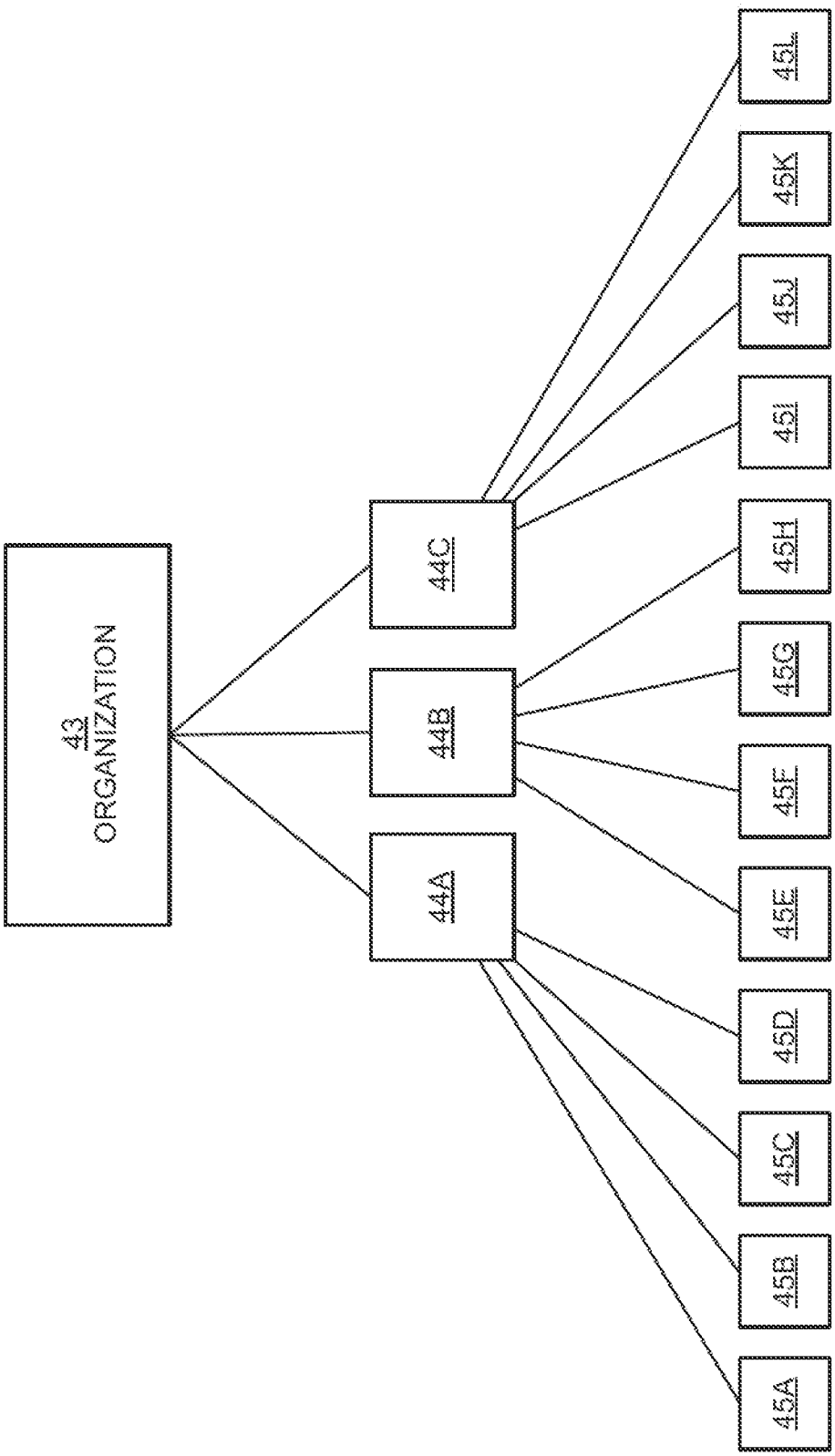



FIG. 42


43
ORGANIZATION
44A
44B
44C
45A
45B
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45E
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45G
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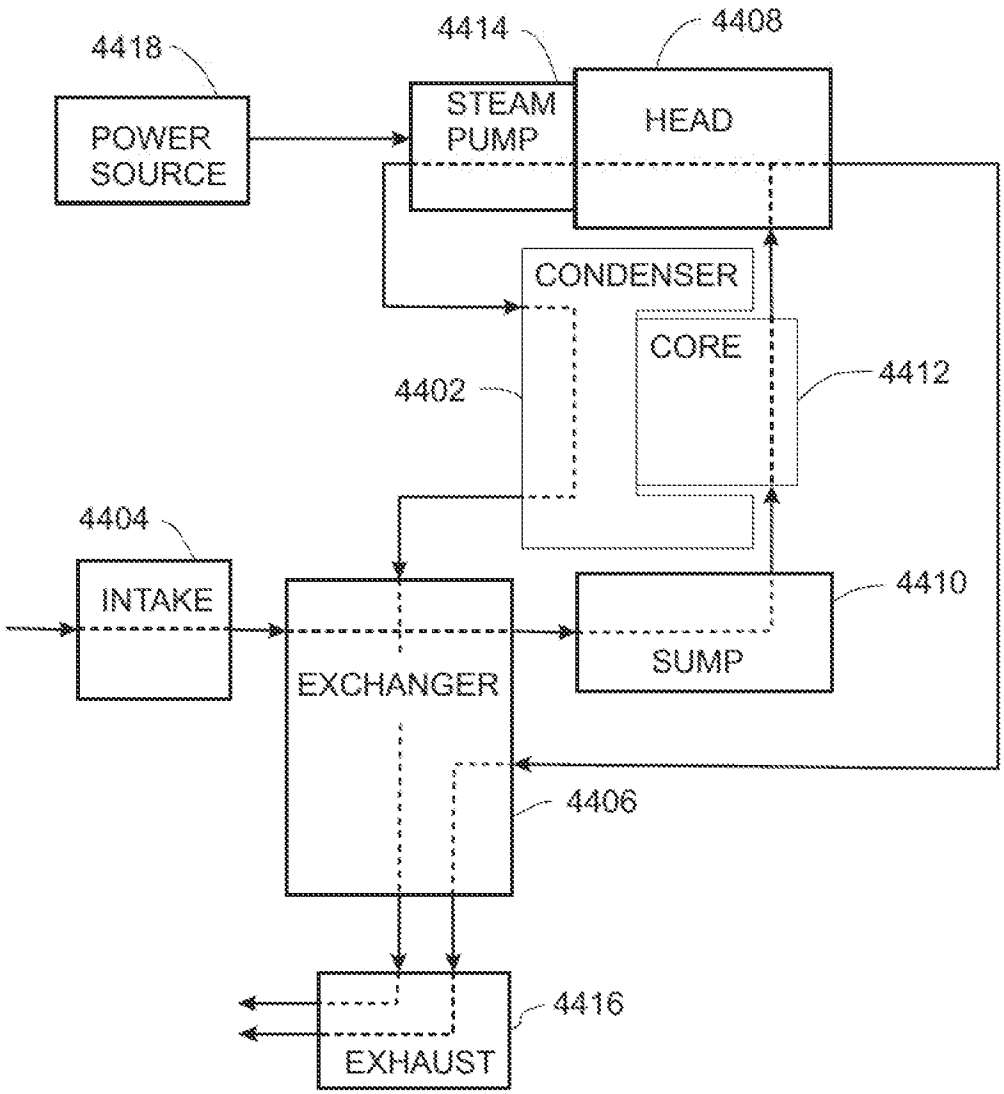
45K
45L

FIG.43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STEAM PUMP
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CONDENSER
CORE
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4402
4404
INTAKE
EXCHANGER
SUMP
4410
4406
4416
EXHAUST

FIG.44

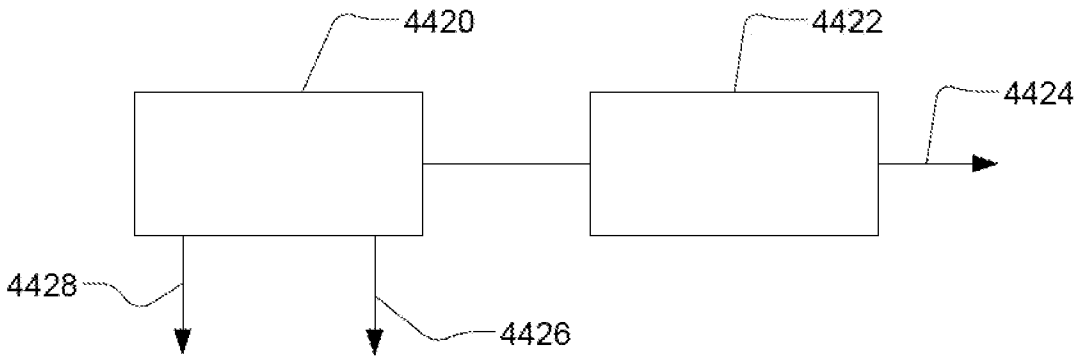
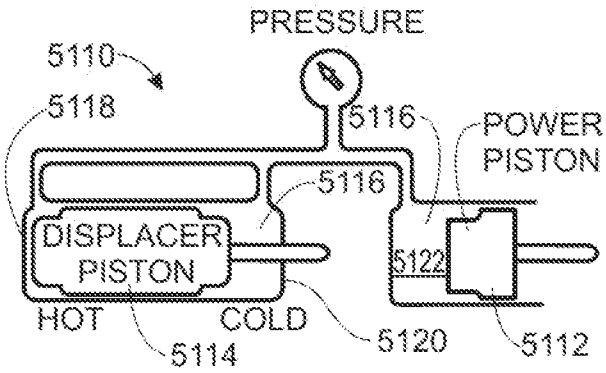
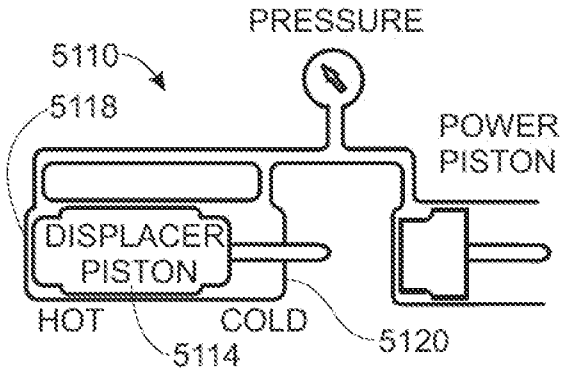



FIG. 44A



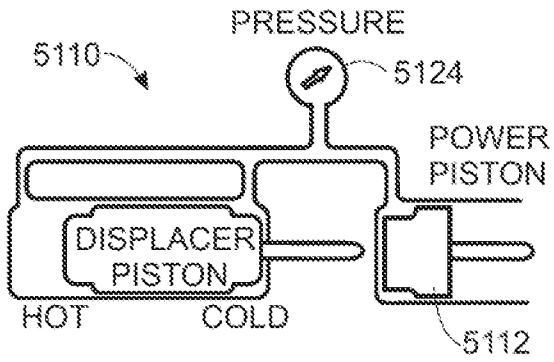

READY FOR START OF COMPRESSION STROKE

FIG. 45A
PRIOR ART



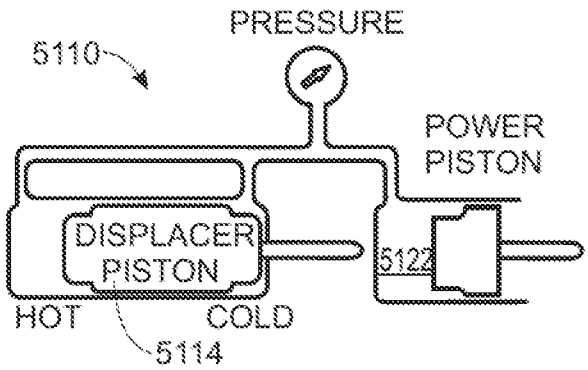

END OF COMPRESSION STROKE

FIG. 45B
PRIOR ART




READY FOR START OF EXPANSION STROKE

FIG. 45C
PRIOR ART




END OF EXPANSION STROKE

FIG. 45D
PRIOR ART

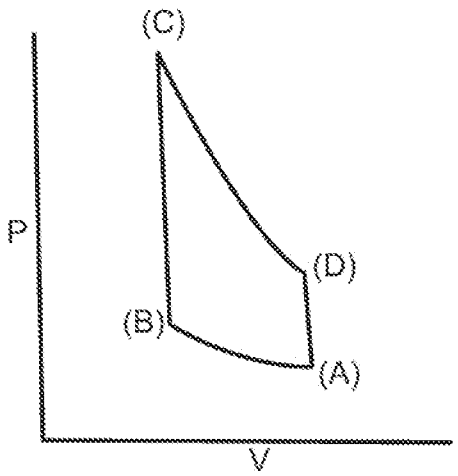



FIG. 45E
PRIOR ART

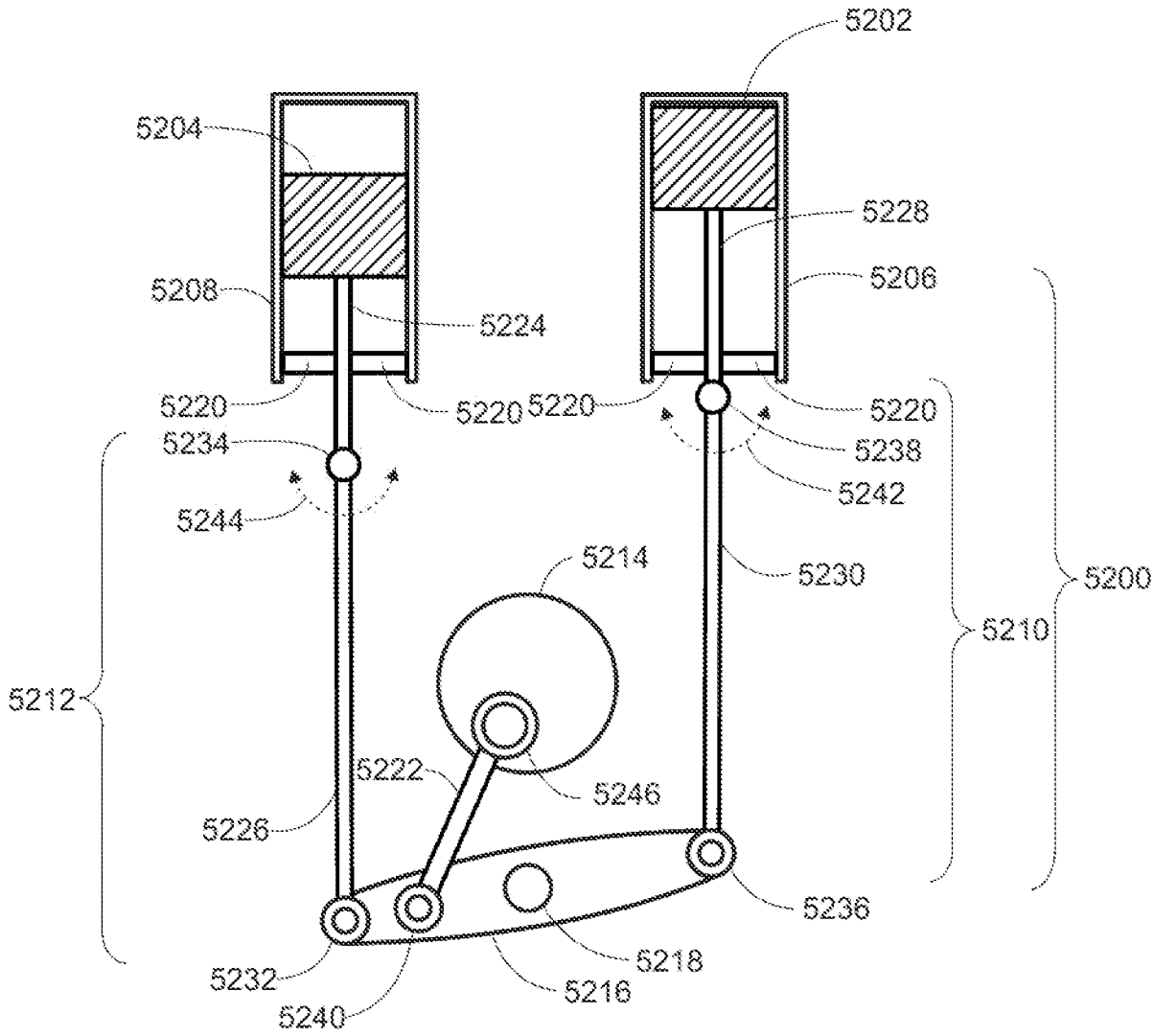

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FIG. 46

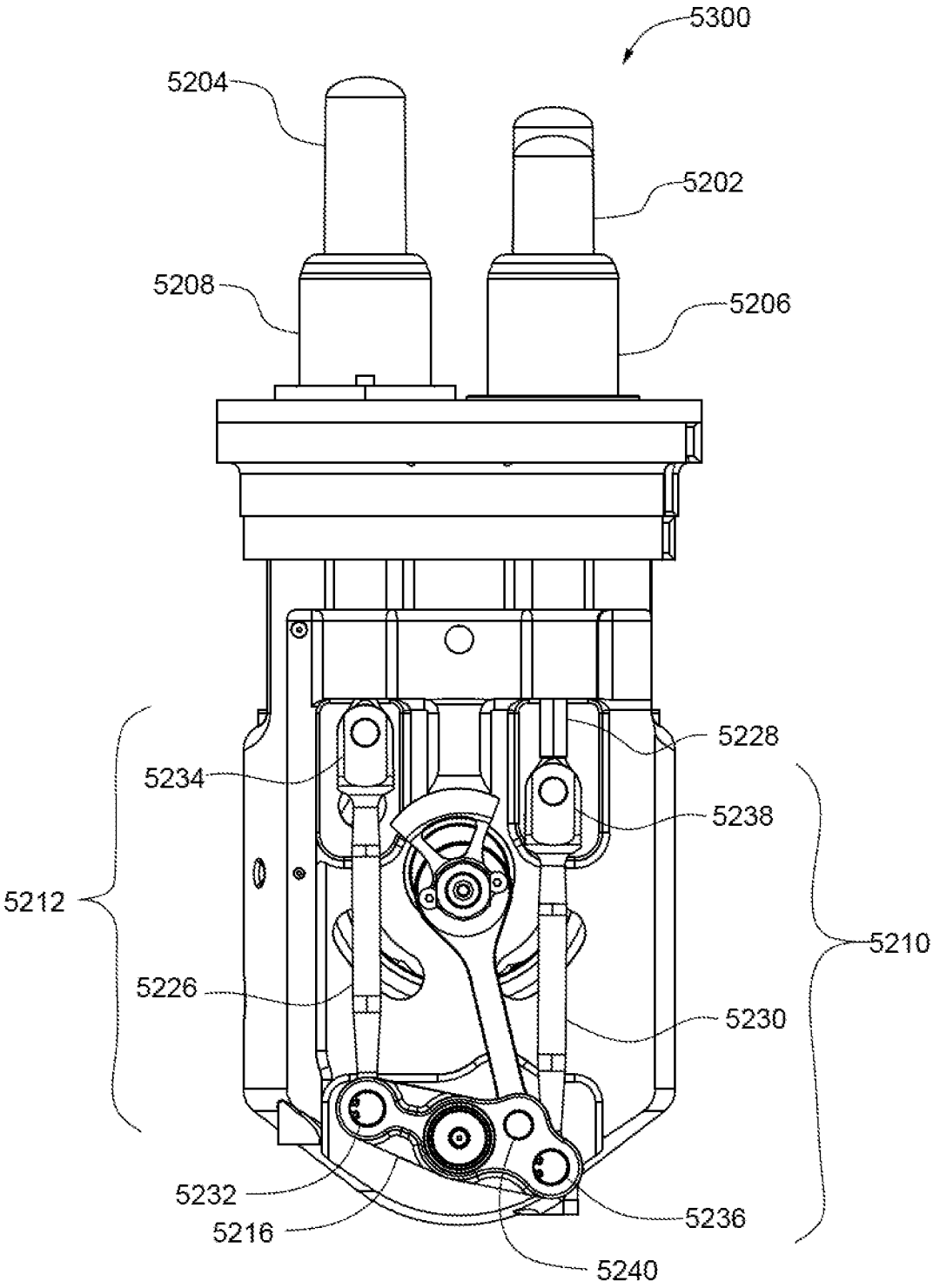
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FIG. 47

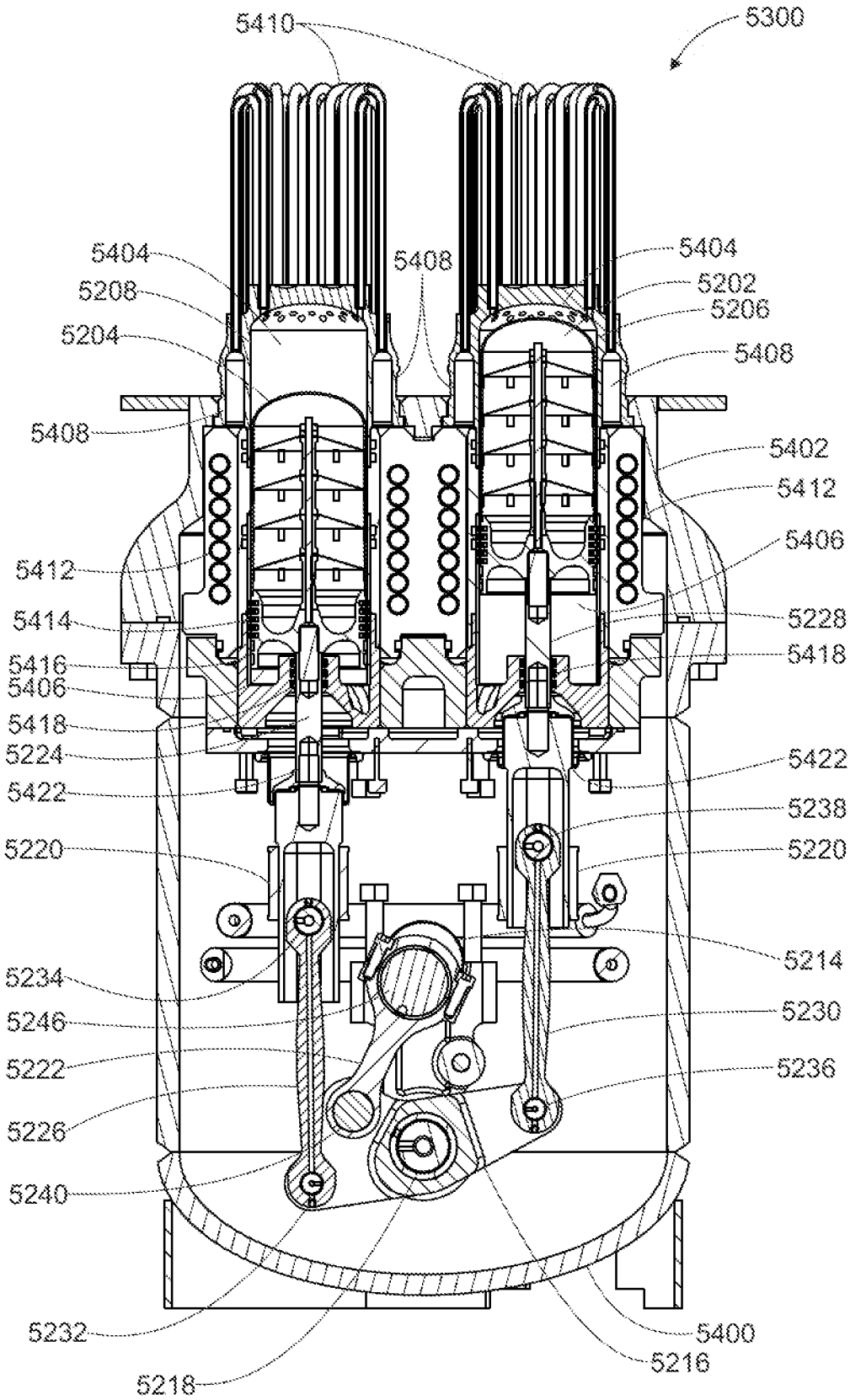
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FIG. 48

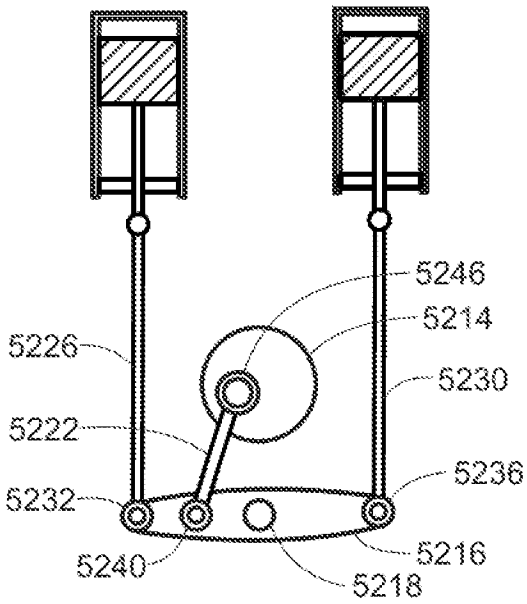


FIG. 49A

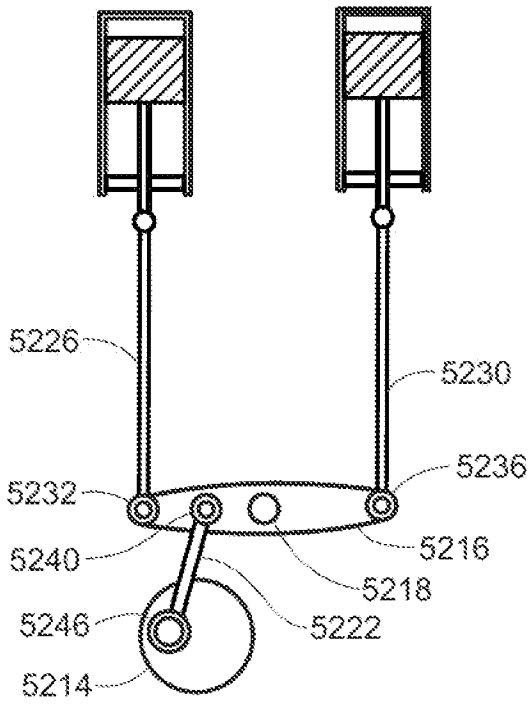


FIG. 49B

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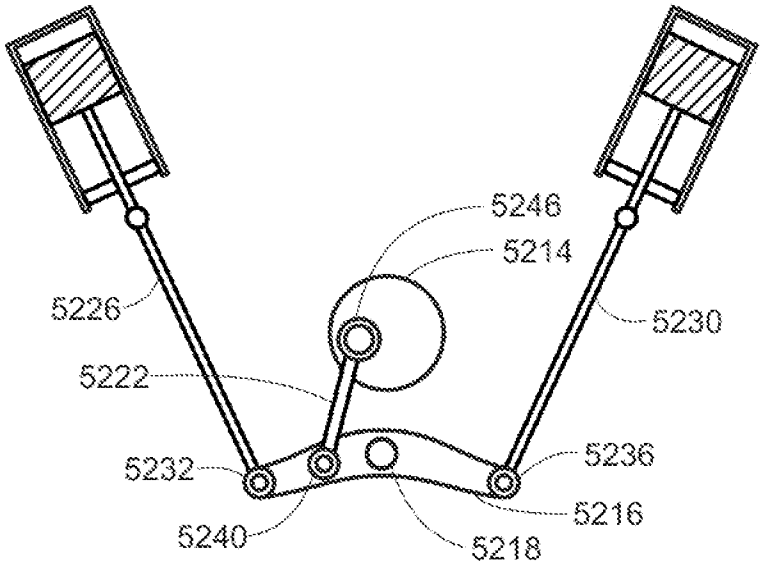



FIG. 49C

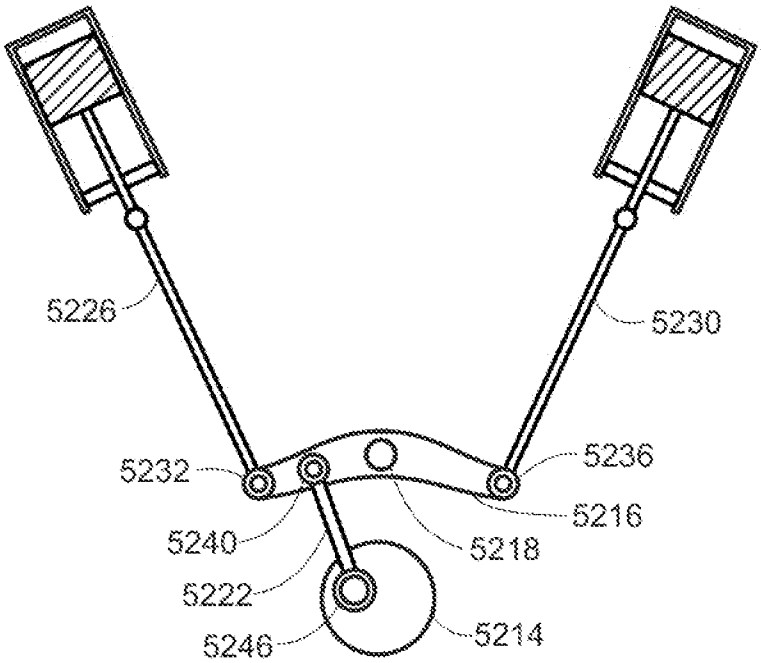



FIG. 49D

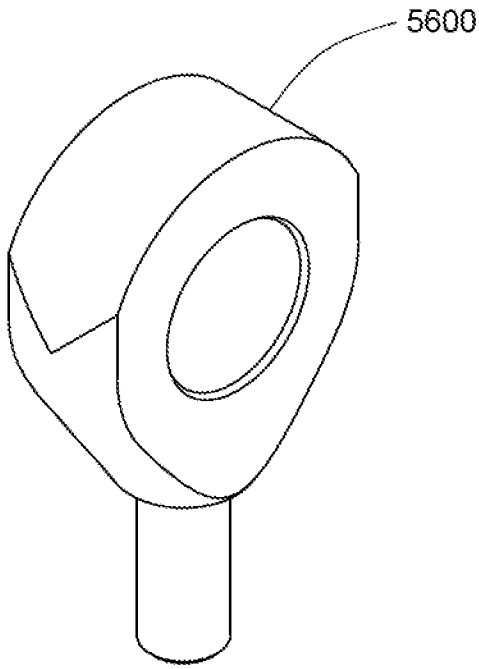



FIG. 50

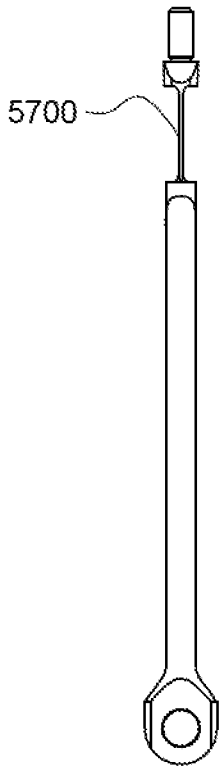



FIG. 51A

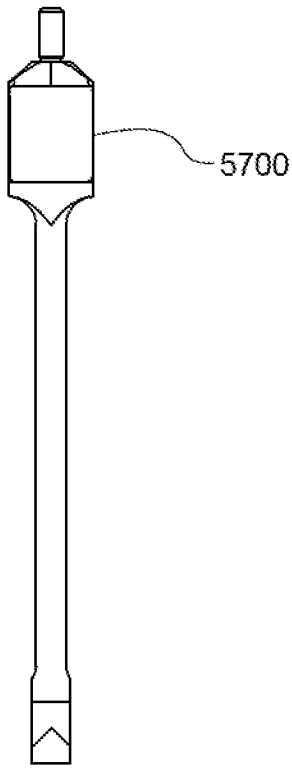
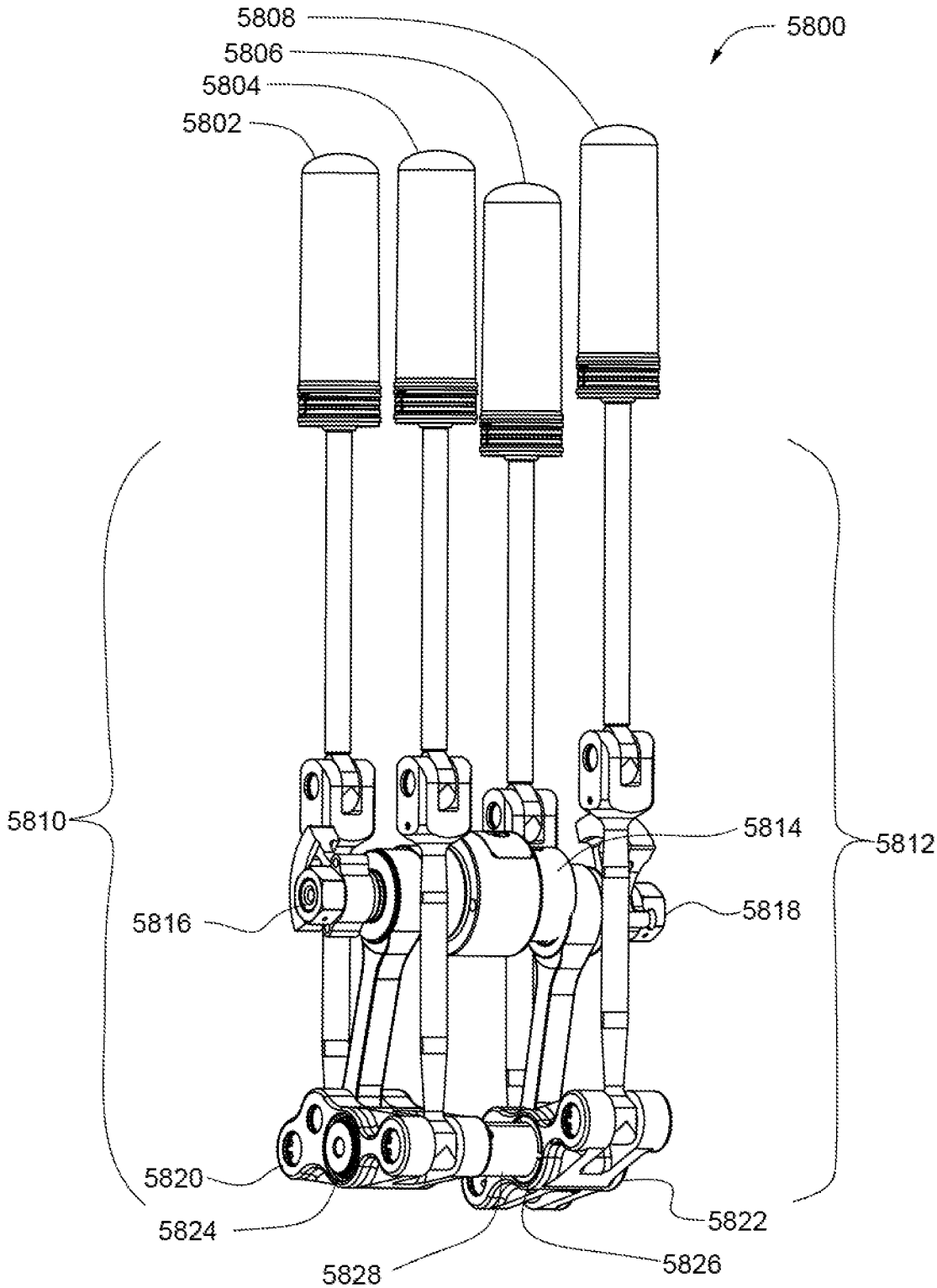



FIG. 51B


5808
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5828

FIG. 52

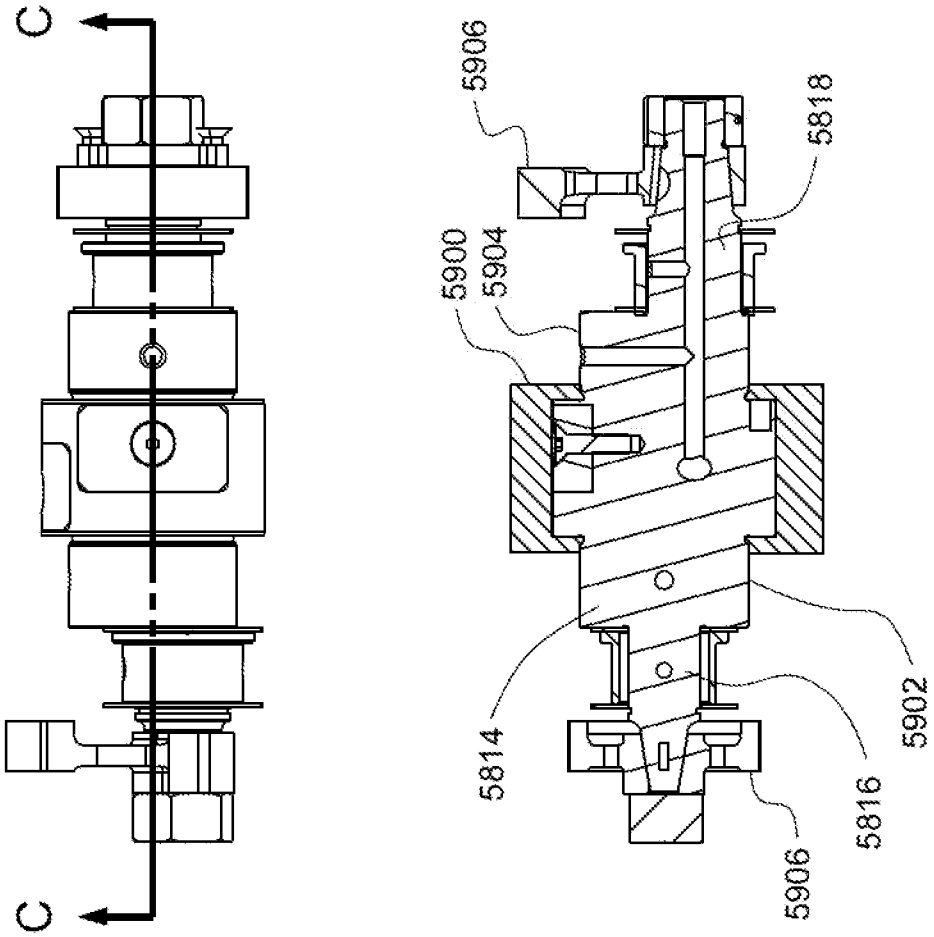
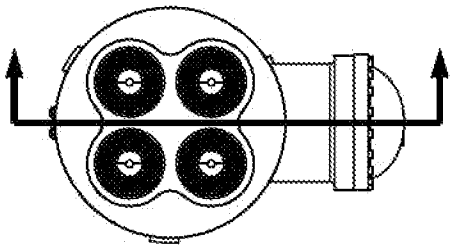



FIG. 53



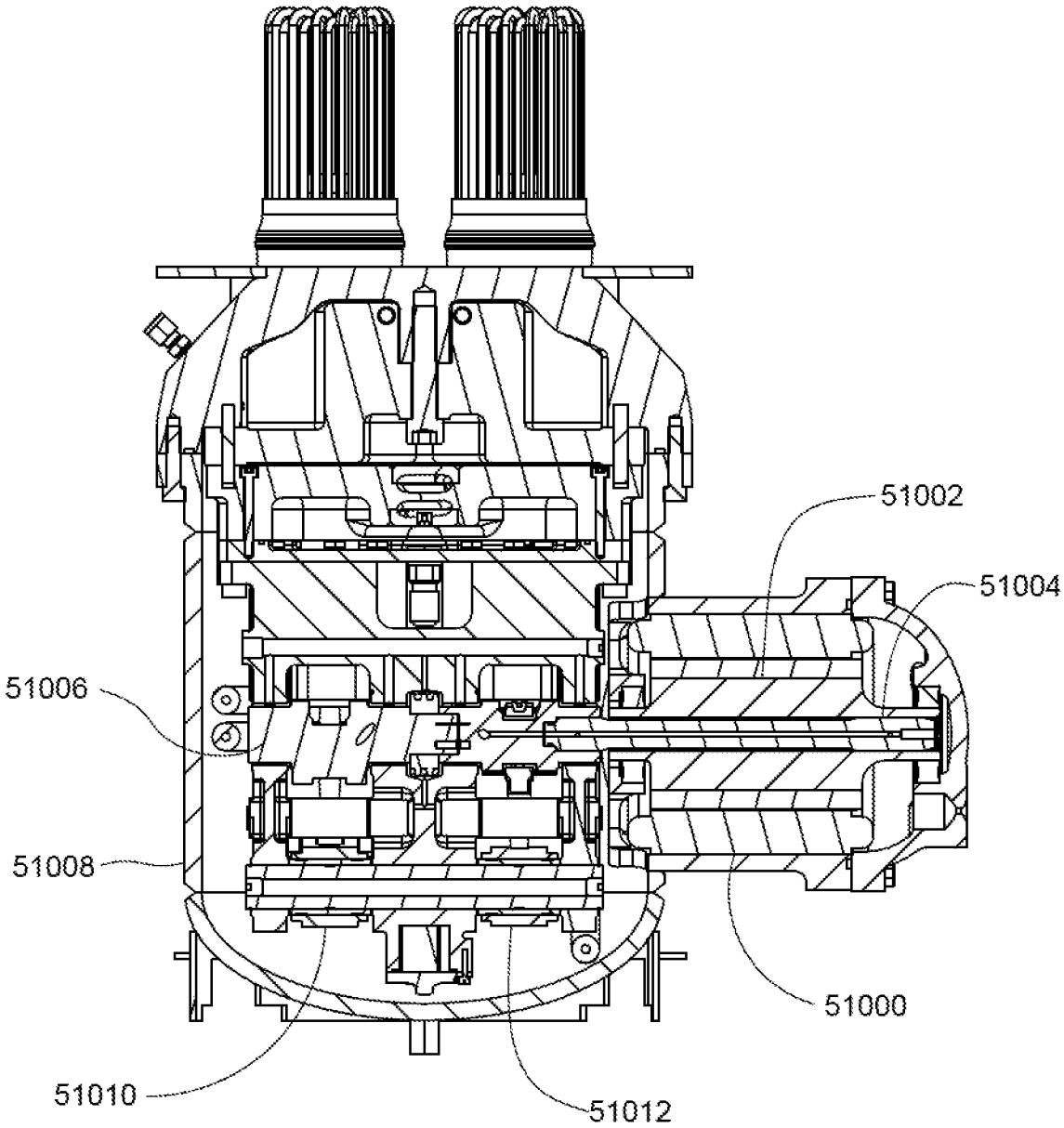



FIG. 54A

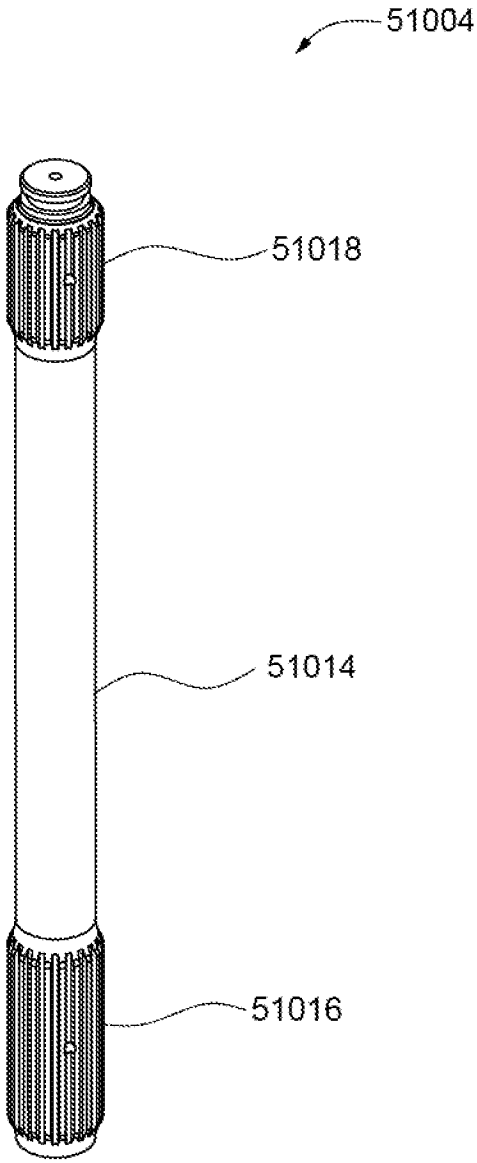



FIG. 54B

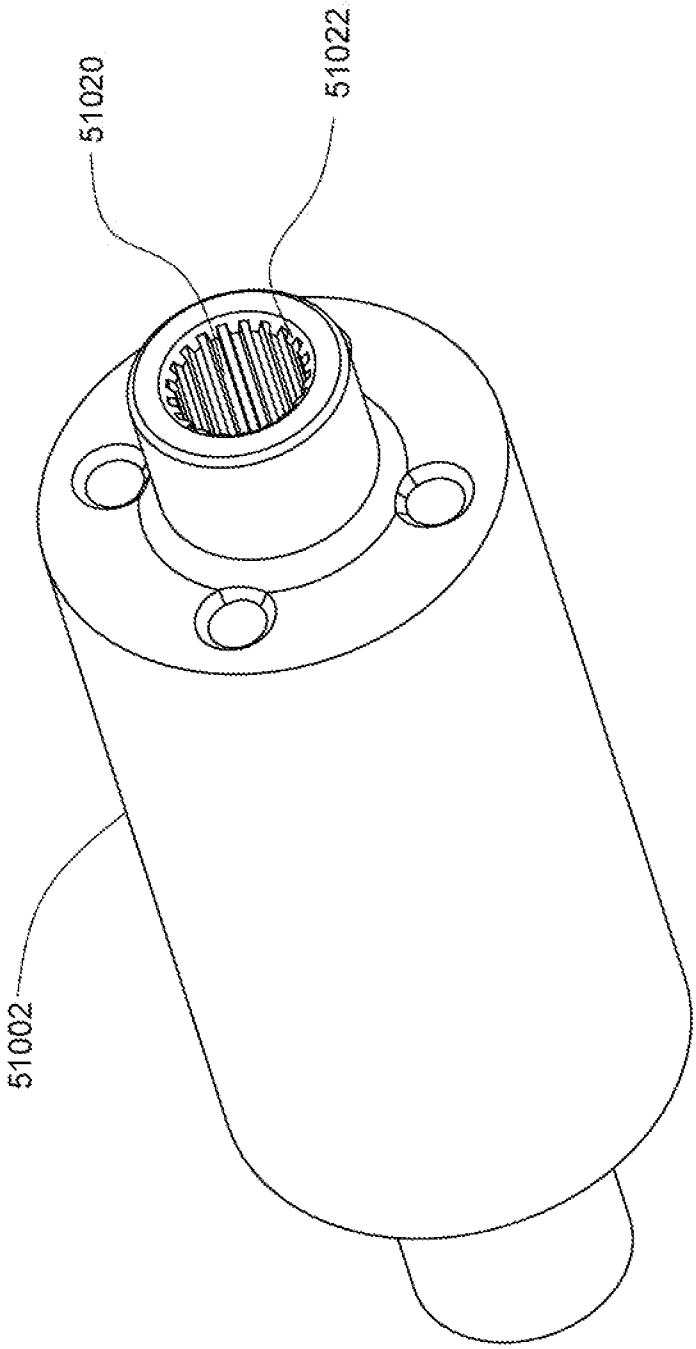



FIG. 54C

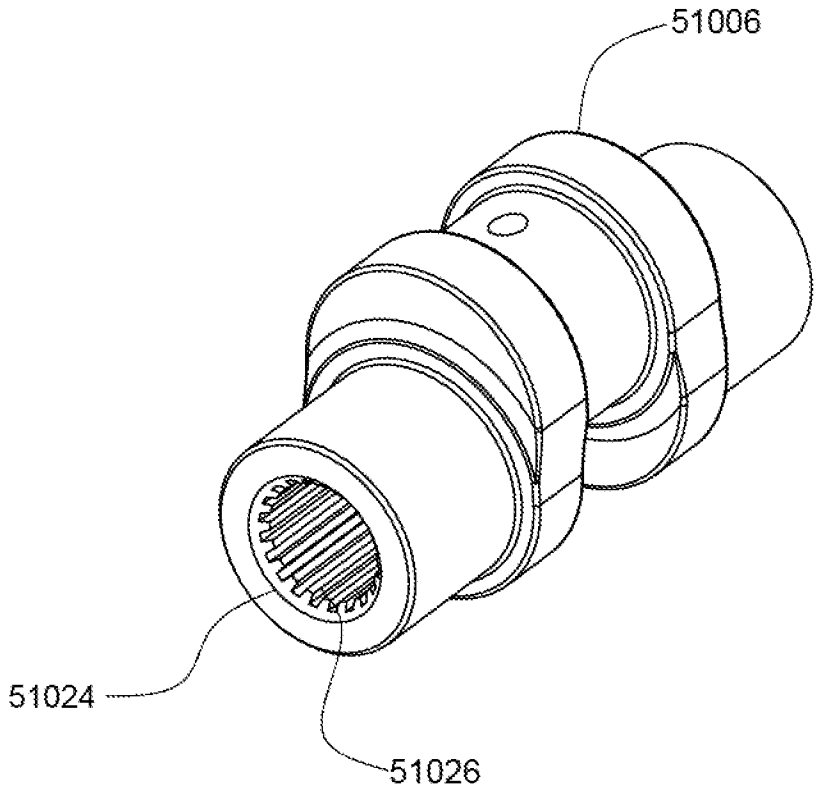



FIG. 54D

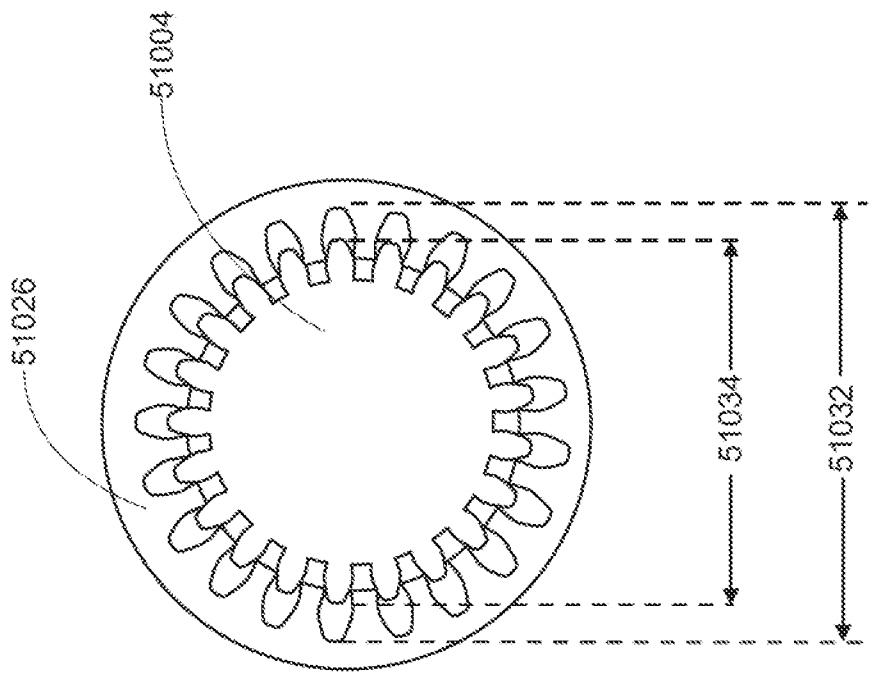



FIG. 54F

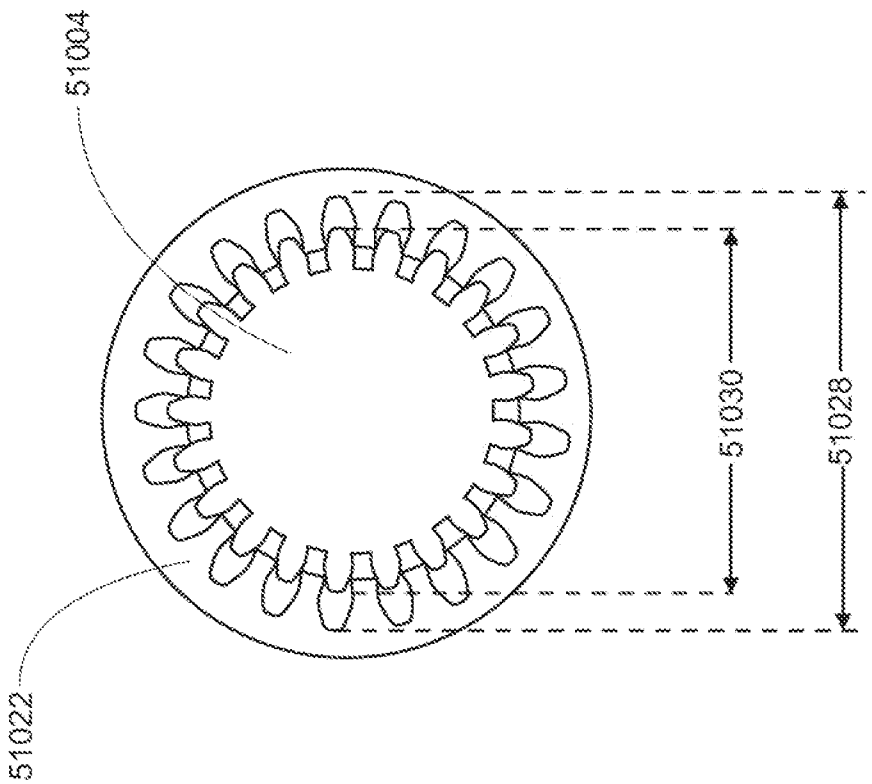
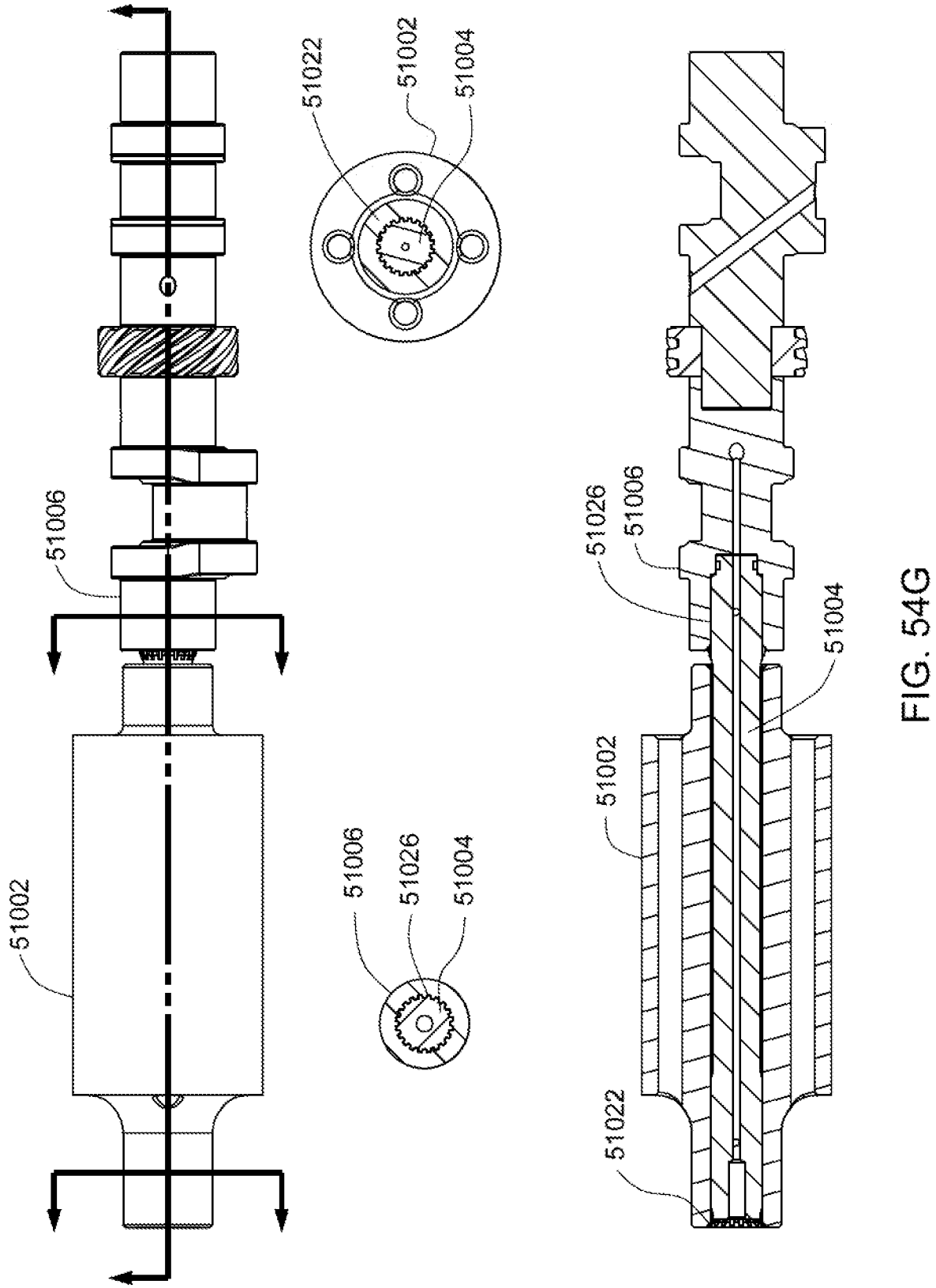



FIG. 54E


51022
51002
51004
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51026
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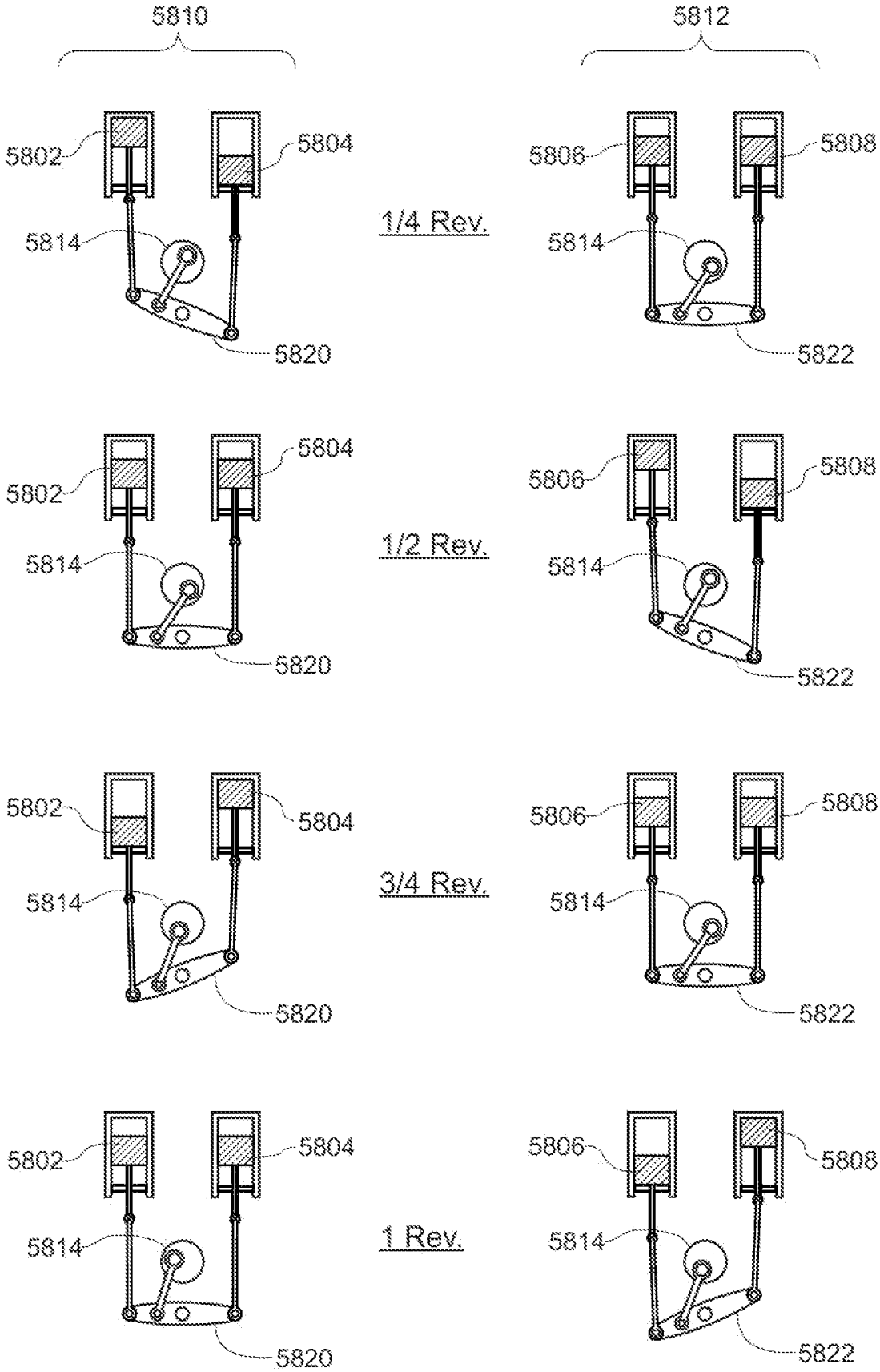
51002
51022

FIG. 54G


5810
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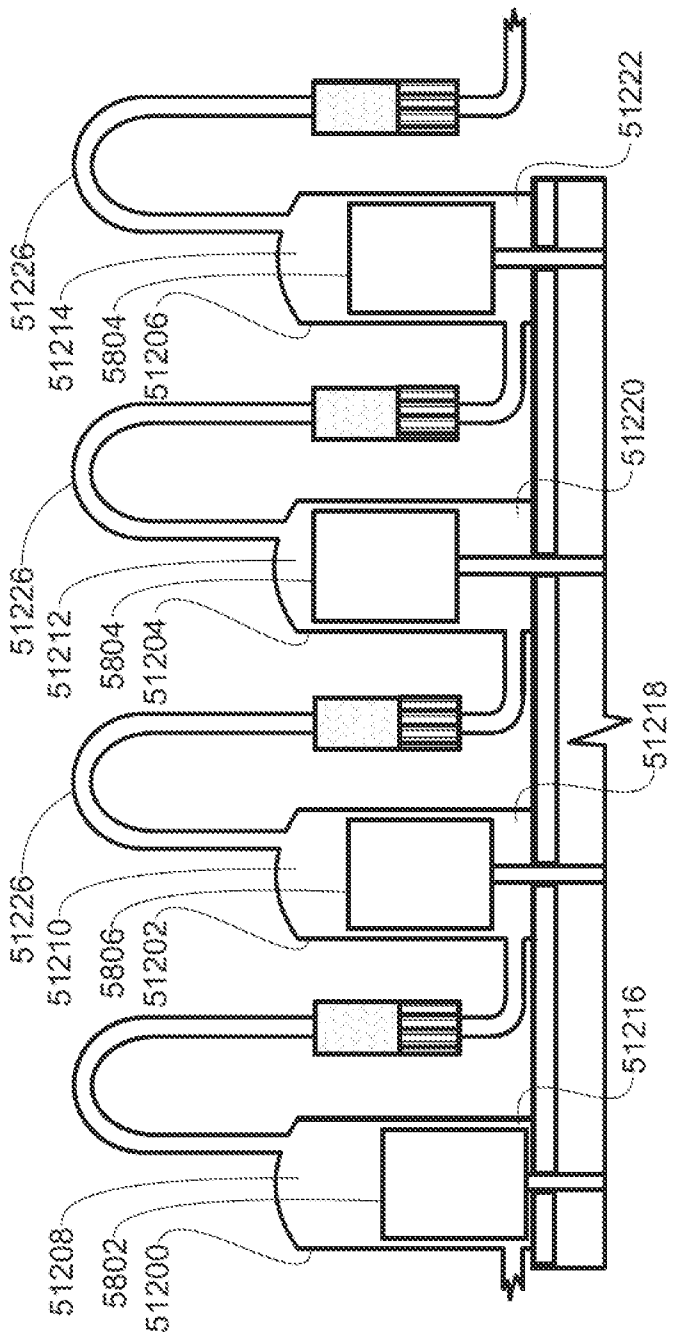
5822
1/4 Rev.
1/2 Rev.
3/4 Rev.
1 Rev.

FIG. 55


51222
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51200

FIG. 56A

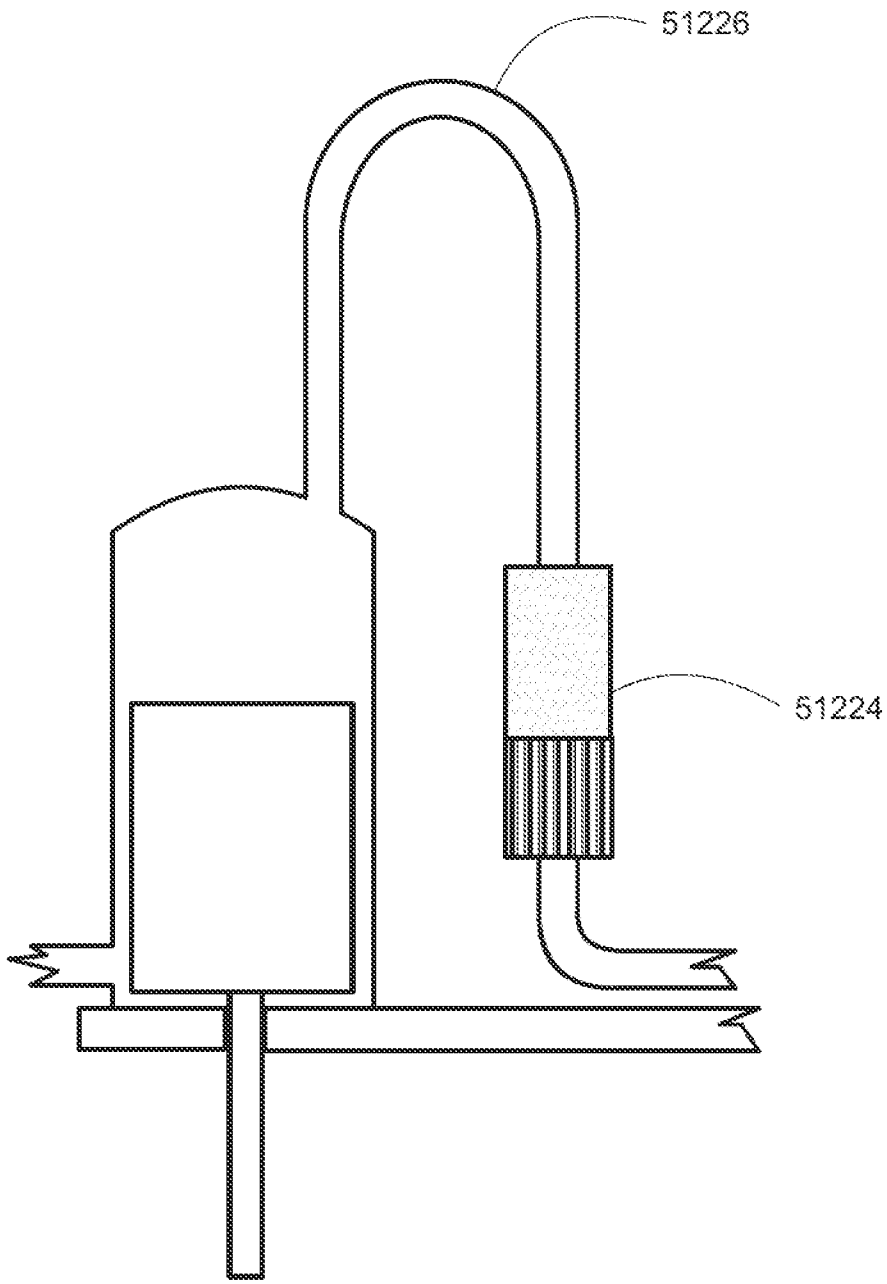


FIG.56B

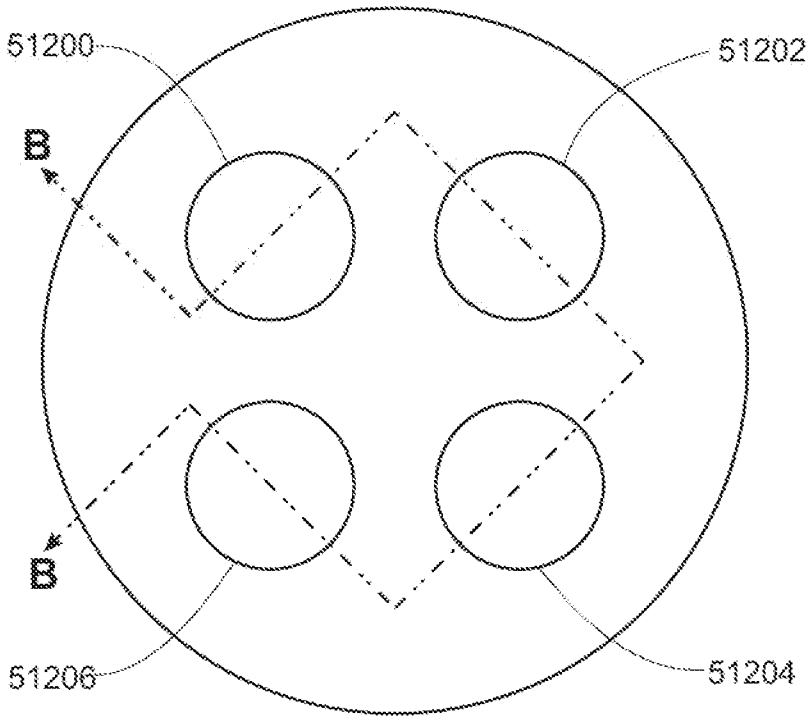


FIG. 56C

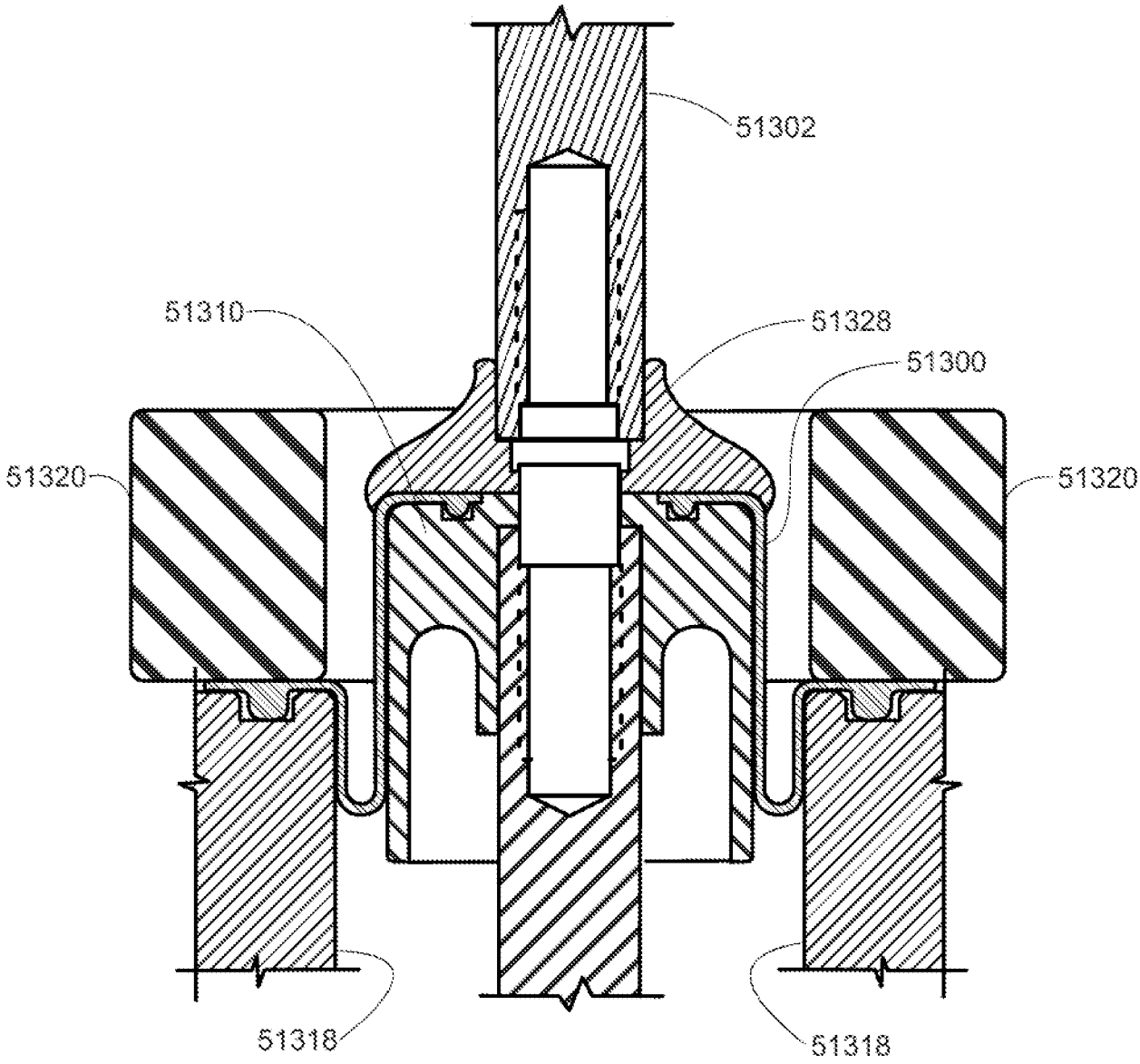


FIG. 57A

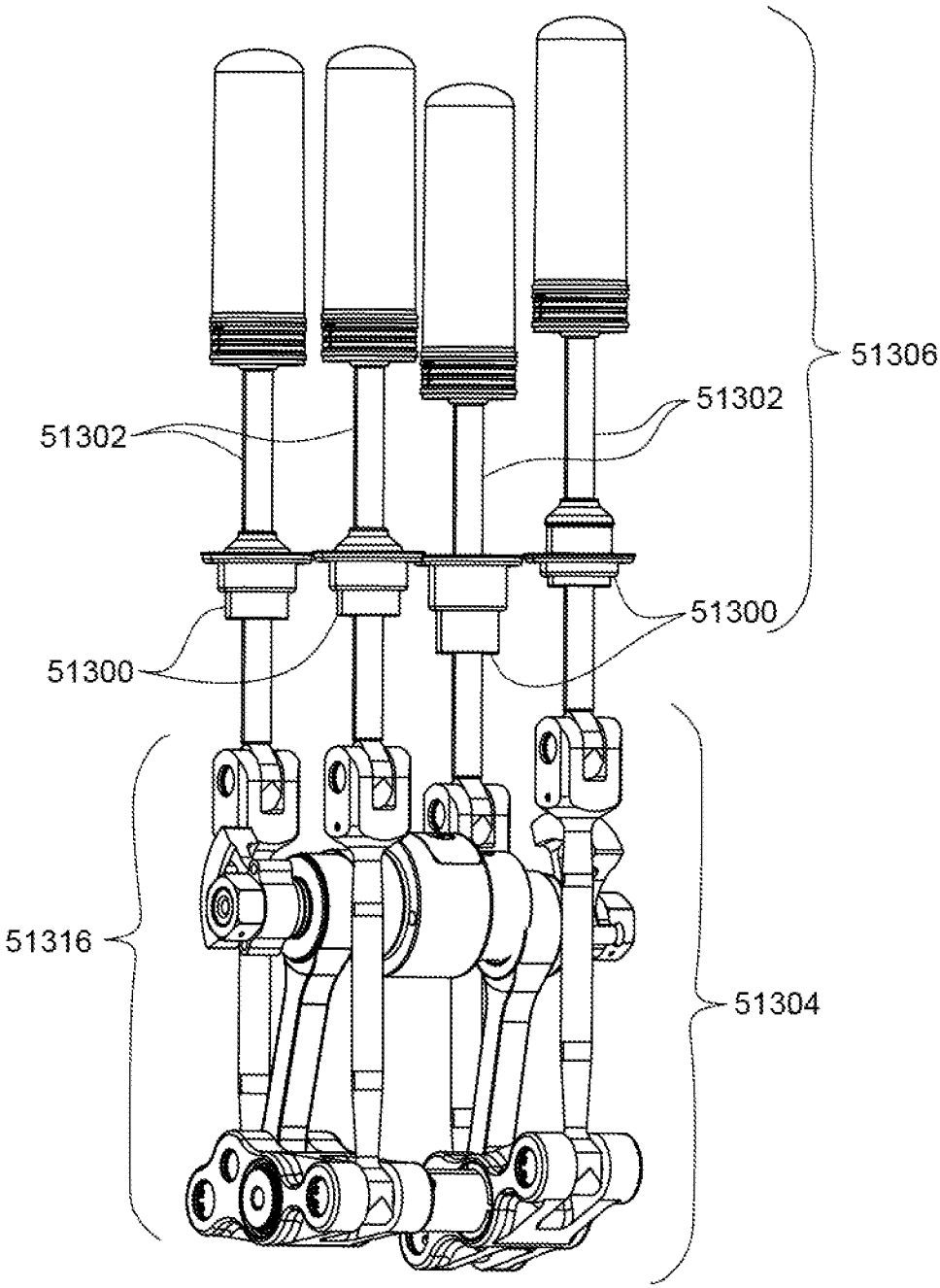


FIG. 57B

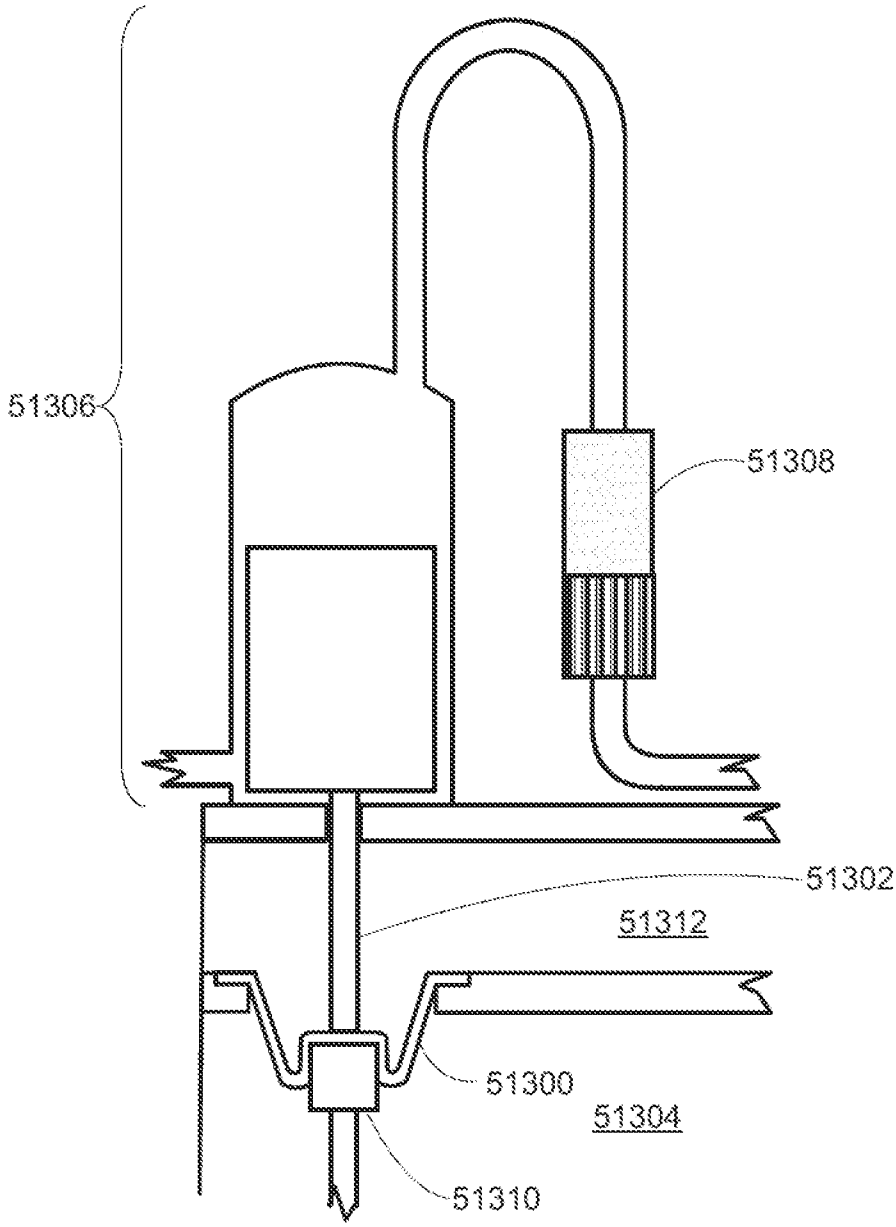


FIG.57C

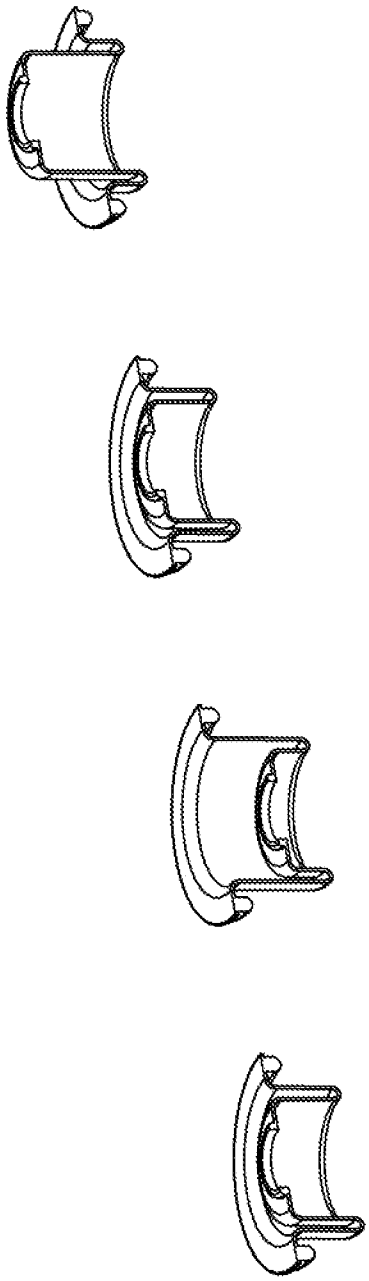


FIG. 57D

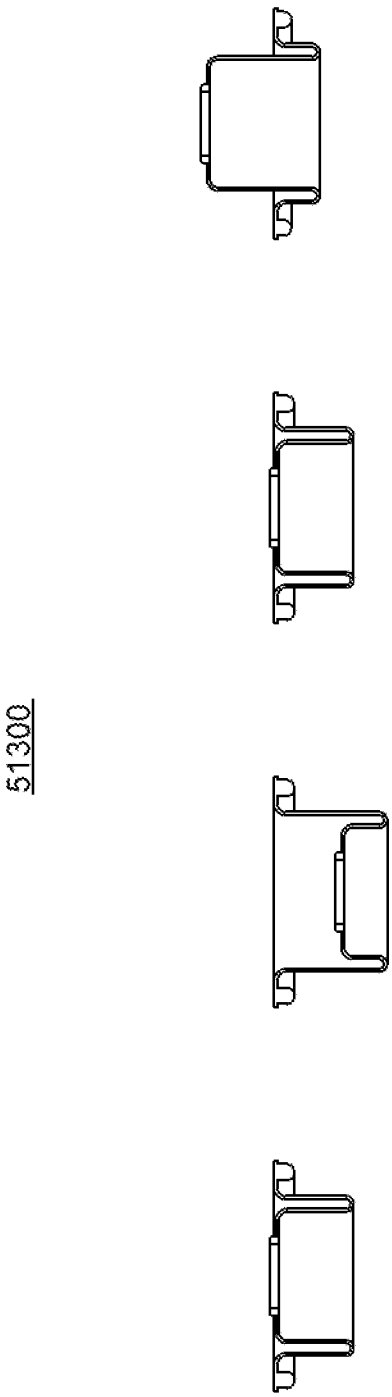


FIG. 57E

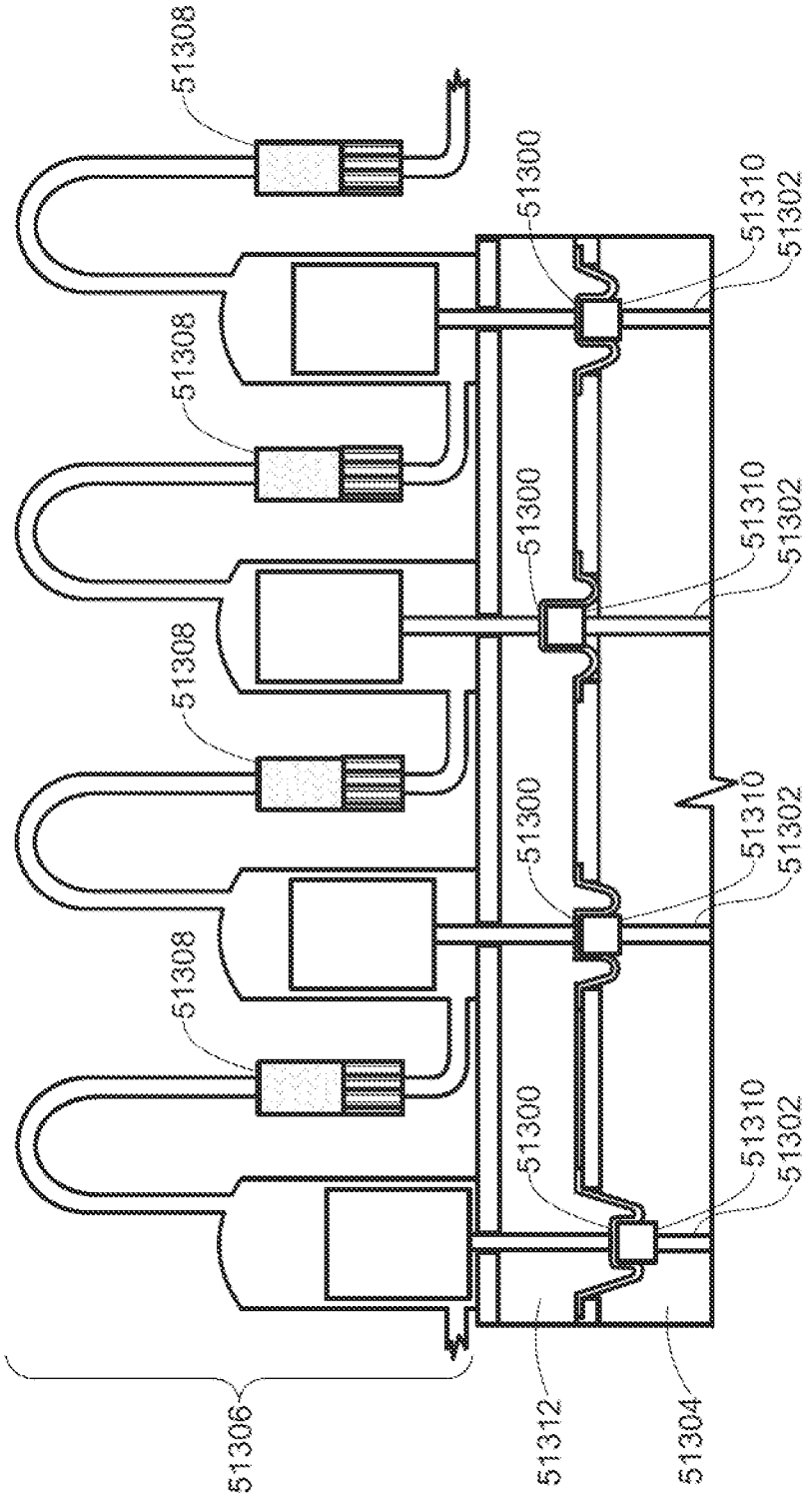
51308
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FIG.57F

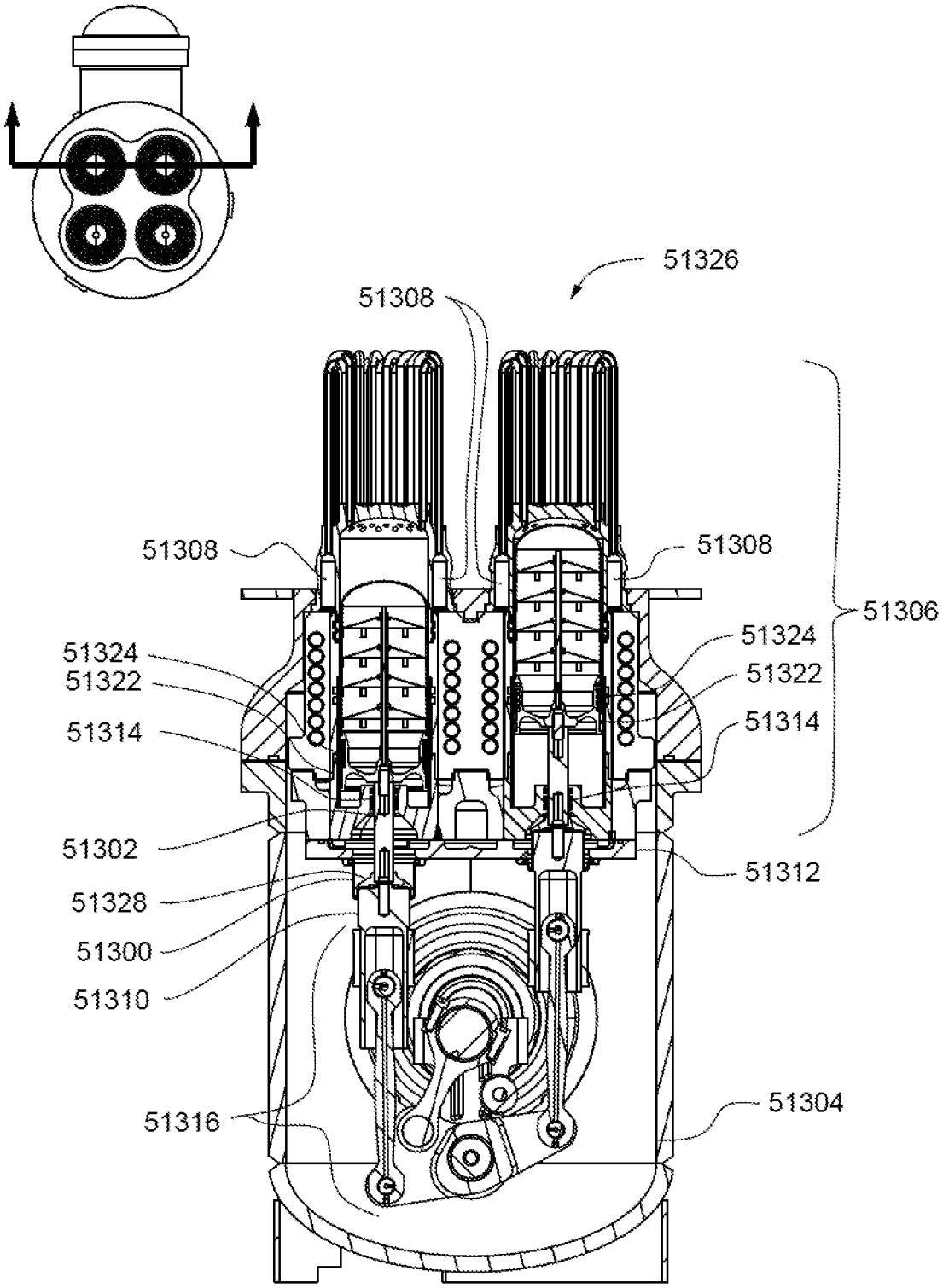
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FIG. 57G

FIG. 58A

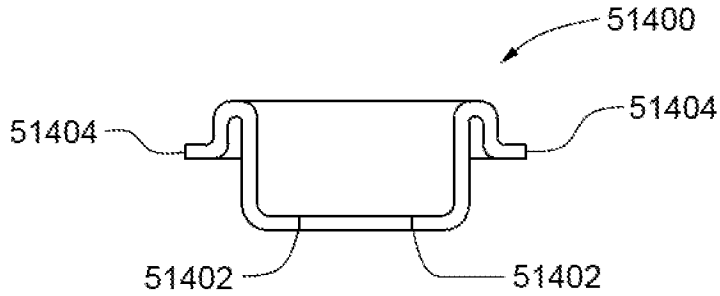



FIG. 58B

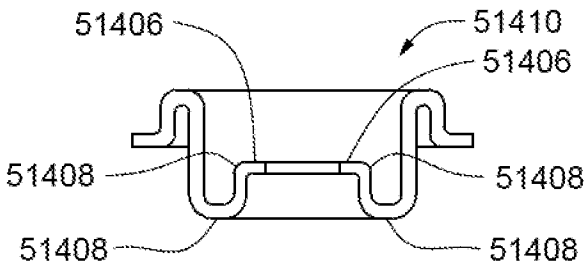



FIG. 58C

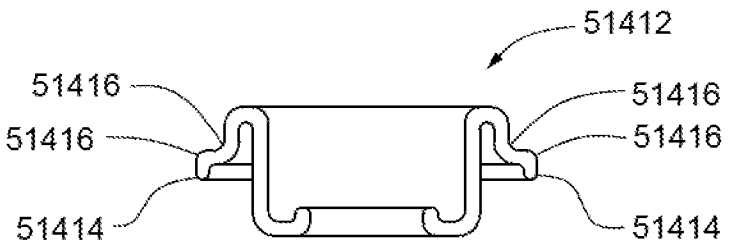



FIG. 58D

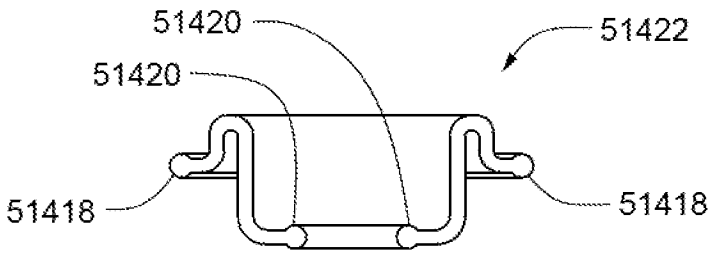
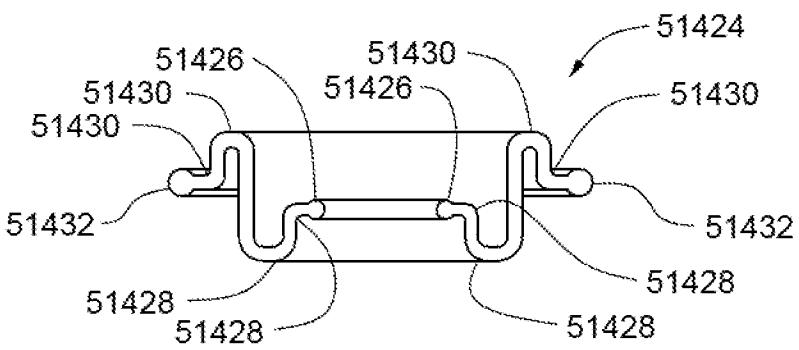
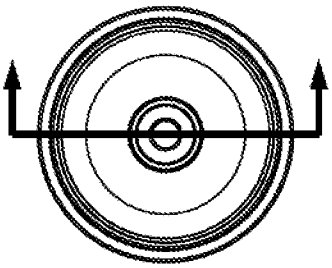



FIG. 58E





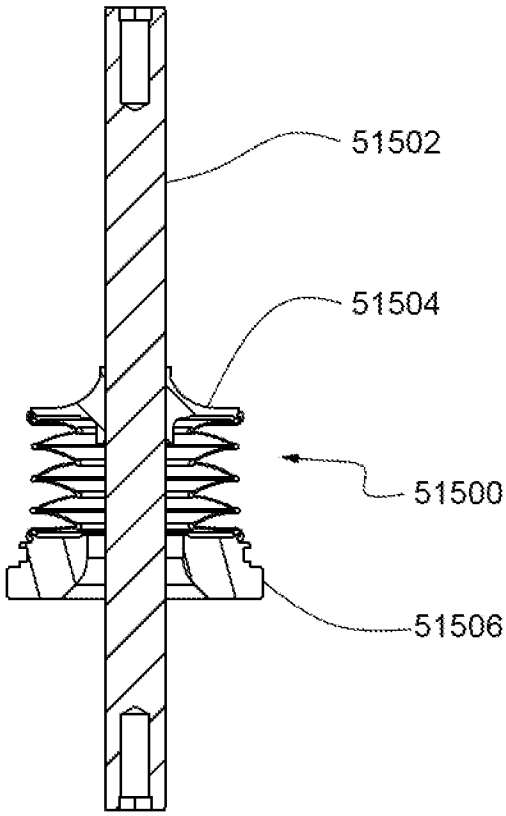



FIG. 59A

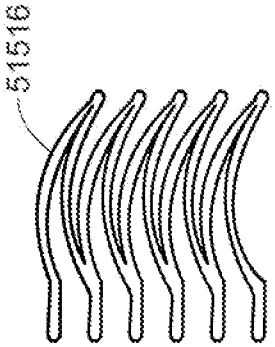



FIG. 59E

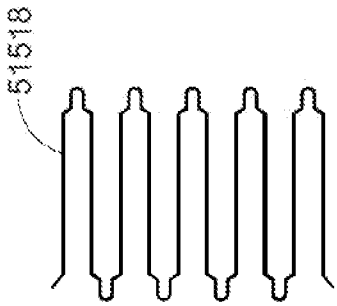



FIG. 59F

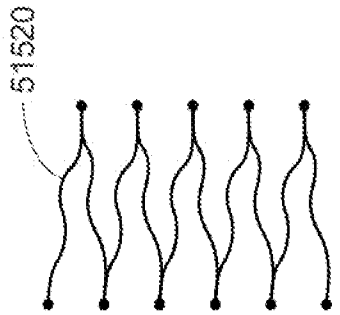



FIG. 59G

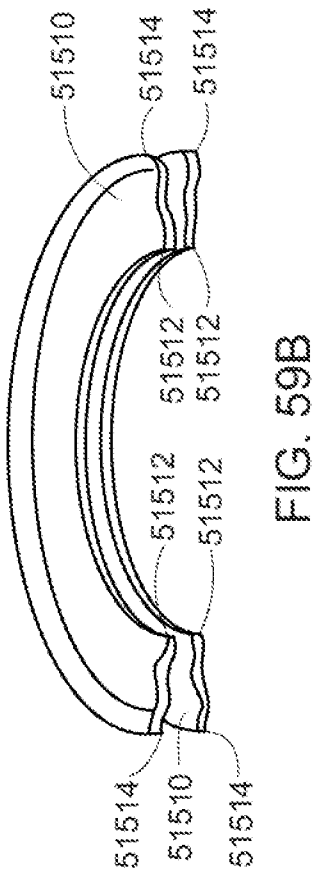



FIG. 59B

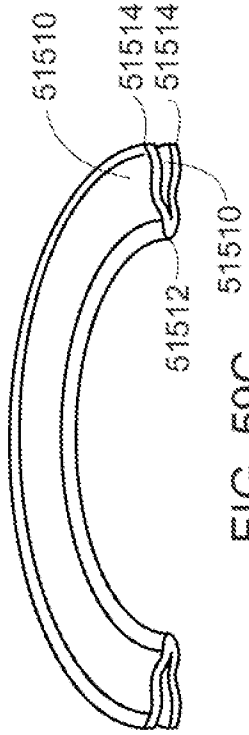



FIG. 59C

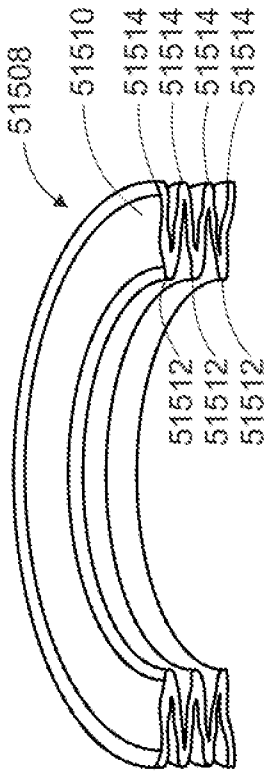



FIG. 59D

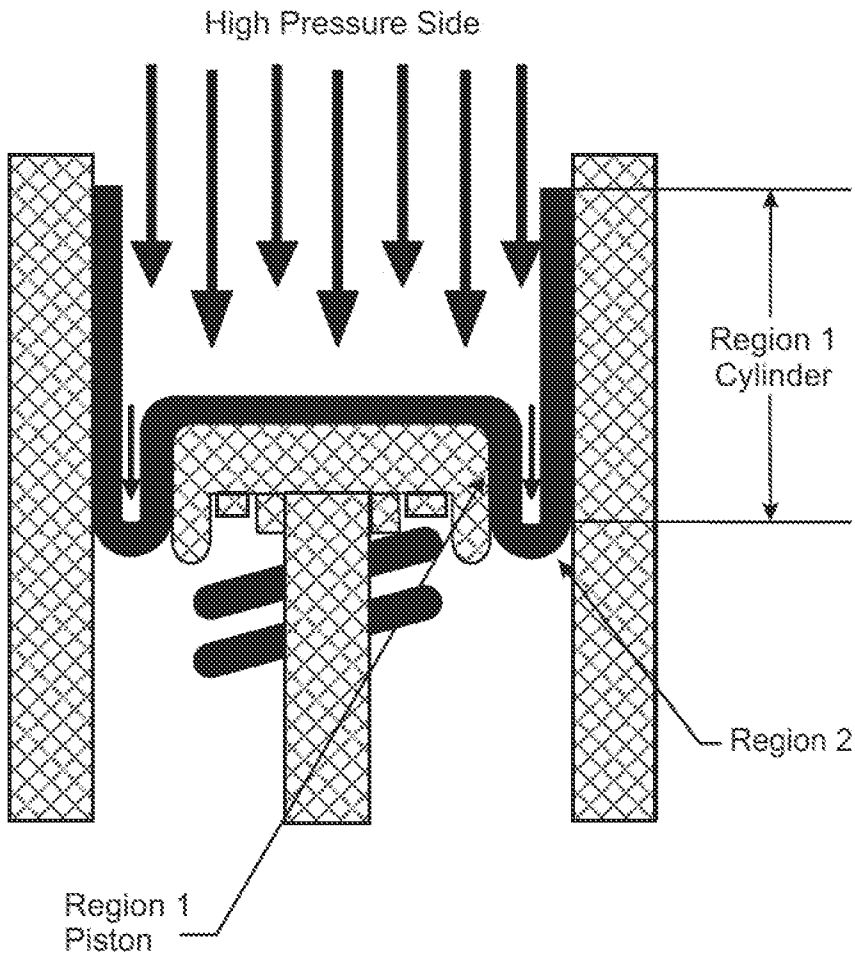

High Pressure Side
Region 1
Cylinder
Region 2
Region 1
Piston

FIG. 59H

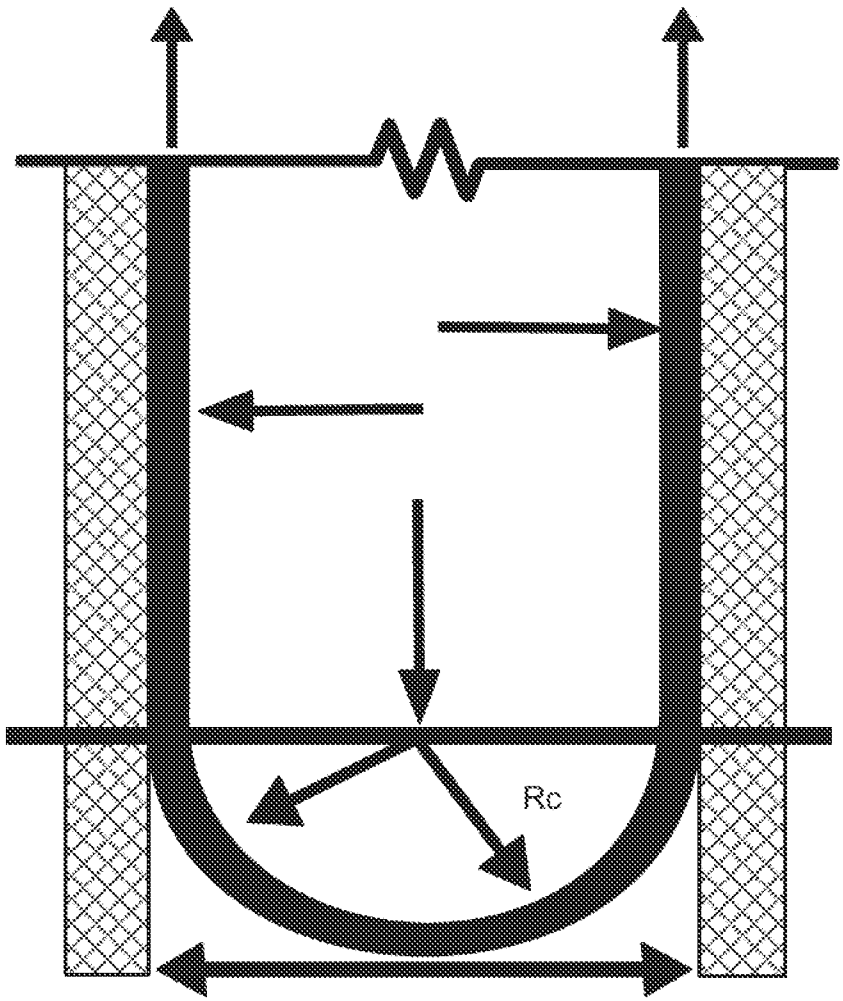



FIG. 59I

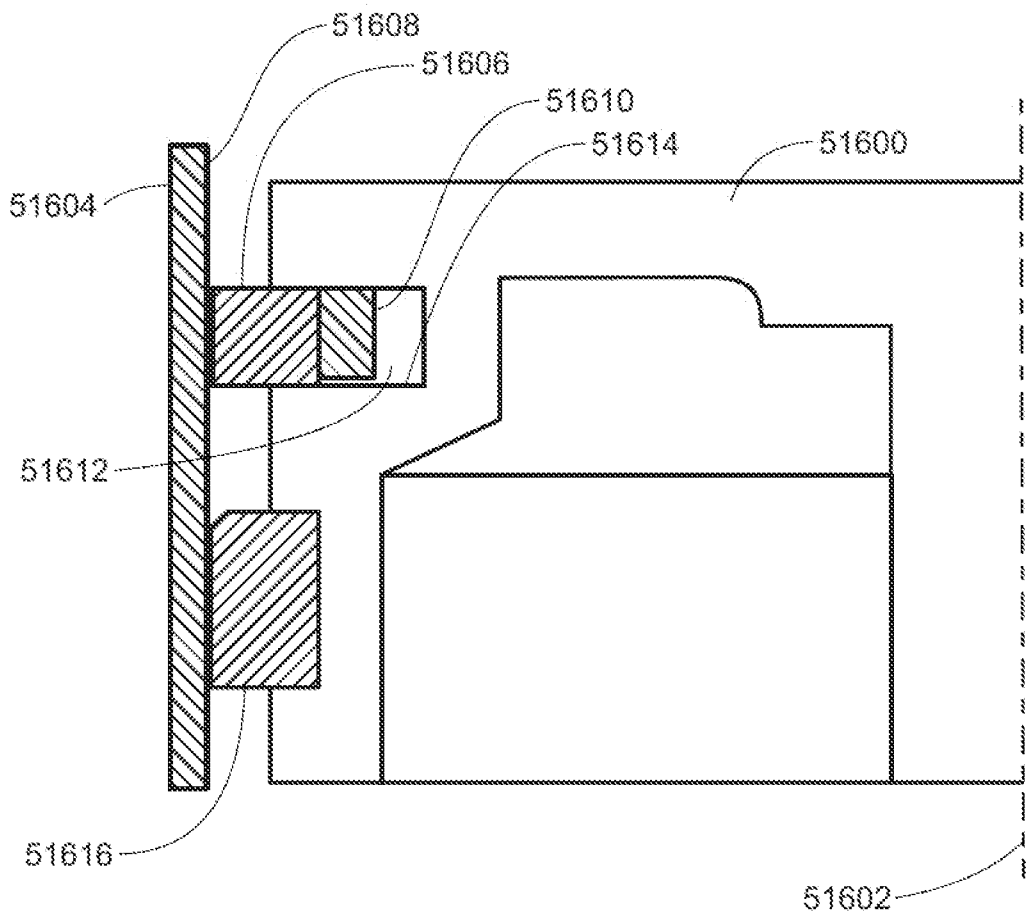



FIG. 60

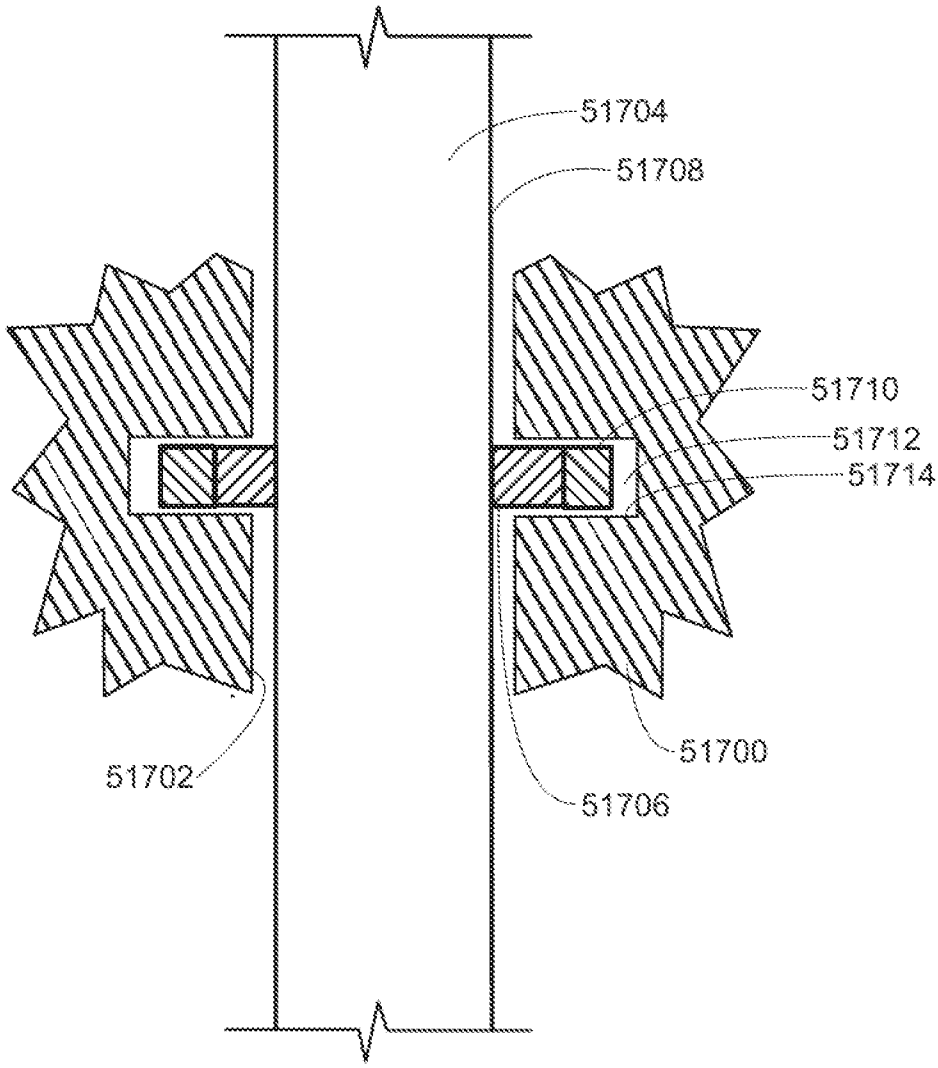



FIG. 61

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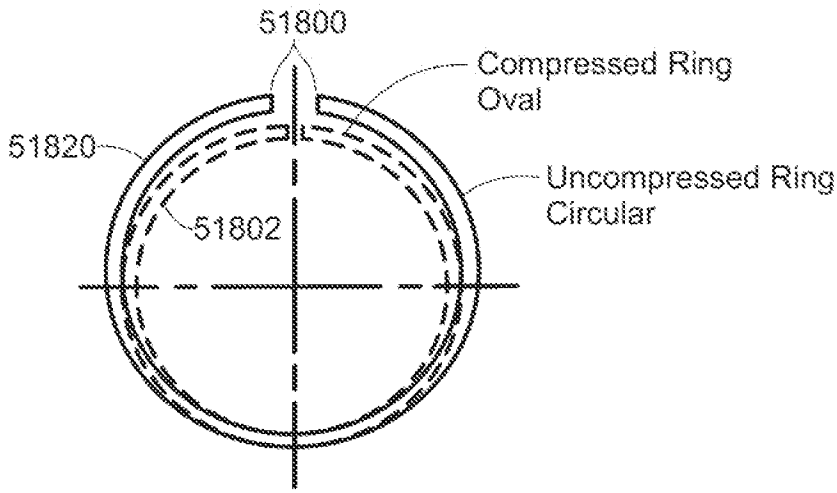


FIG. 62A

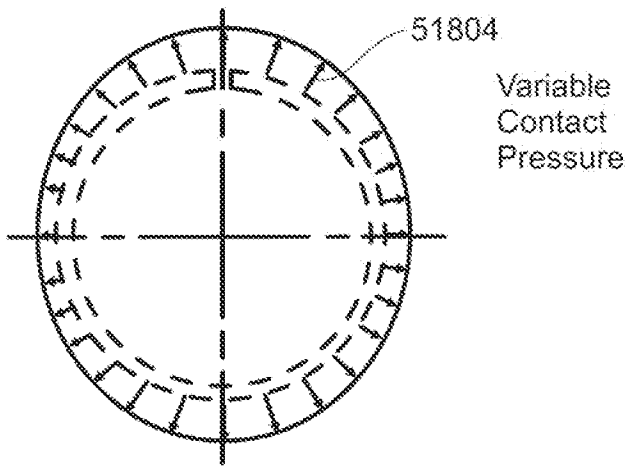


FIG. 62B

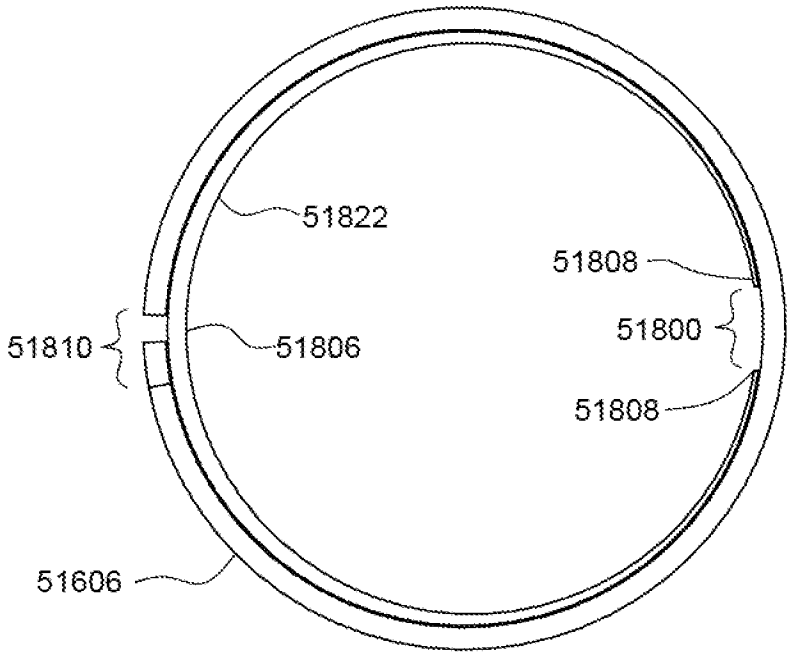


FIG. 62C

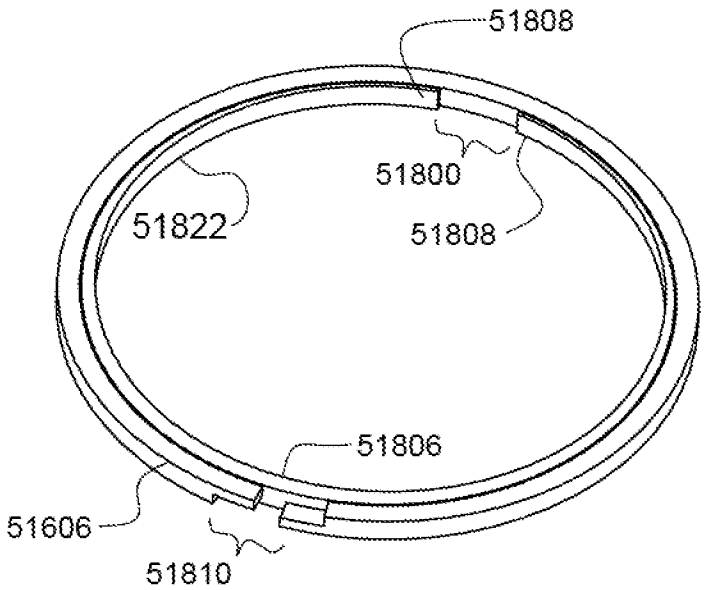


FIG. 62D

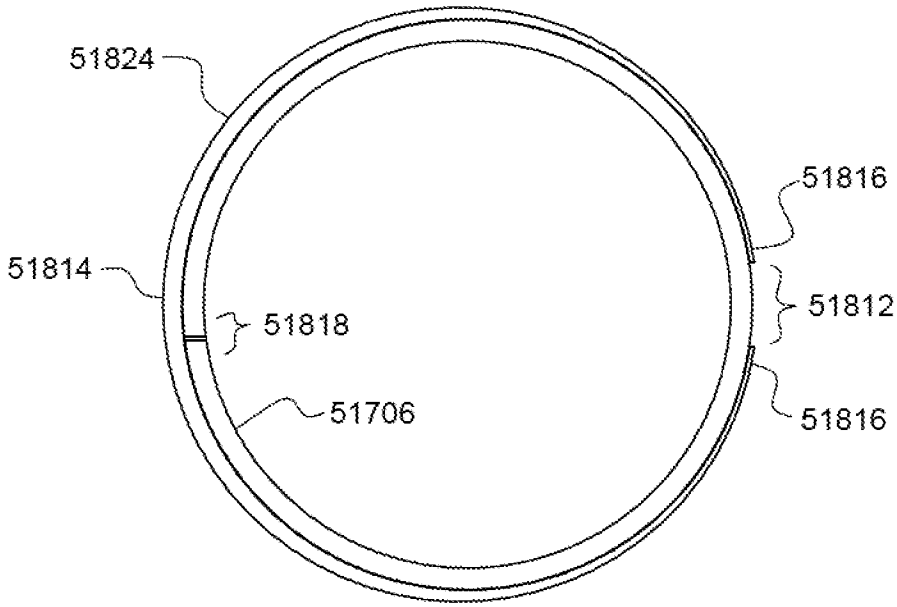


FIG. 62E

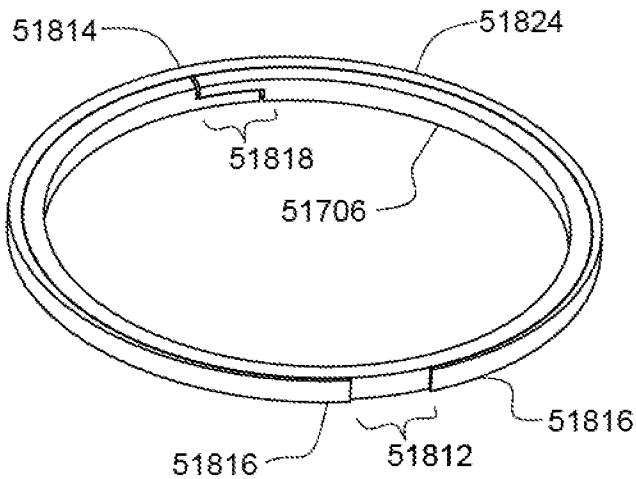


FIG. 62F

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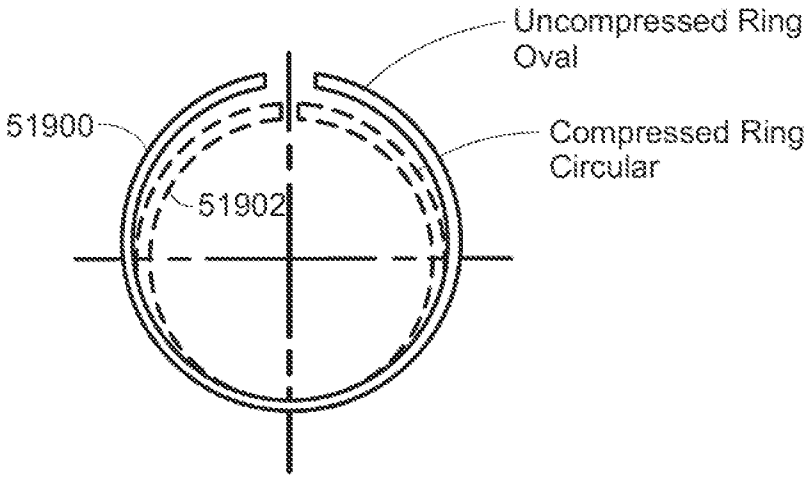



FIG. 63A

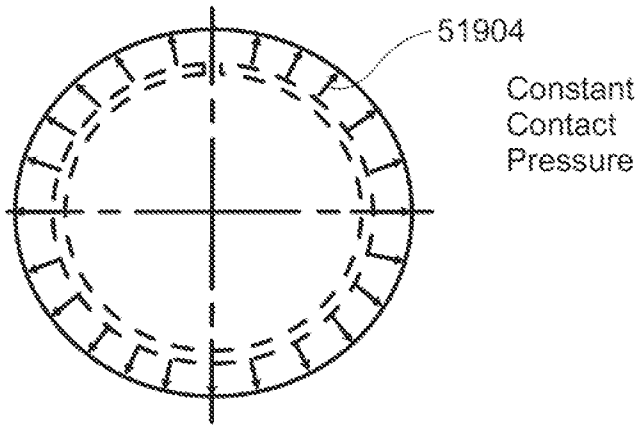



FIG. 63B

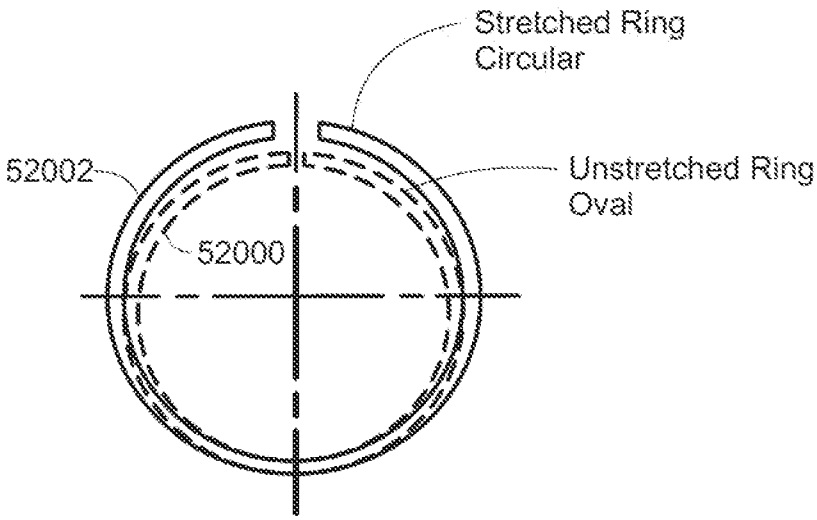



FIG. 64A

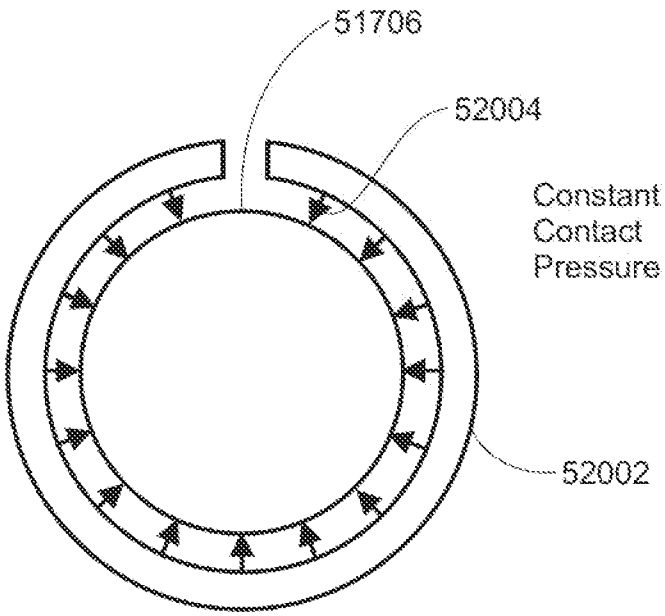



FIG. 64B

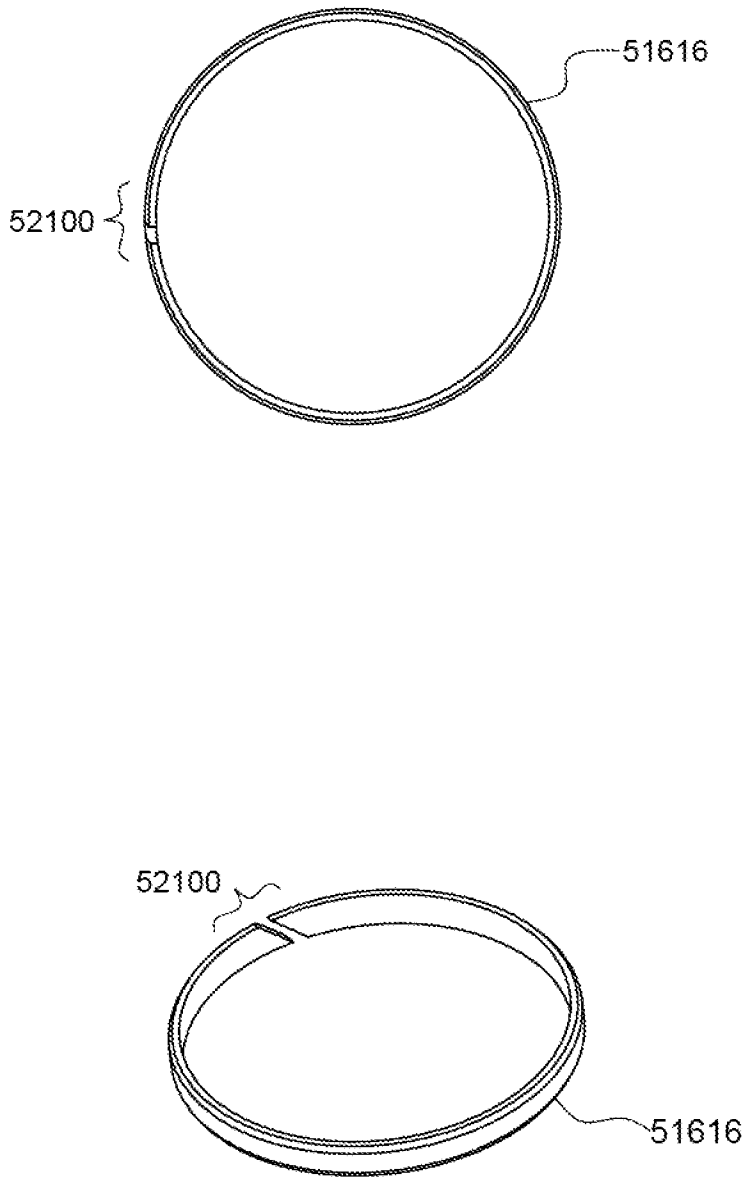



FIG. 65

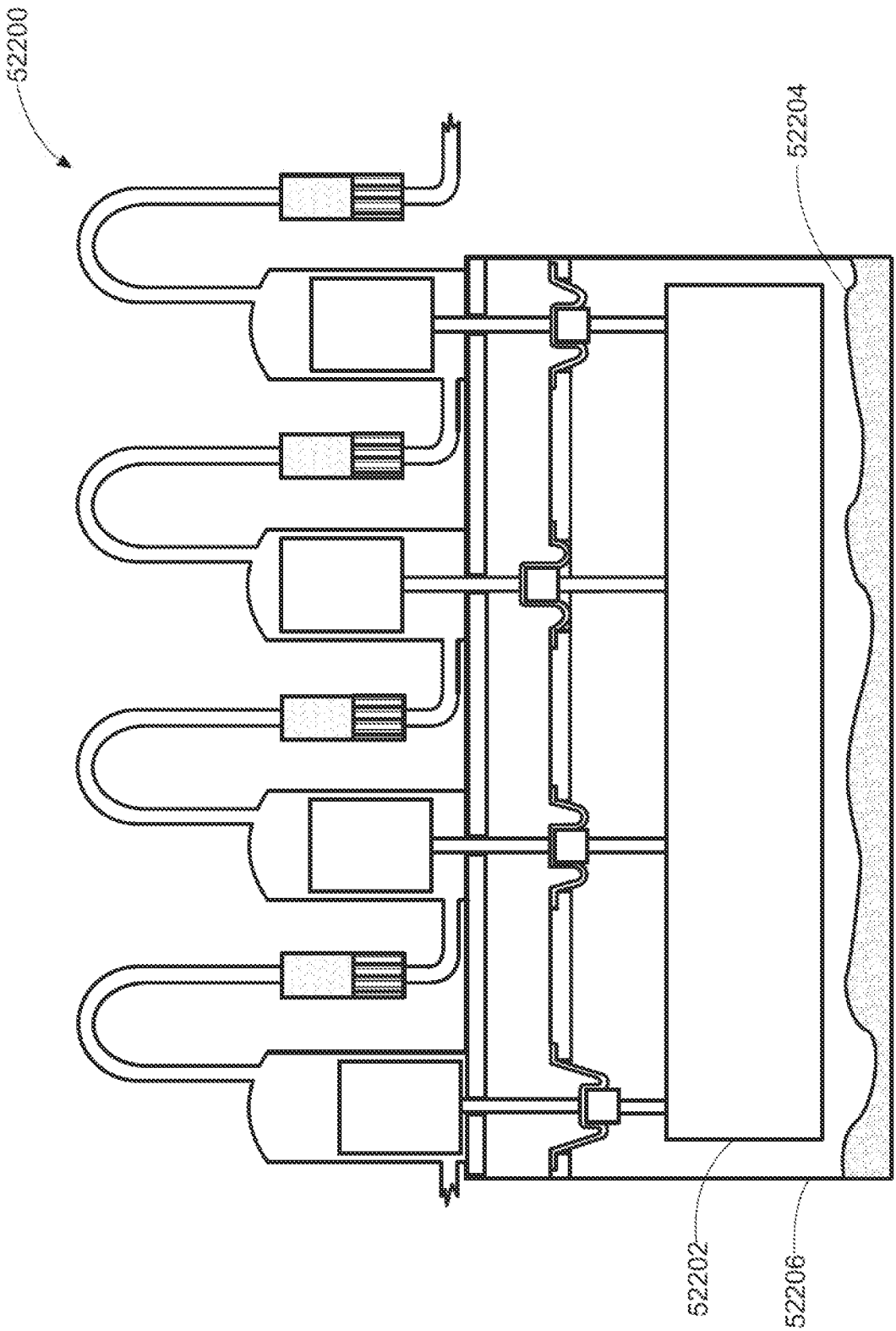



FIG. 66

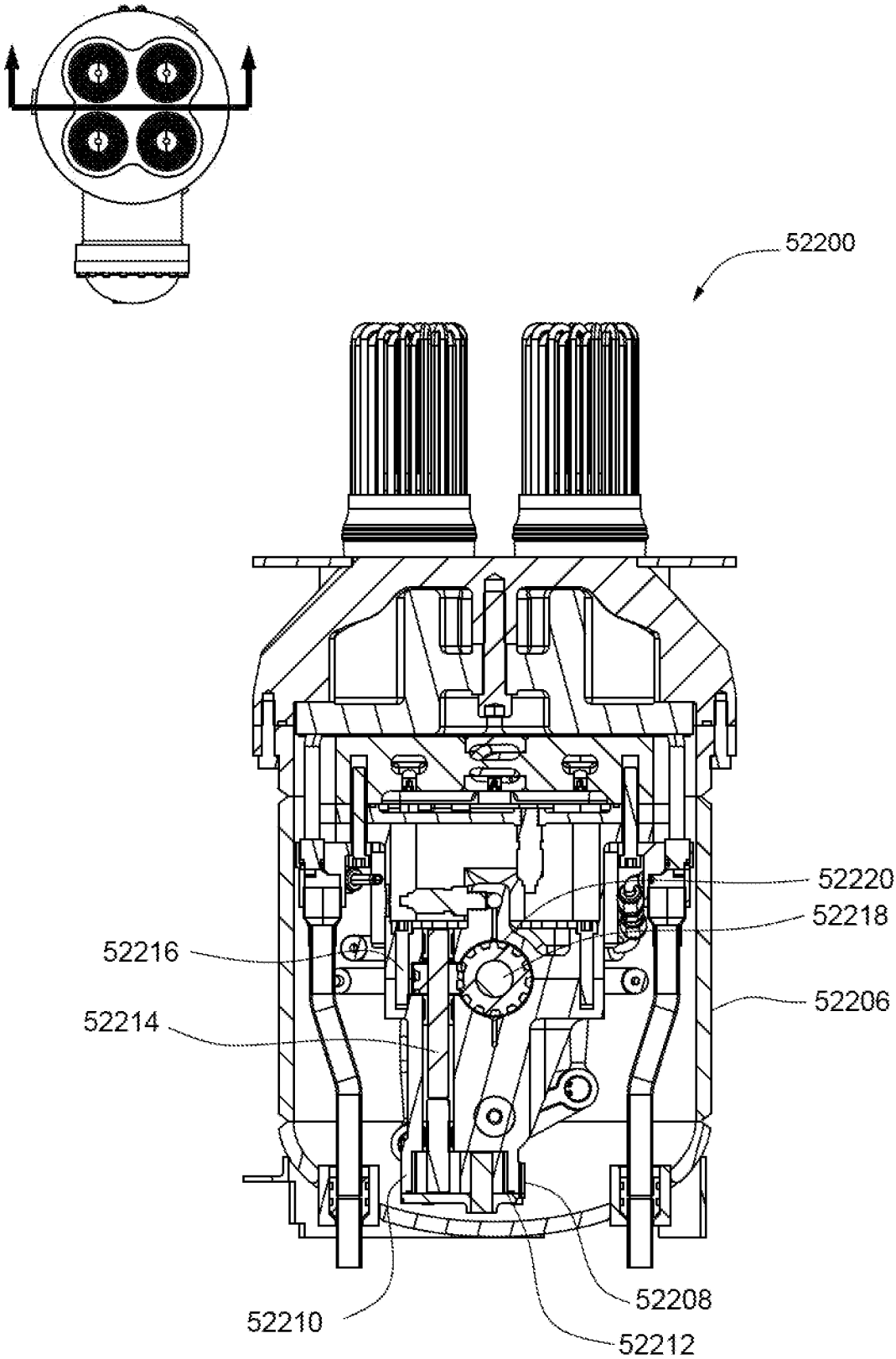



FIG. 67A

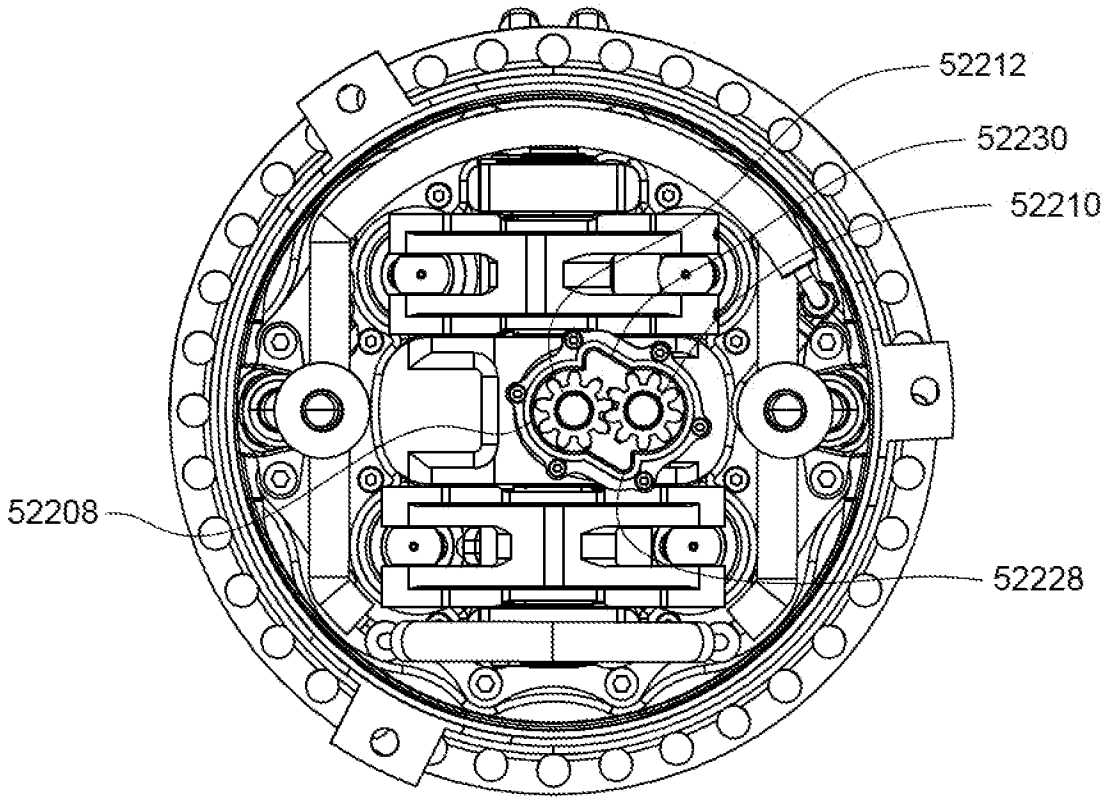



FIG. 67B

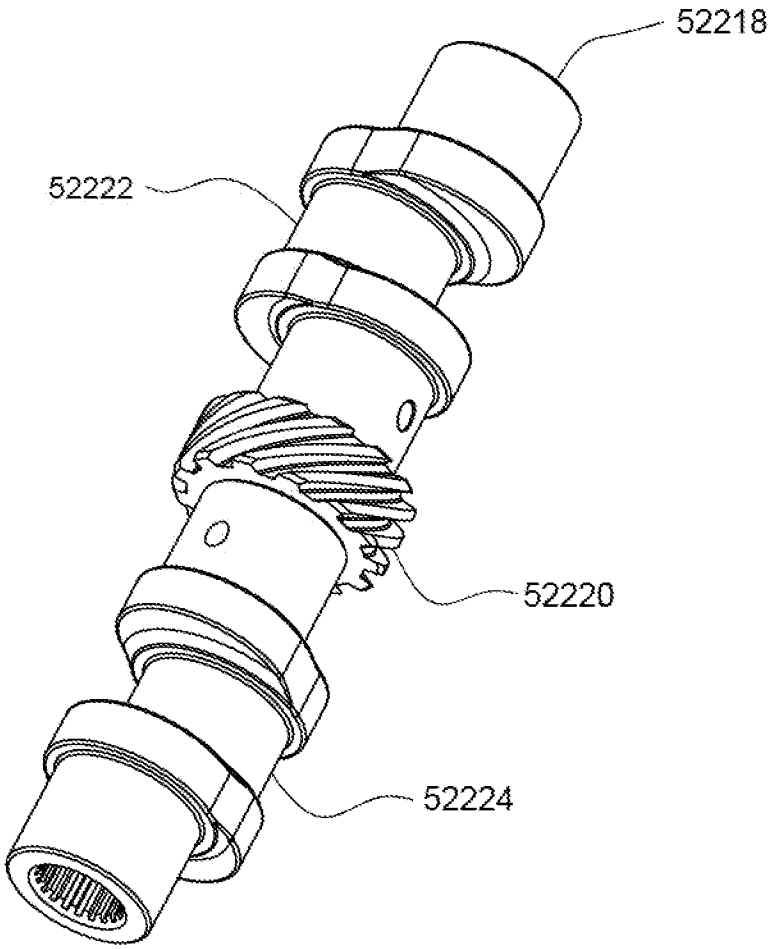



FIG. 68

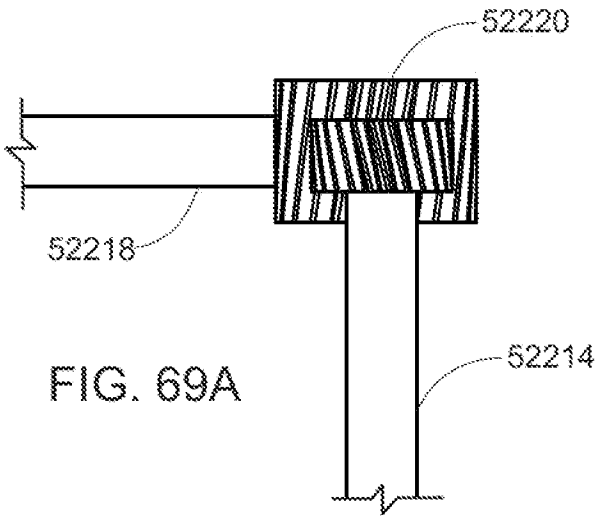



FIG. 69A

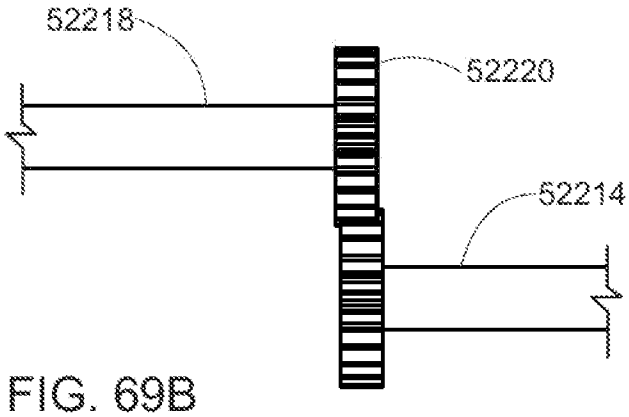



FIG. 69B

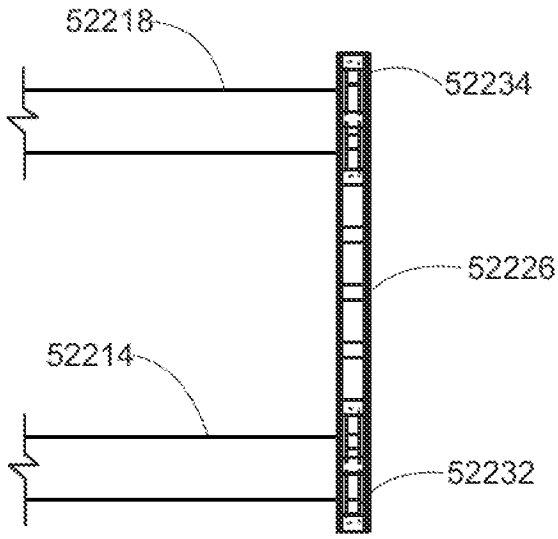



FIG. 69C

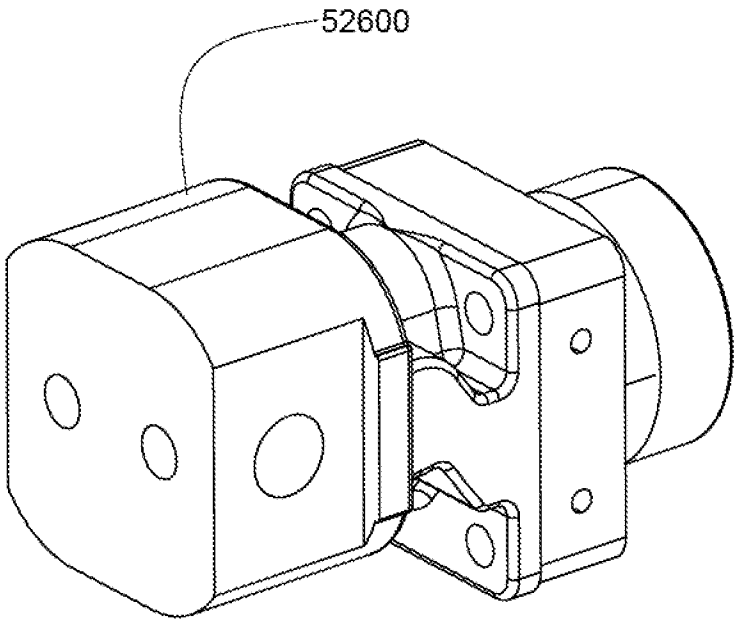



FIG. 70A

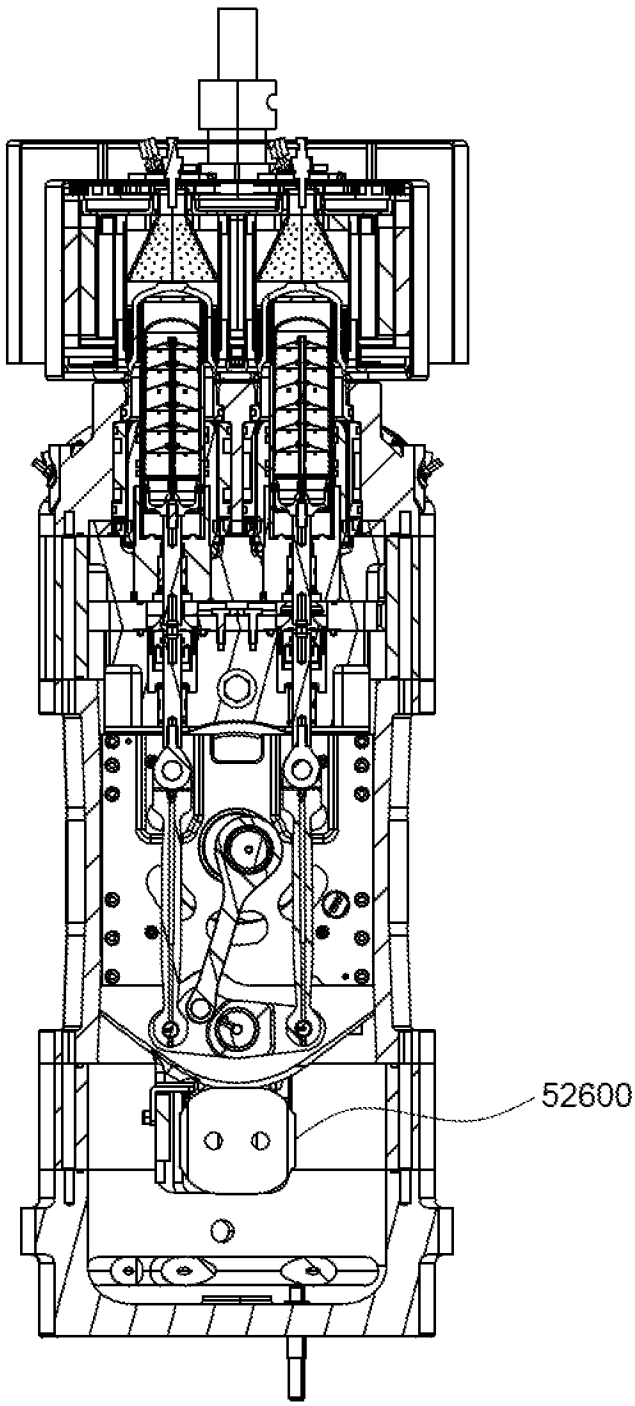



FIG. 70B

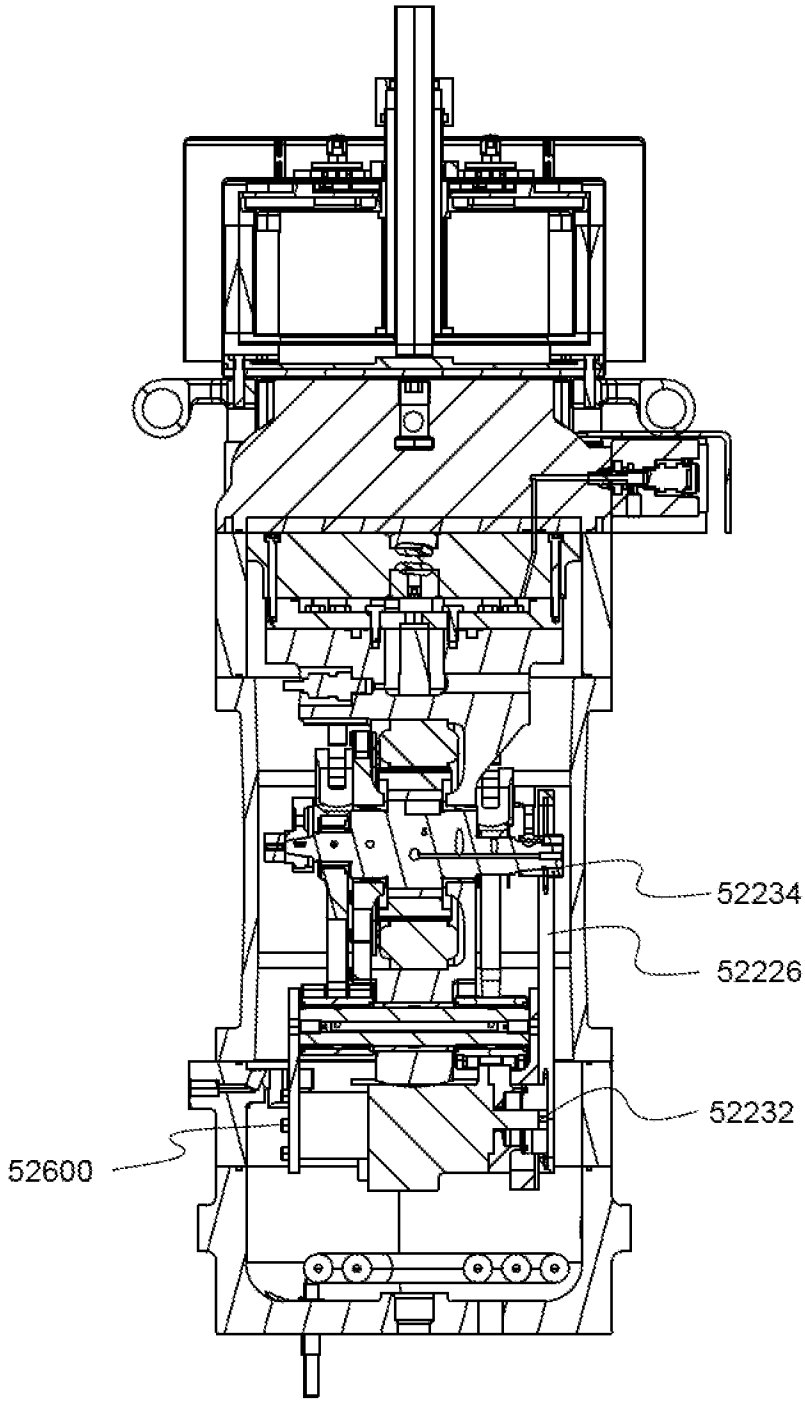



FIG. 70C

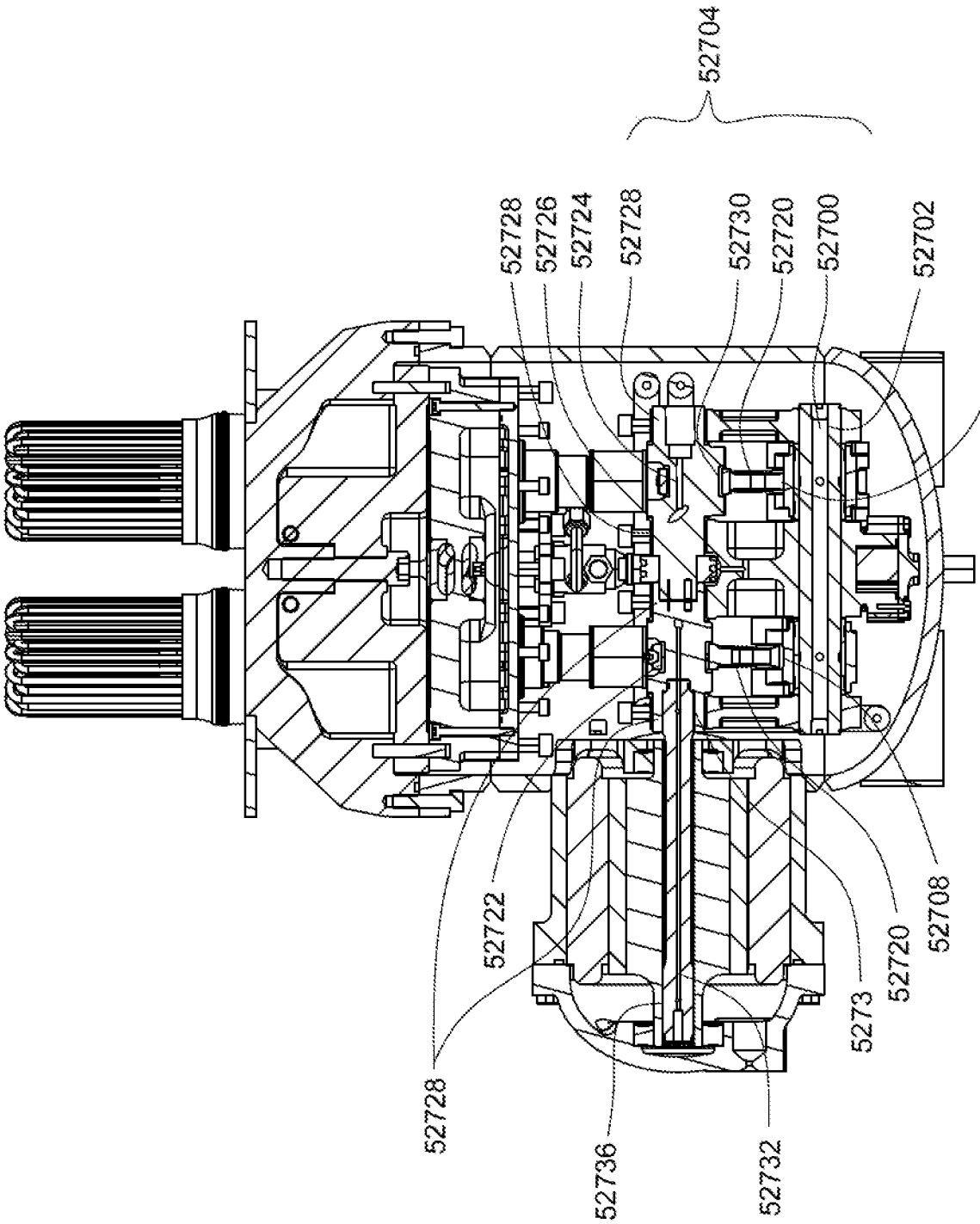

52704
52728
52726
52724
52728
52730
52720
52700
52702
52708
52722
52728
52736
52732
5273
52720
52708

FIG. 71A

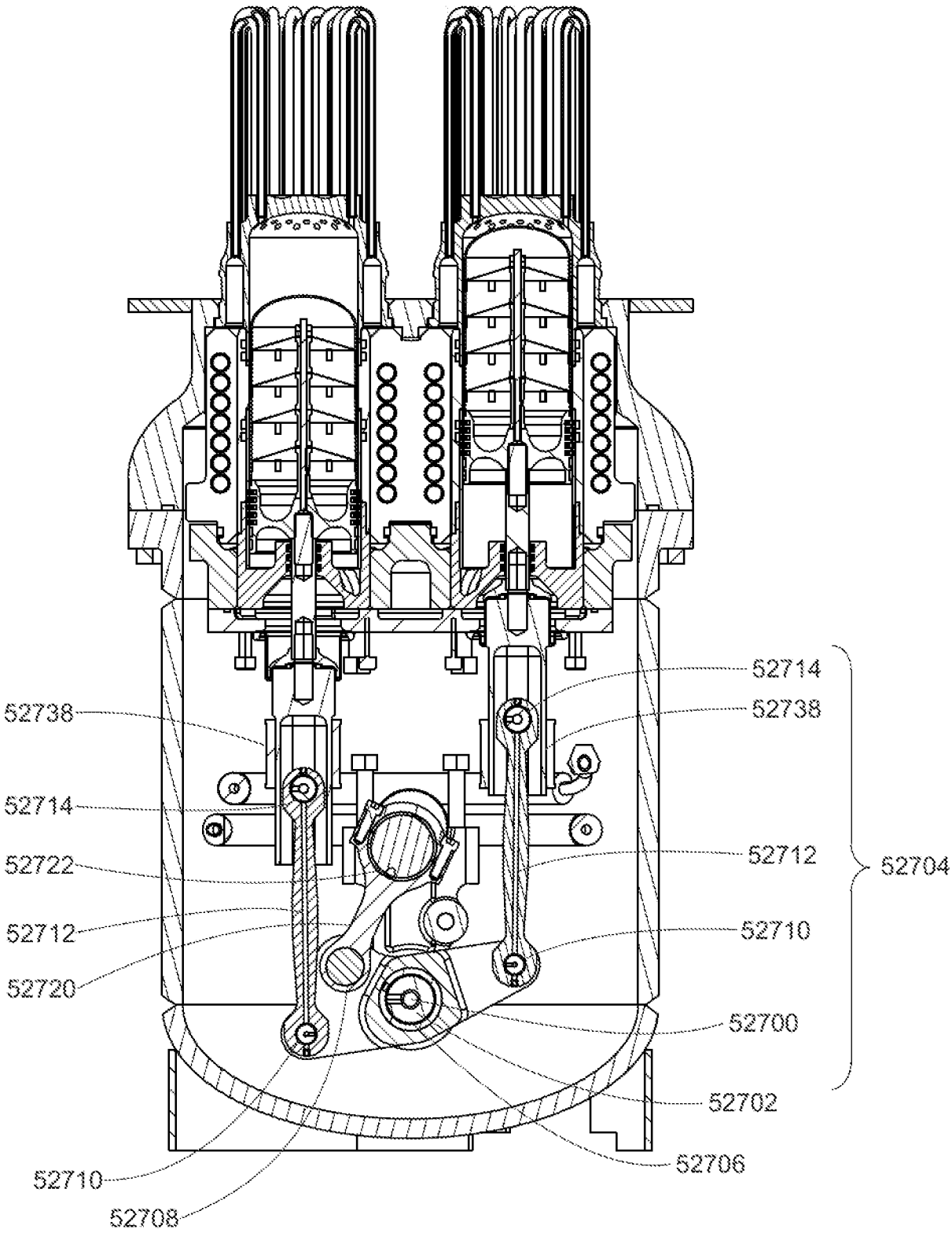

52714
52738
52738
52714
52722
52712
52704
52712
52710
52720
52700
52702
52706
52710
52708

FIG. 71B

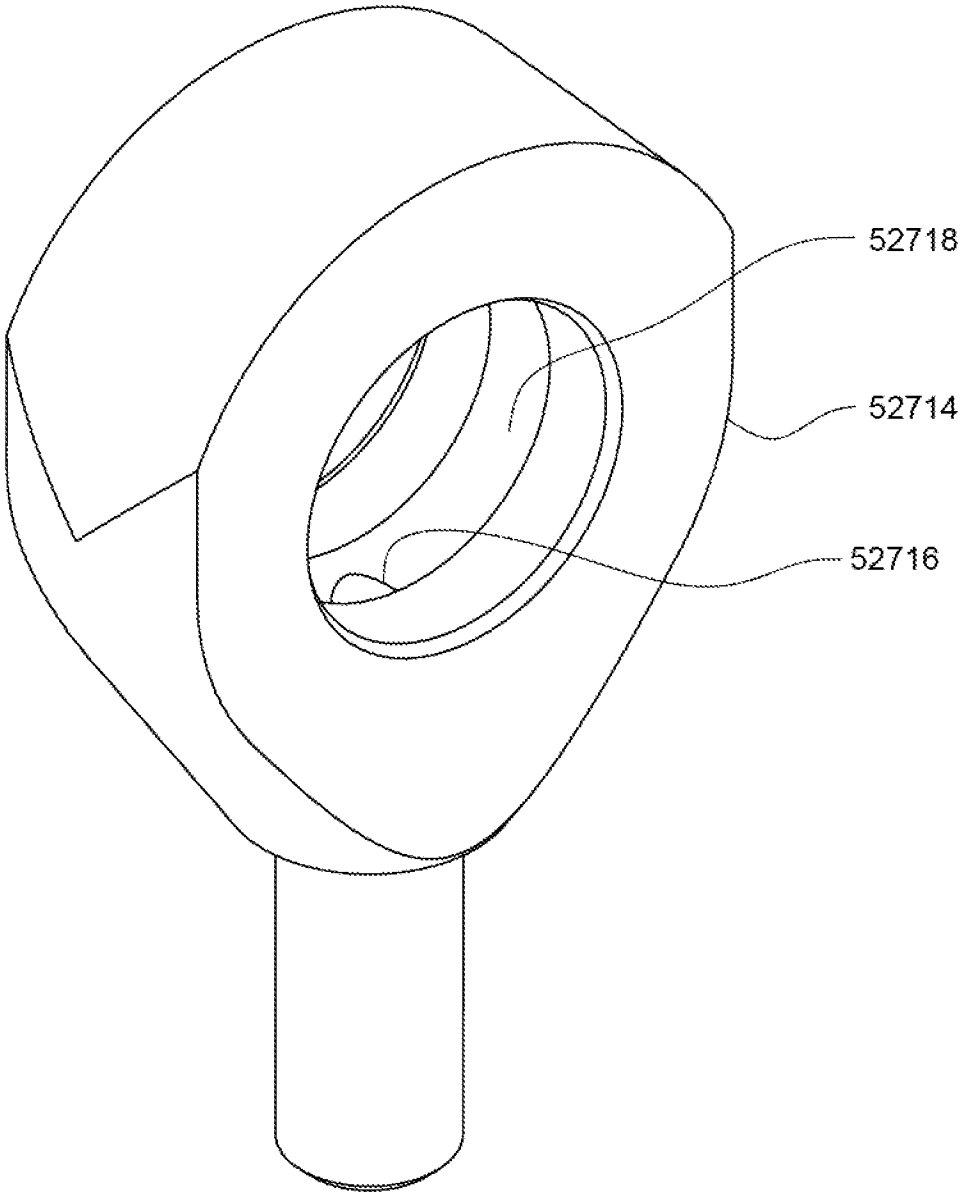



FIG. 71C

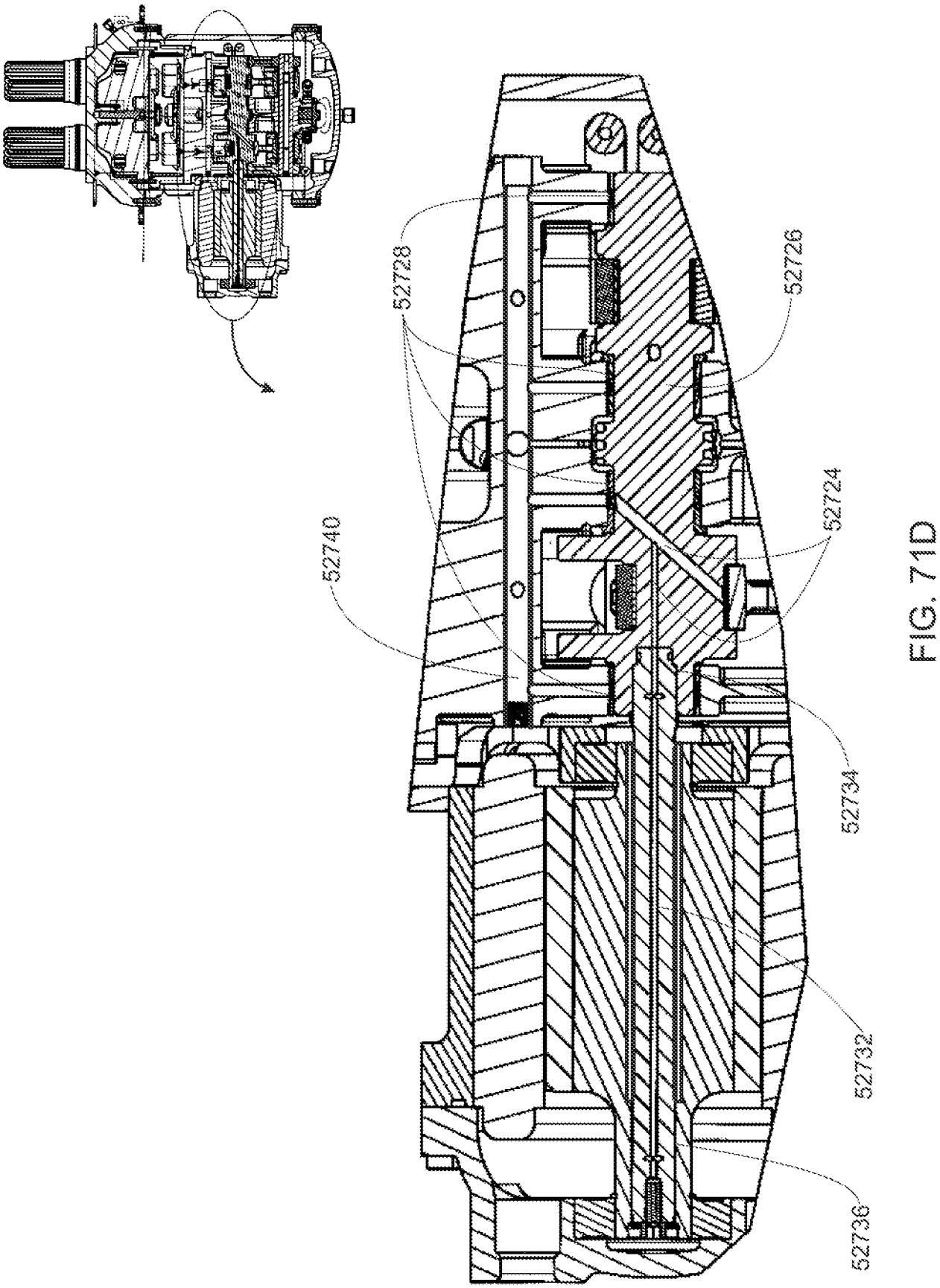



FIG. 71D

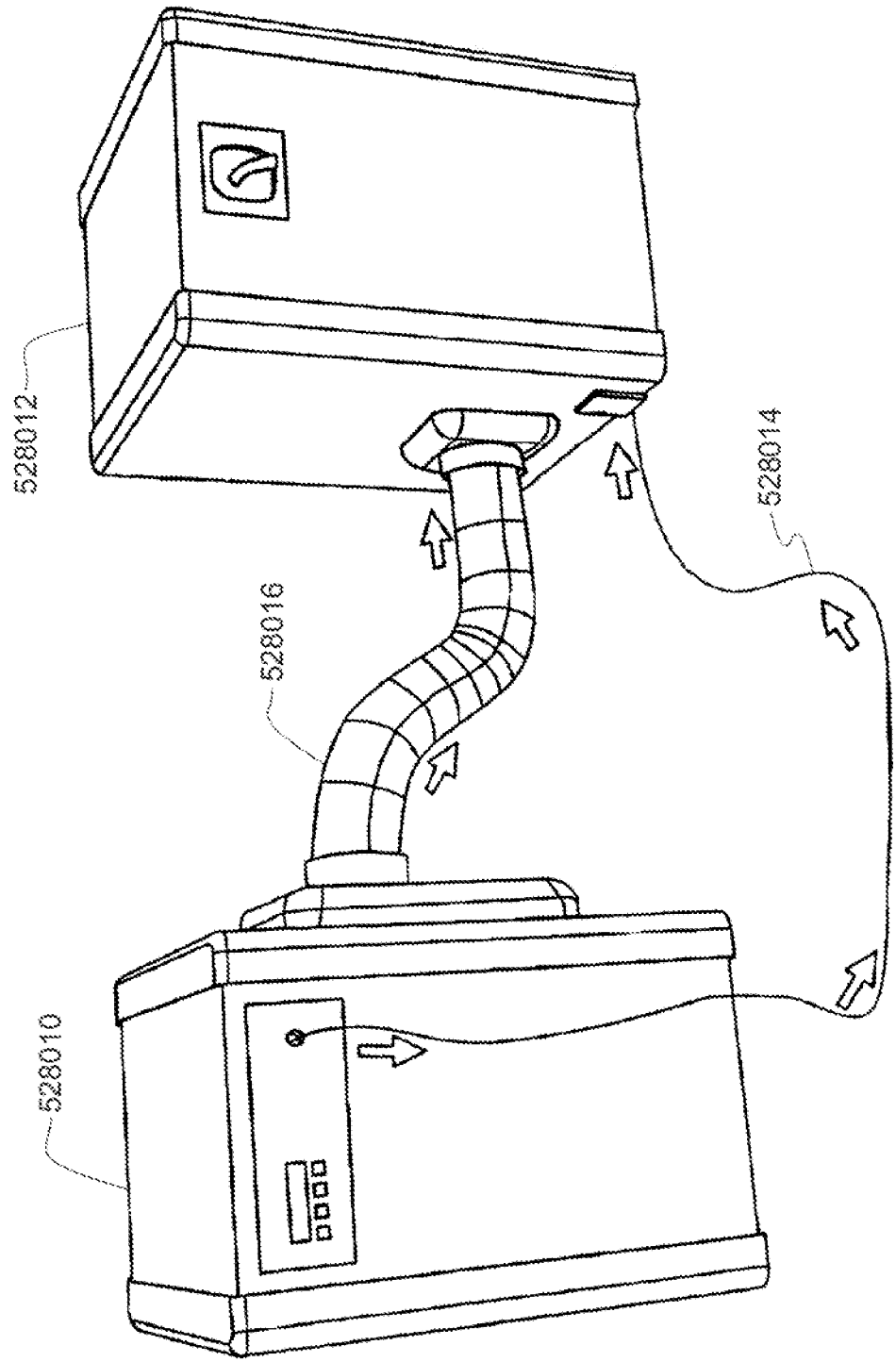



FIG. 72A

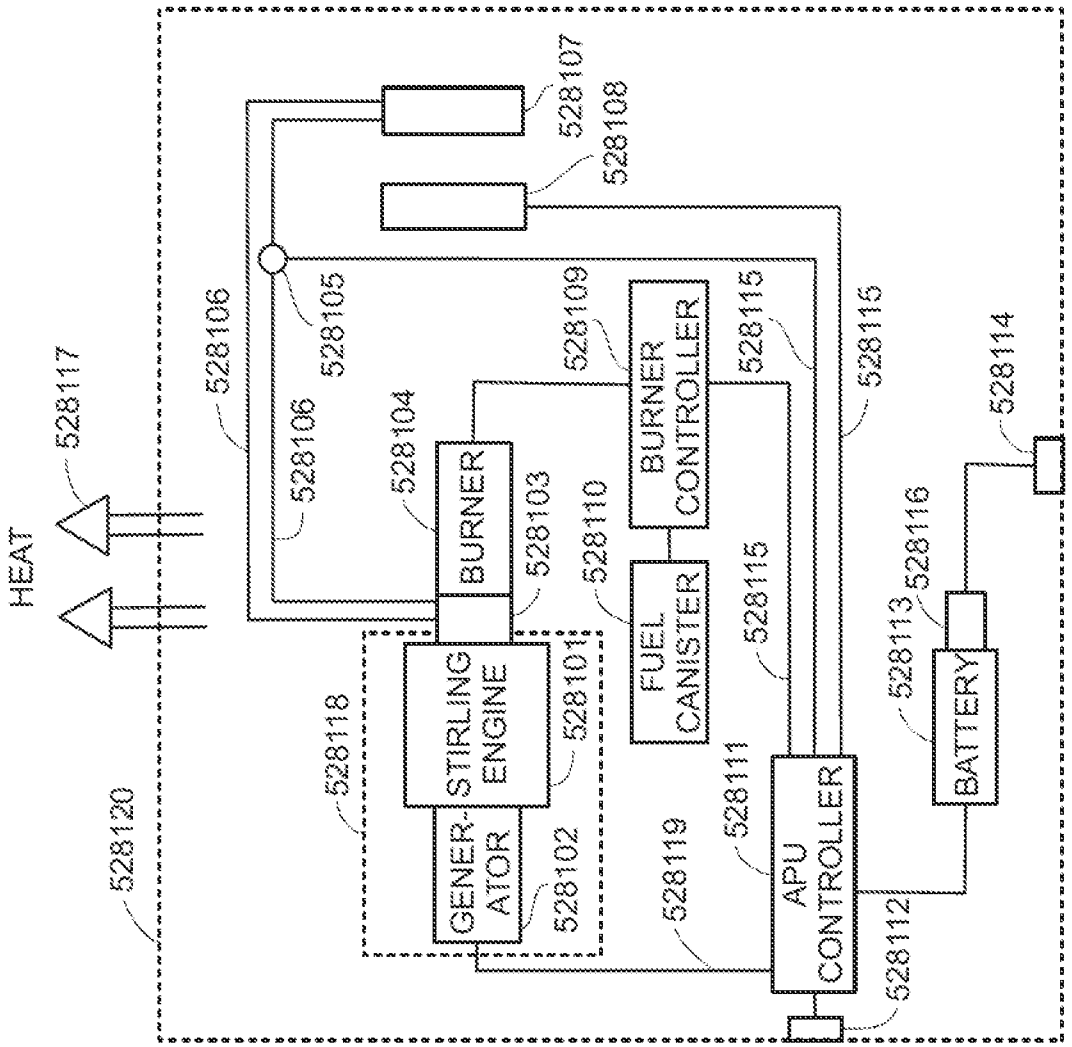

HEAT
528117
528120
528106
528106
528105
528107
528108
528104
BURNER
528103
528110
528109
BURNER CONTROLLER
528115
528115
528114
528116
528113
BATTERY
528118
STIRLING ENGINE
528101
FUEL CANISTER
528115
GENER-ATOR
528102
528119
528111
APU CONTROLLER
528112
2100

FIG. 72B

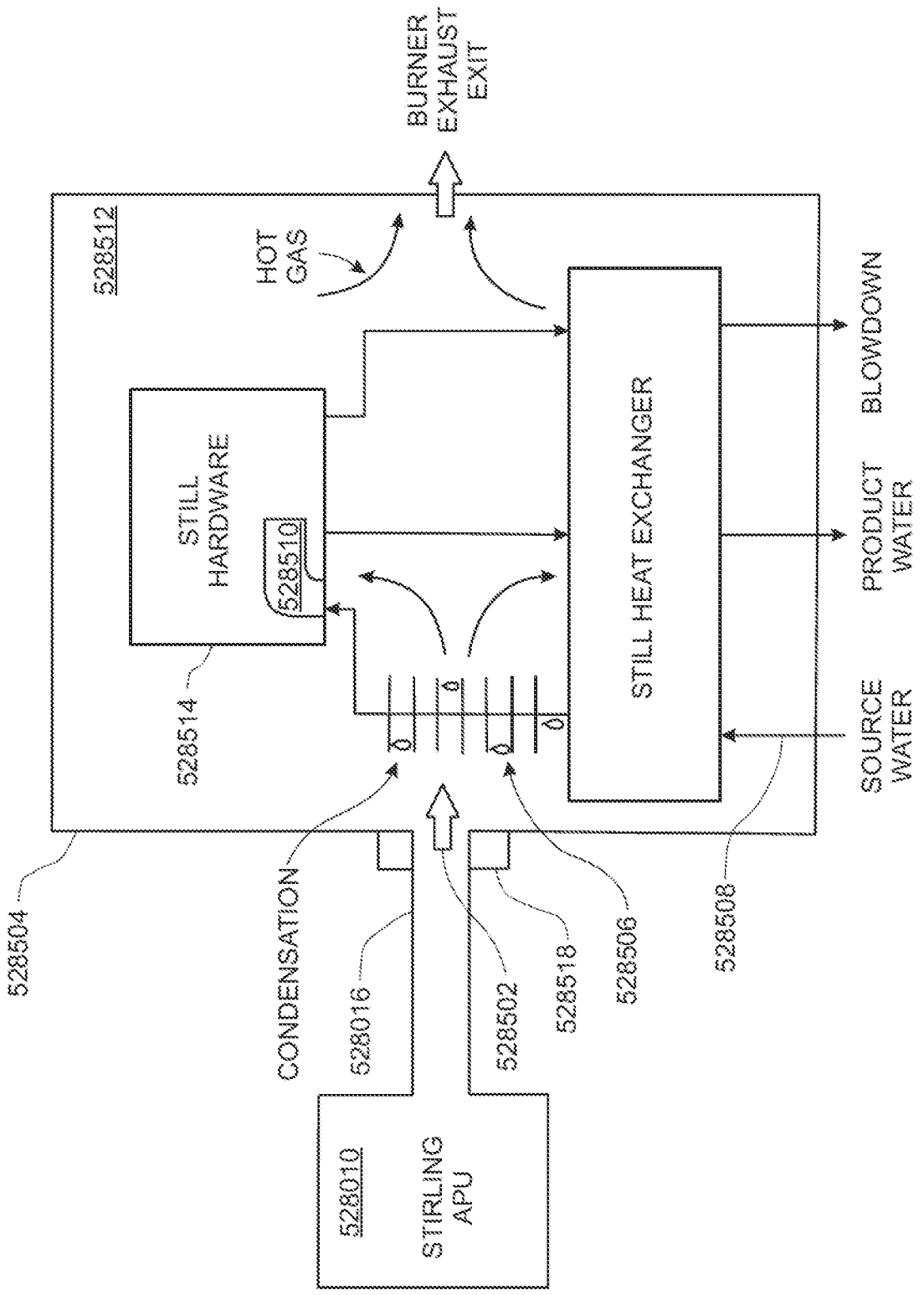

528012
BURNER EXHAUST EXIT
528512
HOT GAS
STILL HARDWARE
528510
528514
STILL HEAT EXCHANGER
BLOWDOWN
PRODUCT WATER
SOURCE WATER
528504
CONDENSATION
528016
528502
528518
528506
528508
528010
STIRLING APU

FIG. 72C

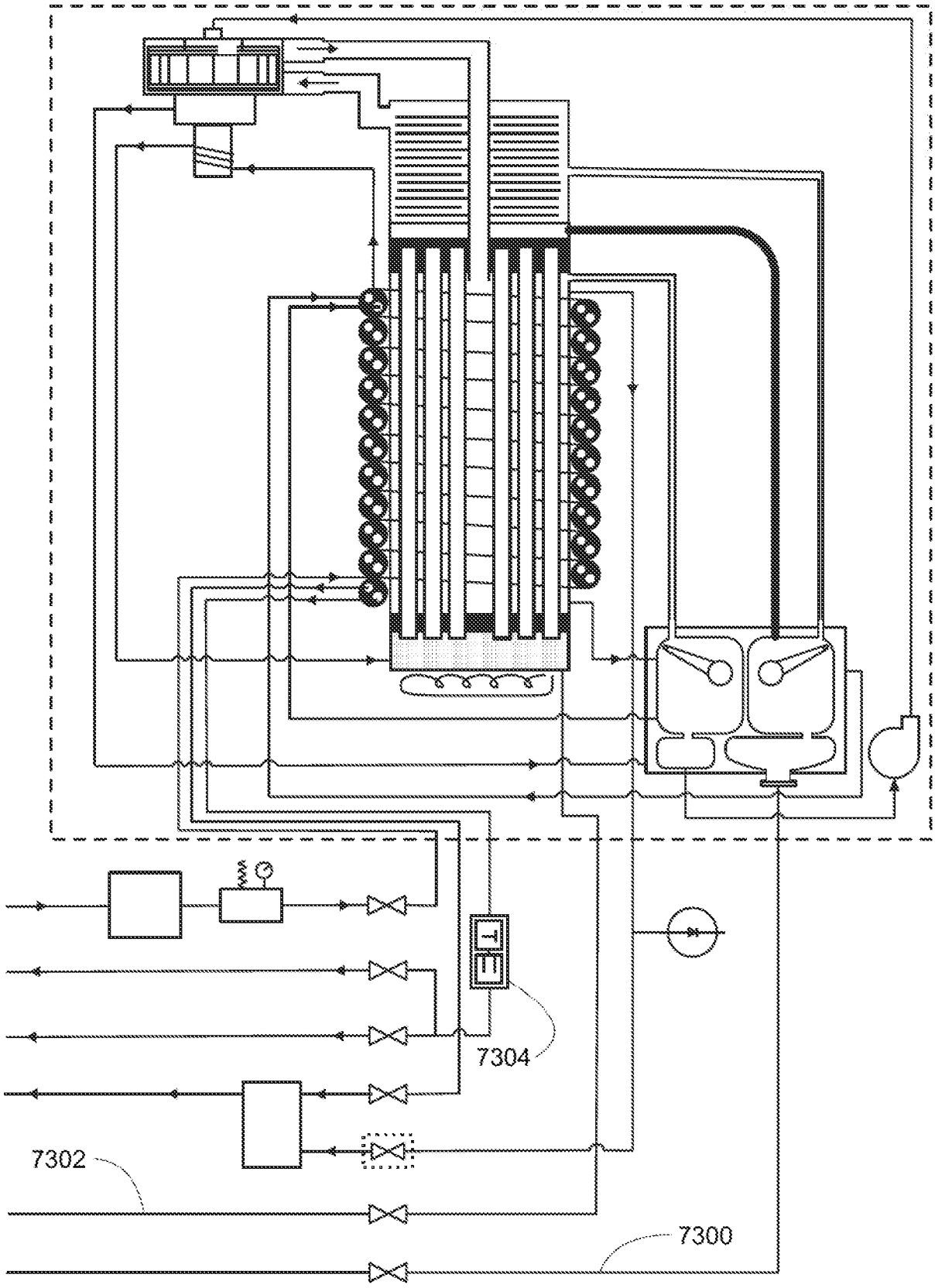



FIG. 73

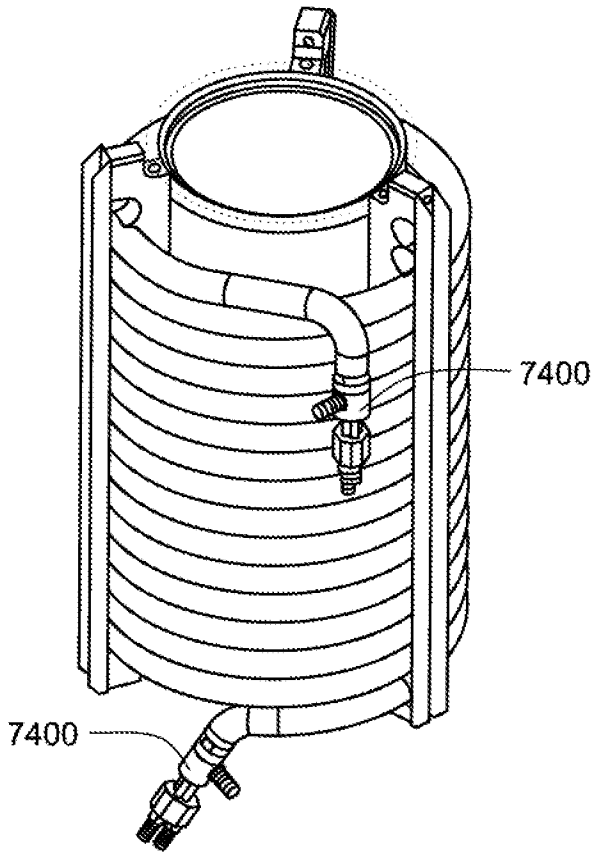



FIG. 74

7400

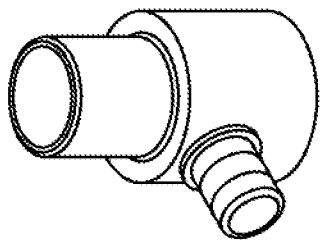


FIG. 74A

246/248

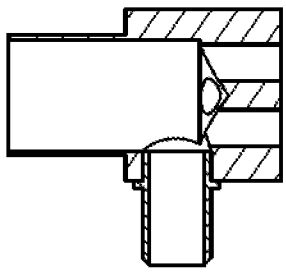


FIG. 74B

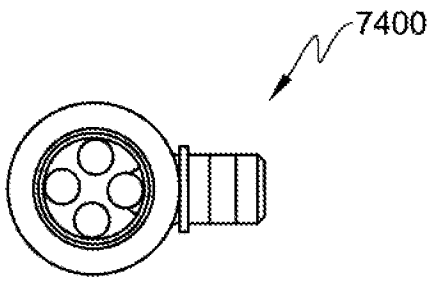



FIG. 74C

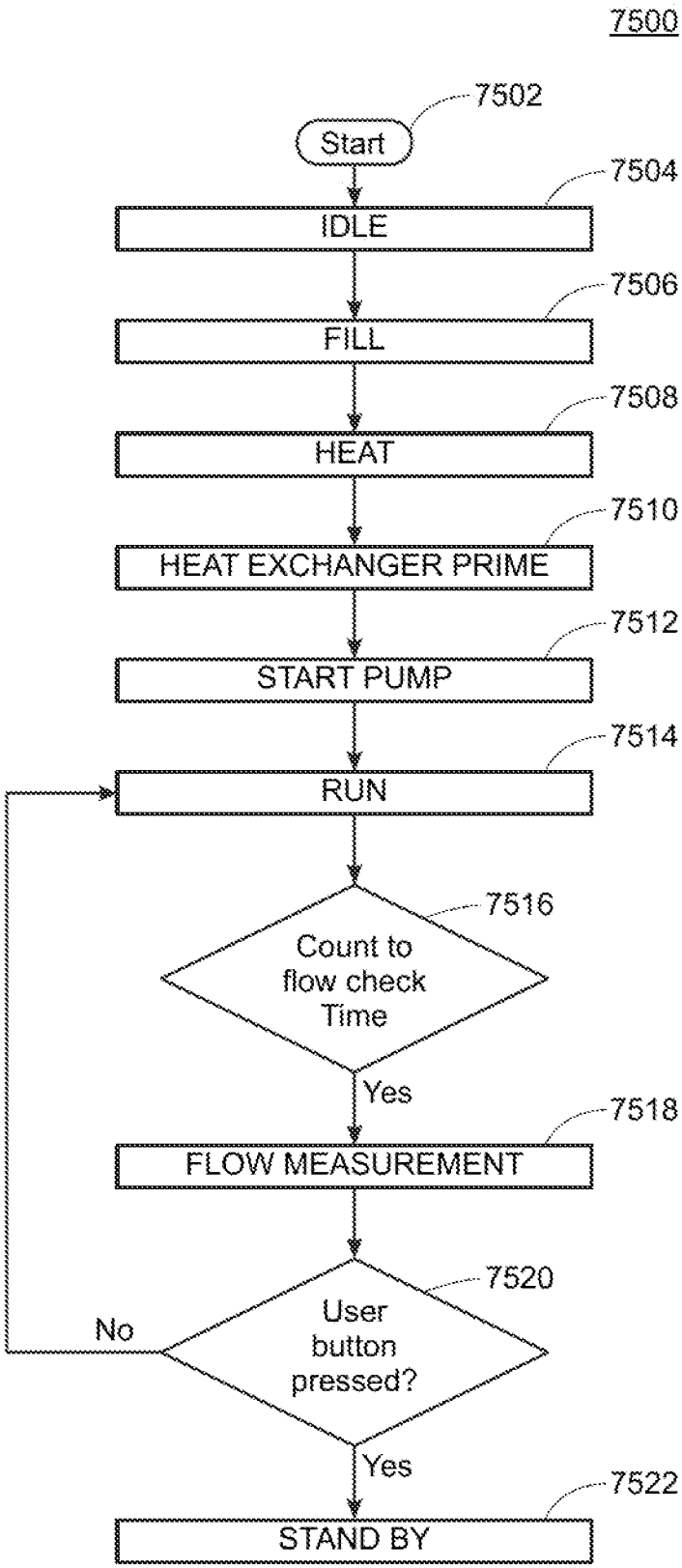

7500
7502
Start
7504
IDLE
7506
FILL
7508
HEAT
7510
HEAT EXCHANGER PRIME
7512
START PUMP
7514
RUN
7516
Count to flow check Time
Yes
7518
FLOW MEASUREMENT
7520
User button pressed?
No
Yes
7522
STAND BY

FIG. 75

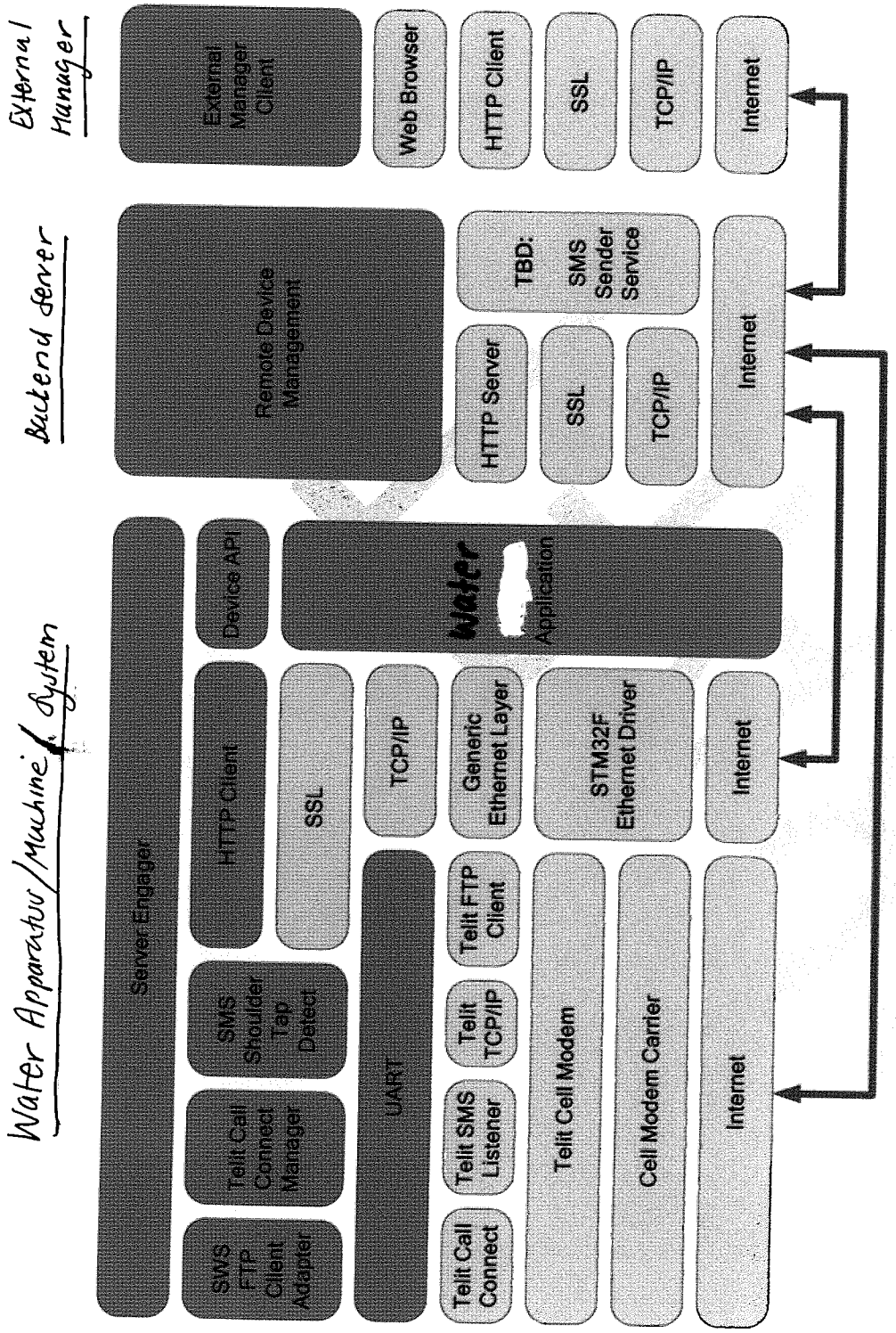

Water Apparatus/Machine System
Backend Server
External Manager
Server Engager
SMS FTP Client Adapter
Telit Call Connect Manager
SMS Shoulder Tap Detect
HTTP Client
Device API
SSL
Water Application
Telit Call Connect
Telit SMS Listener
Telit TCP/IP
Telit FTP Client
TCP/IP
Generic Ethernet Layer
UART
Telit Cell Modem
Cell Modem Carrier
STM32F Ethernet Driver
Internet
Internet
Remote Device Management
HTTP Server
SSL
TCP/IP
Internet
TBD: SMS Sender Service
External Manager Client
Web Browser
HTTP Client
SSL
TCP/IP
Internet

FIG. 76

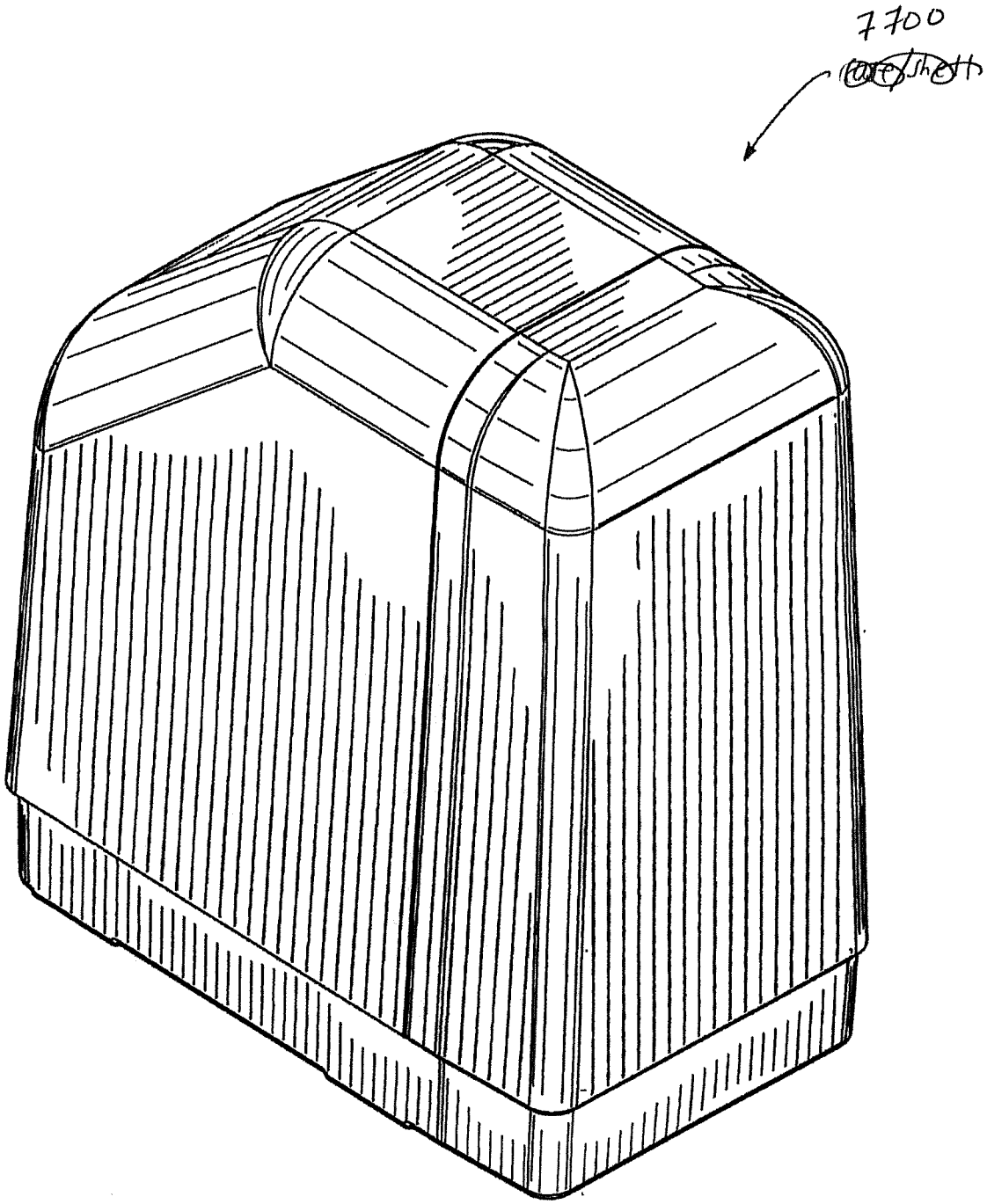



FIG. 77

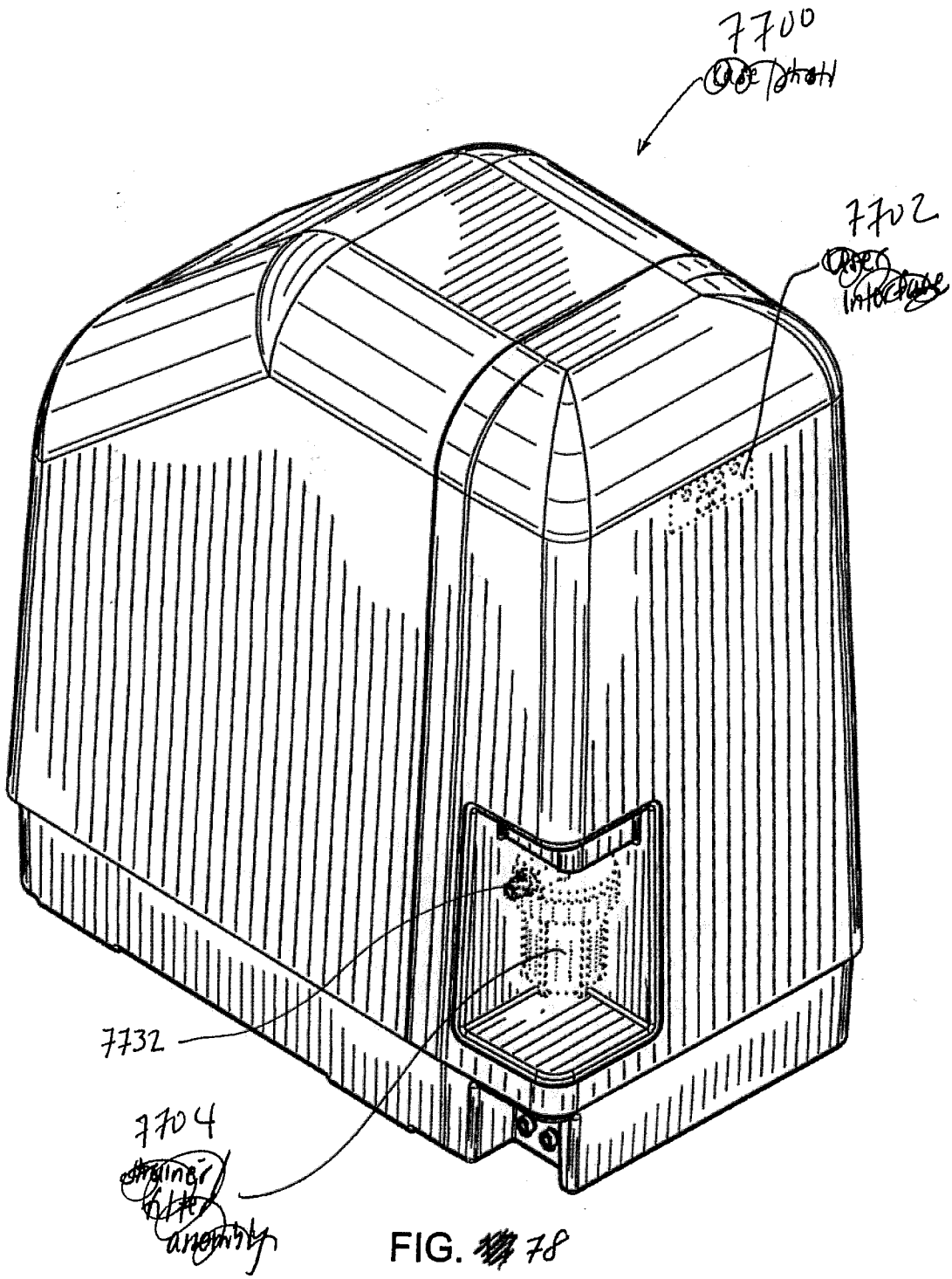



FIG. 78

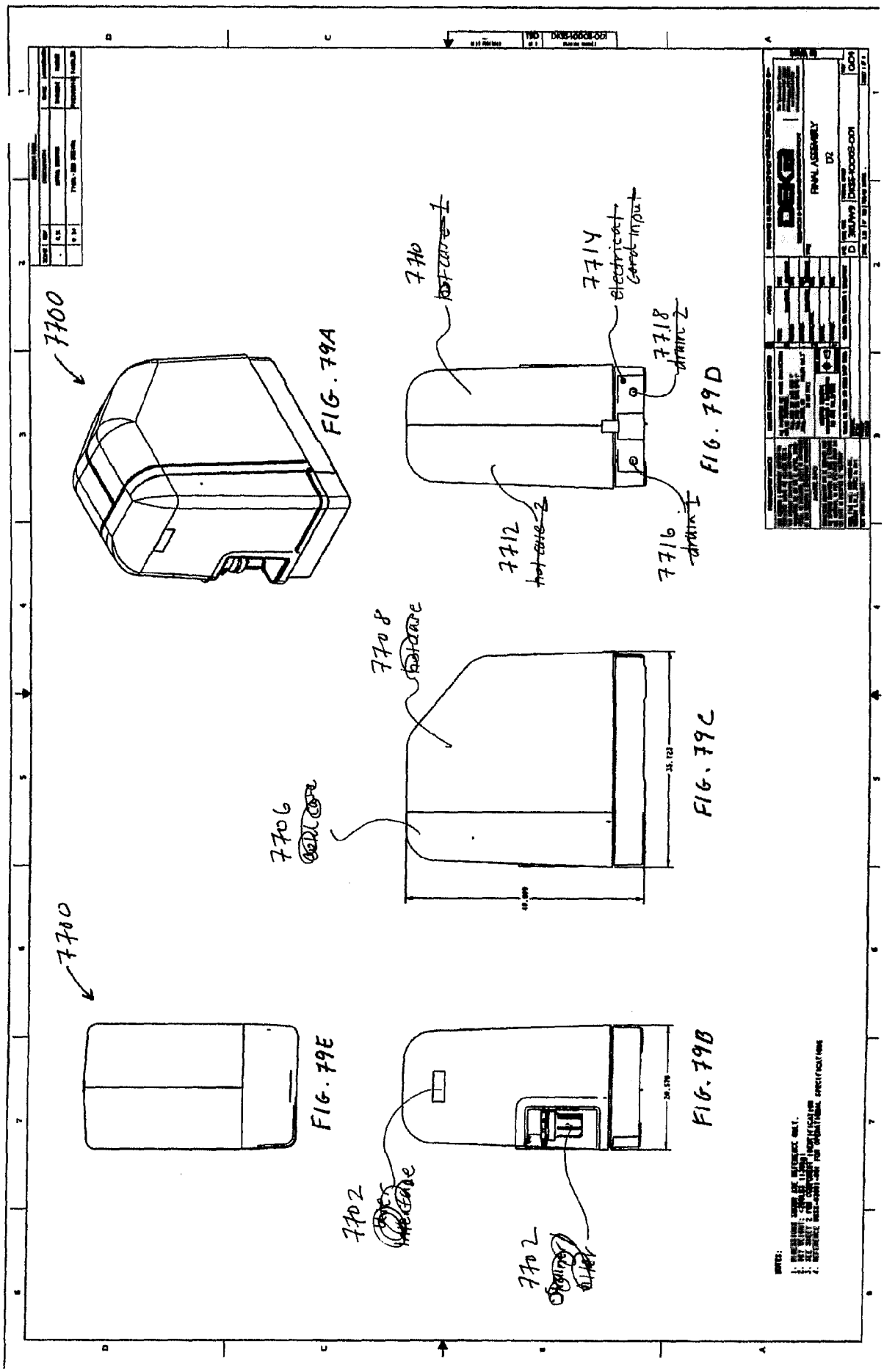



FIG. 79A
FIG. 79D
FIG. 79C
FIG. 79E
FIG. 79B

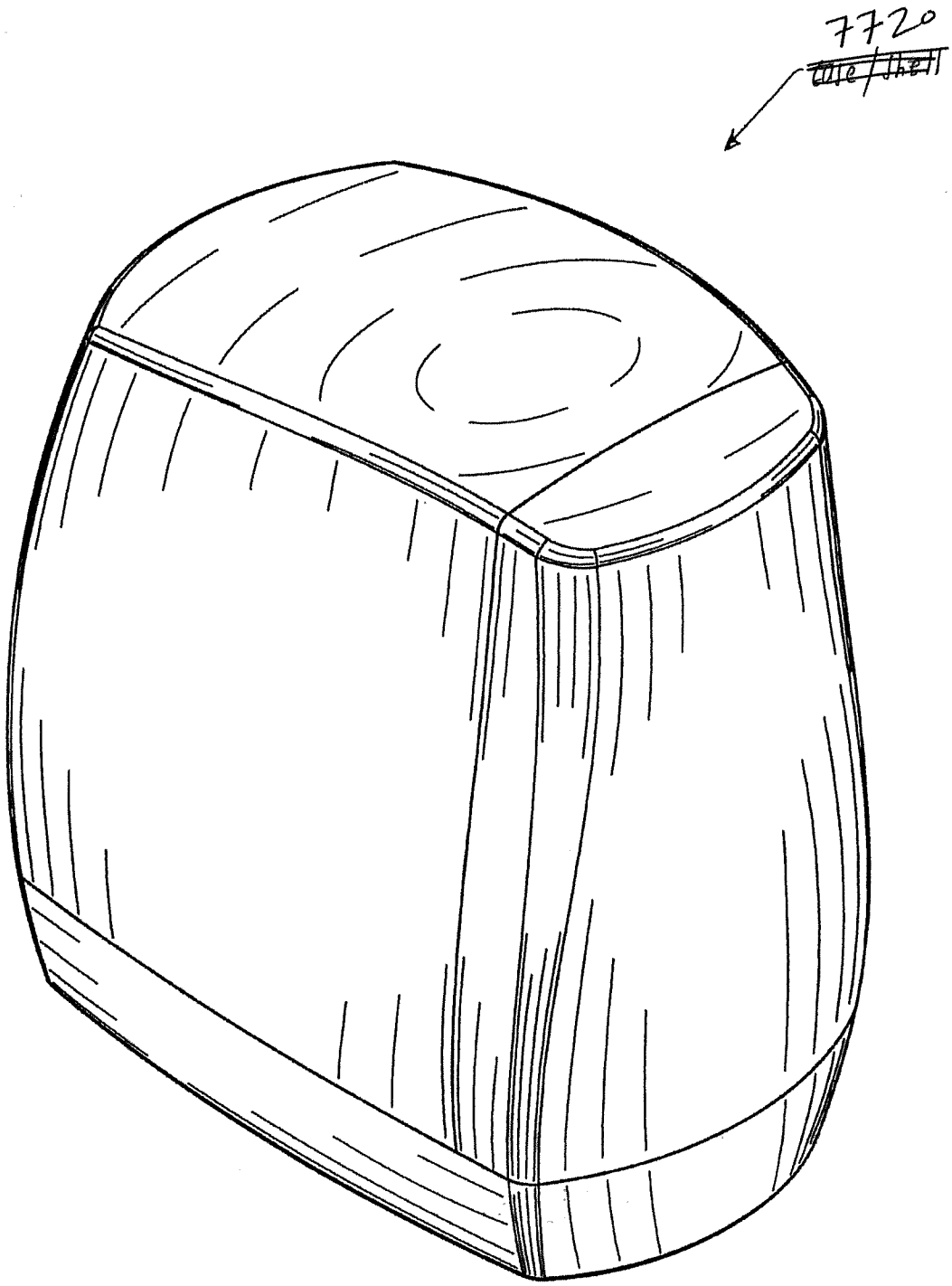



FIG. 7780

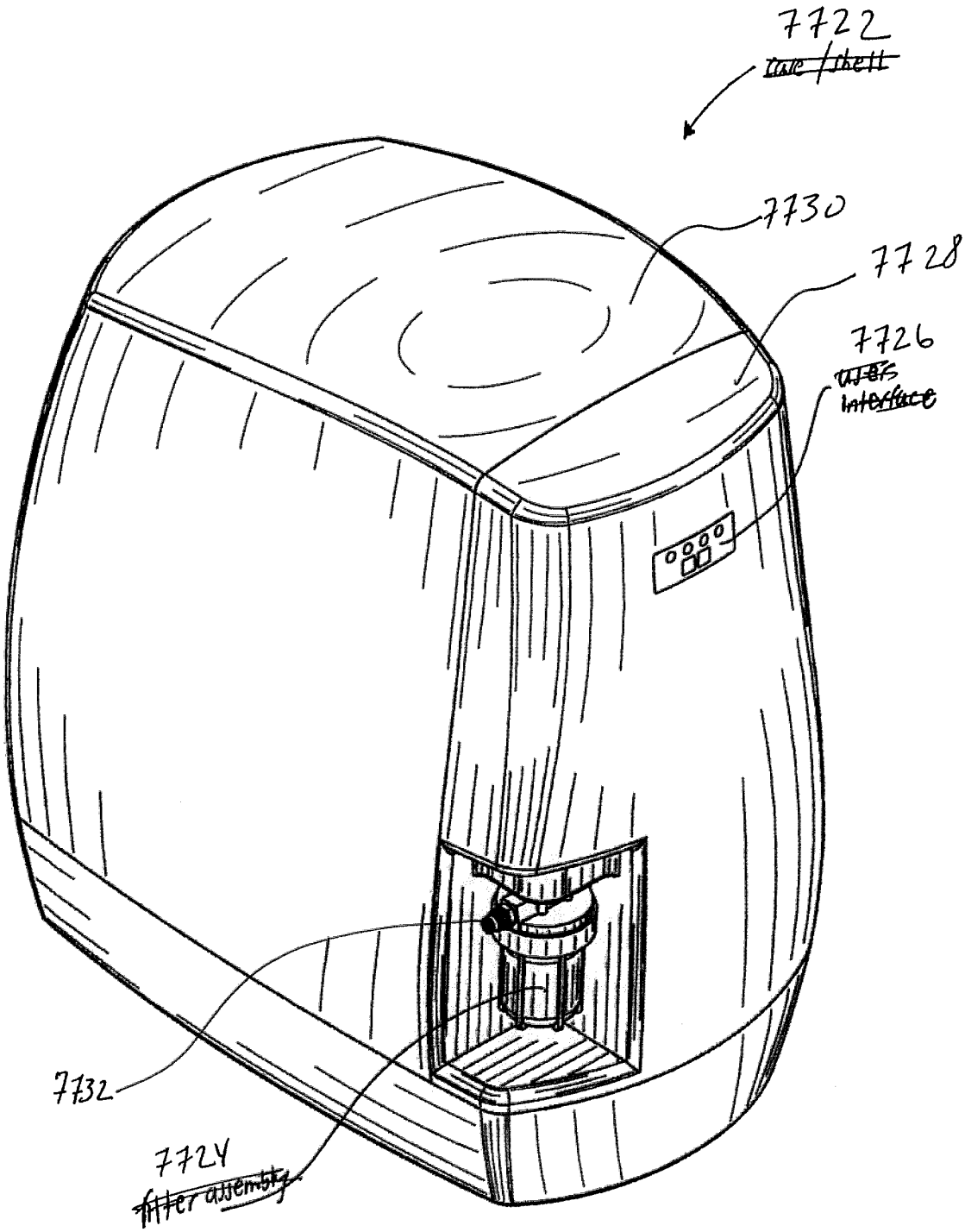

7722
~~case / shell~~
7730
7728
7726
~~UI~~ interface
7732
7724
~~filter assembly~~

FIG. 81

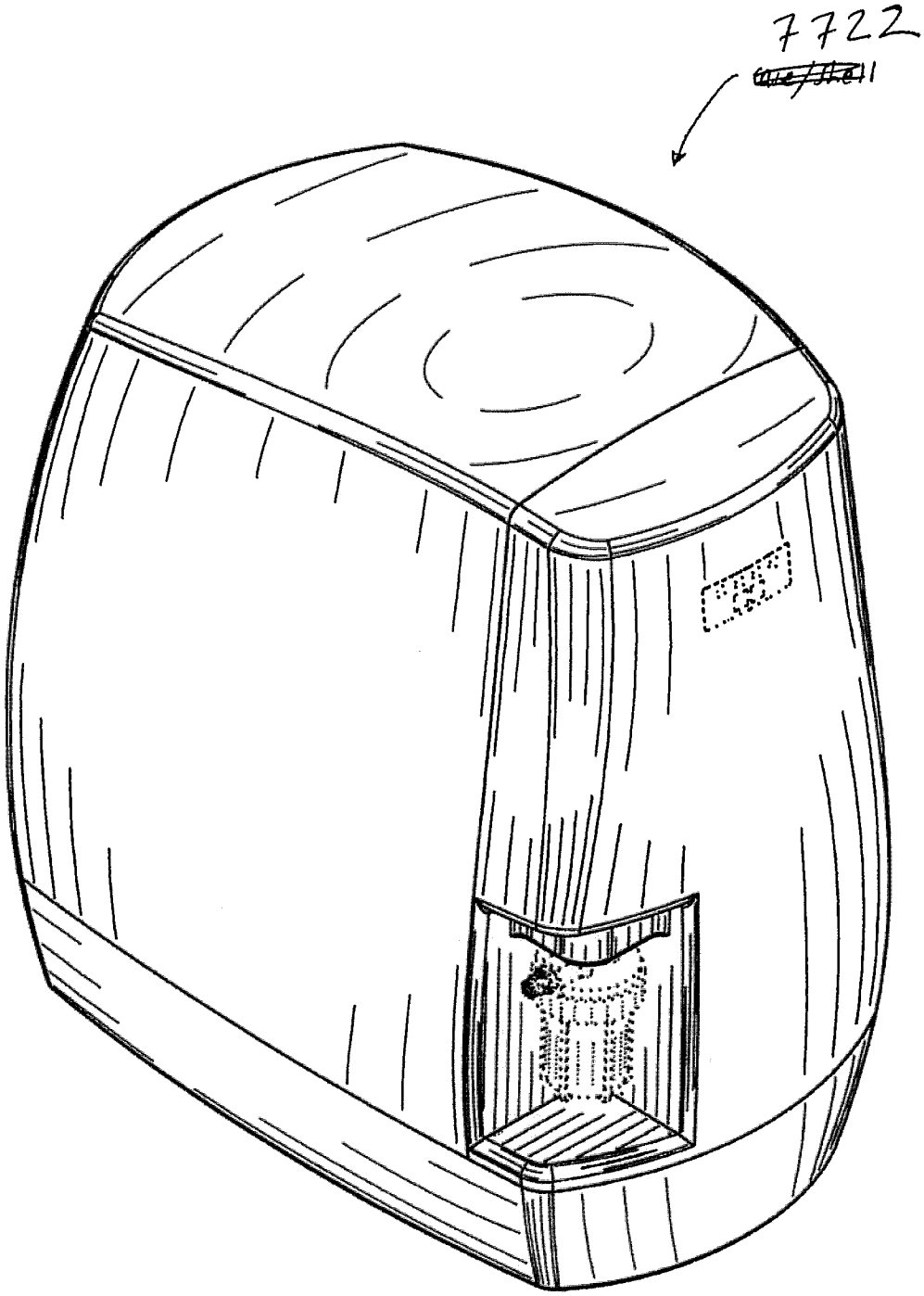



FIG. 82

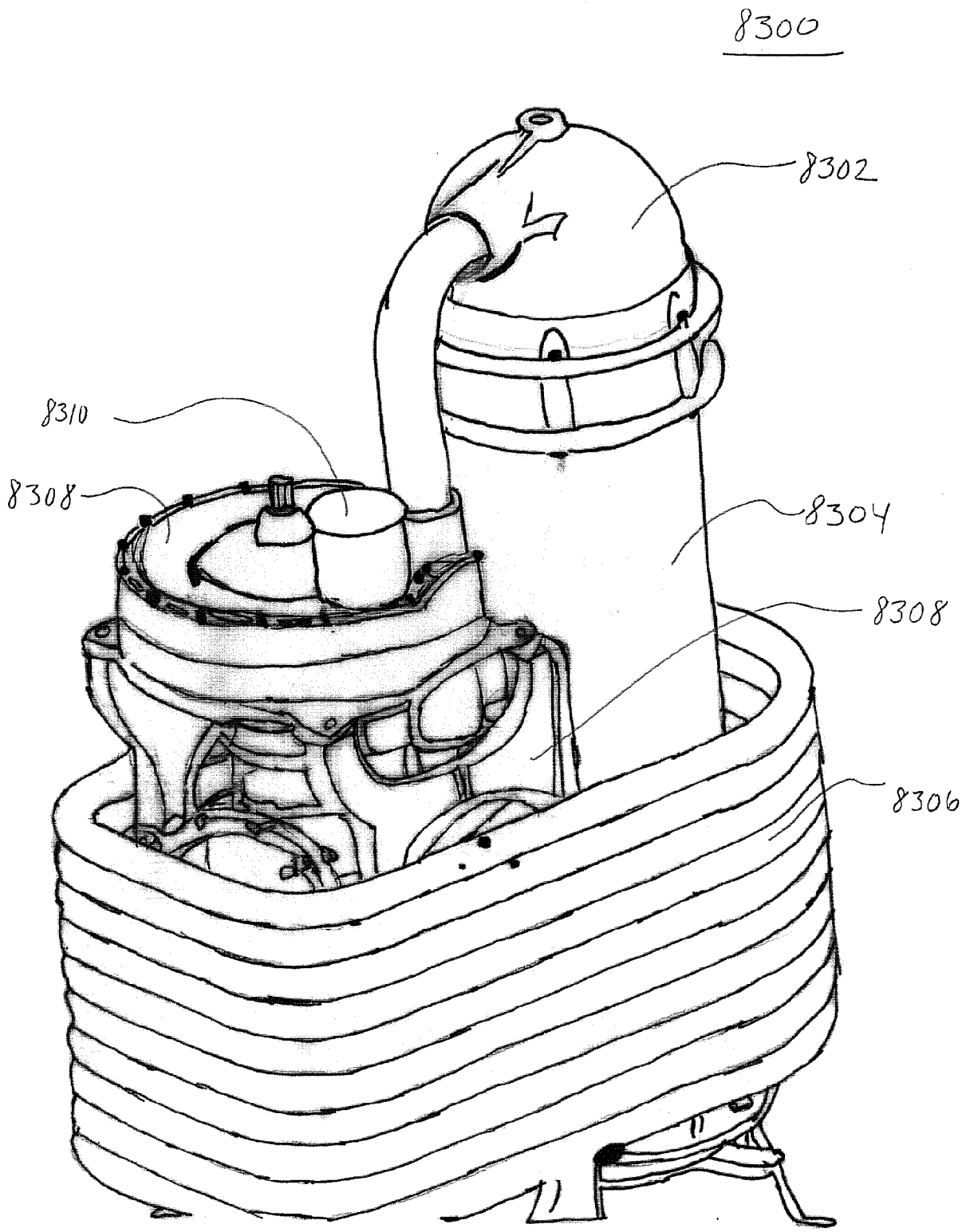



FIG. 83

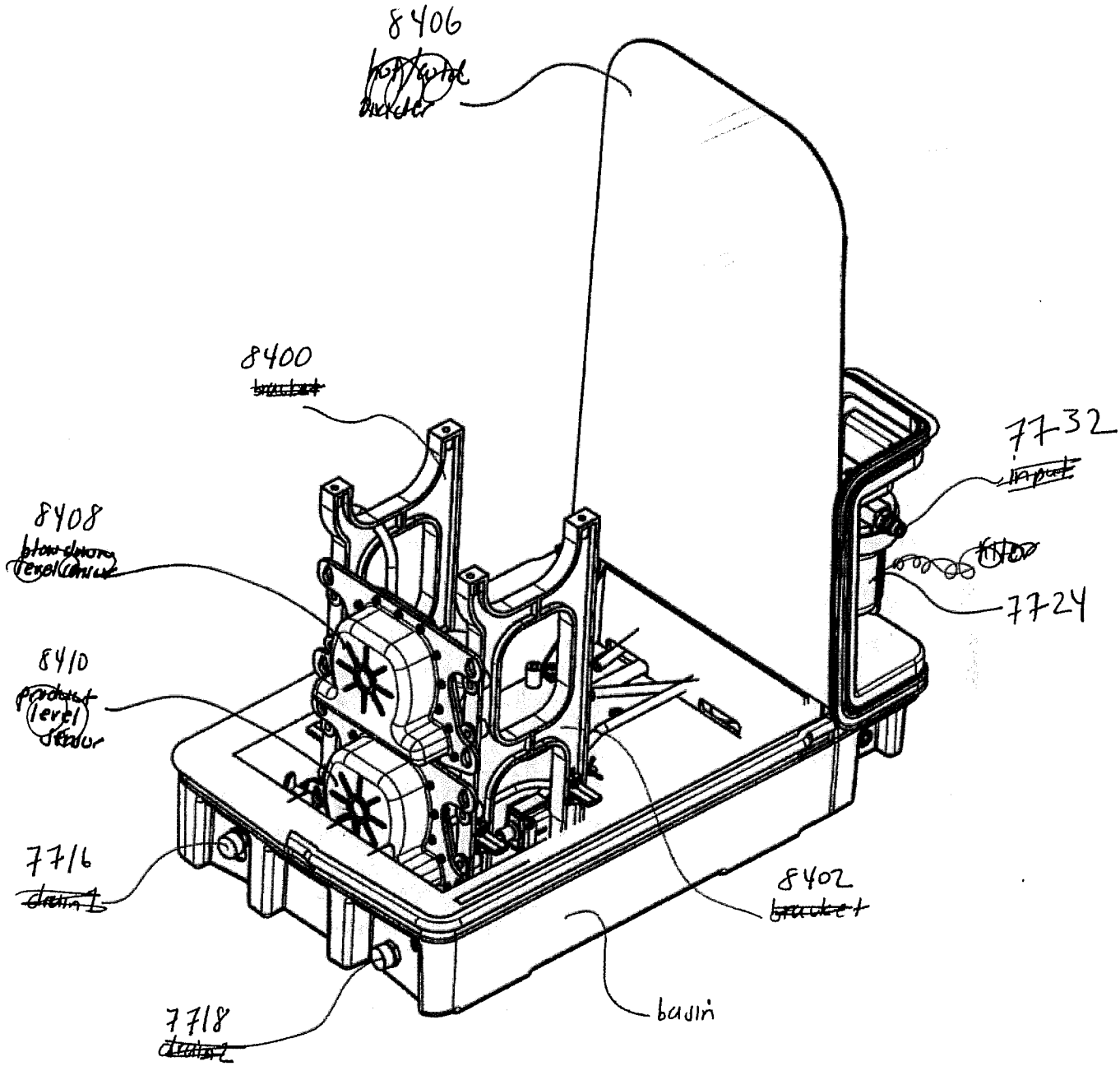



FIG. 84A

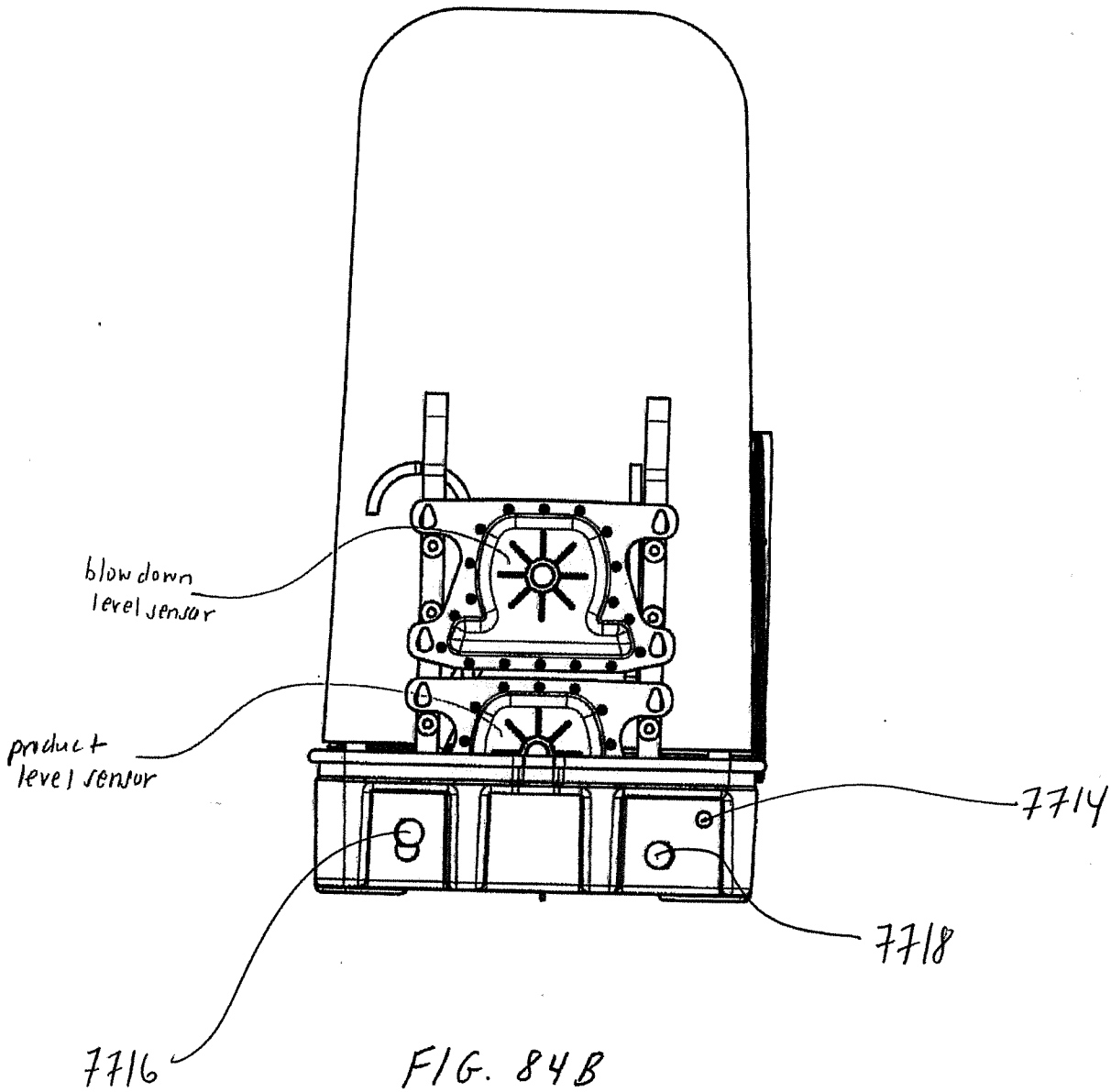



FIG. 84B

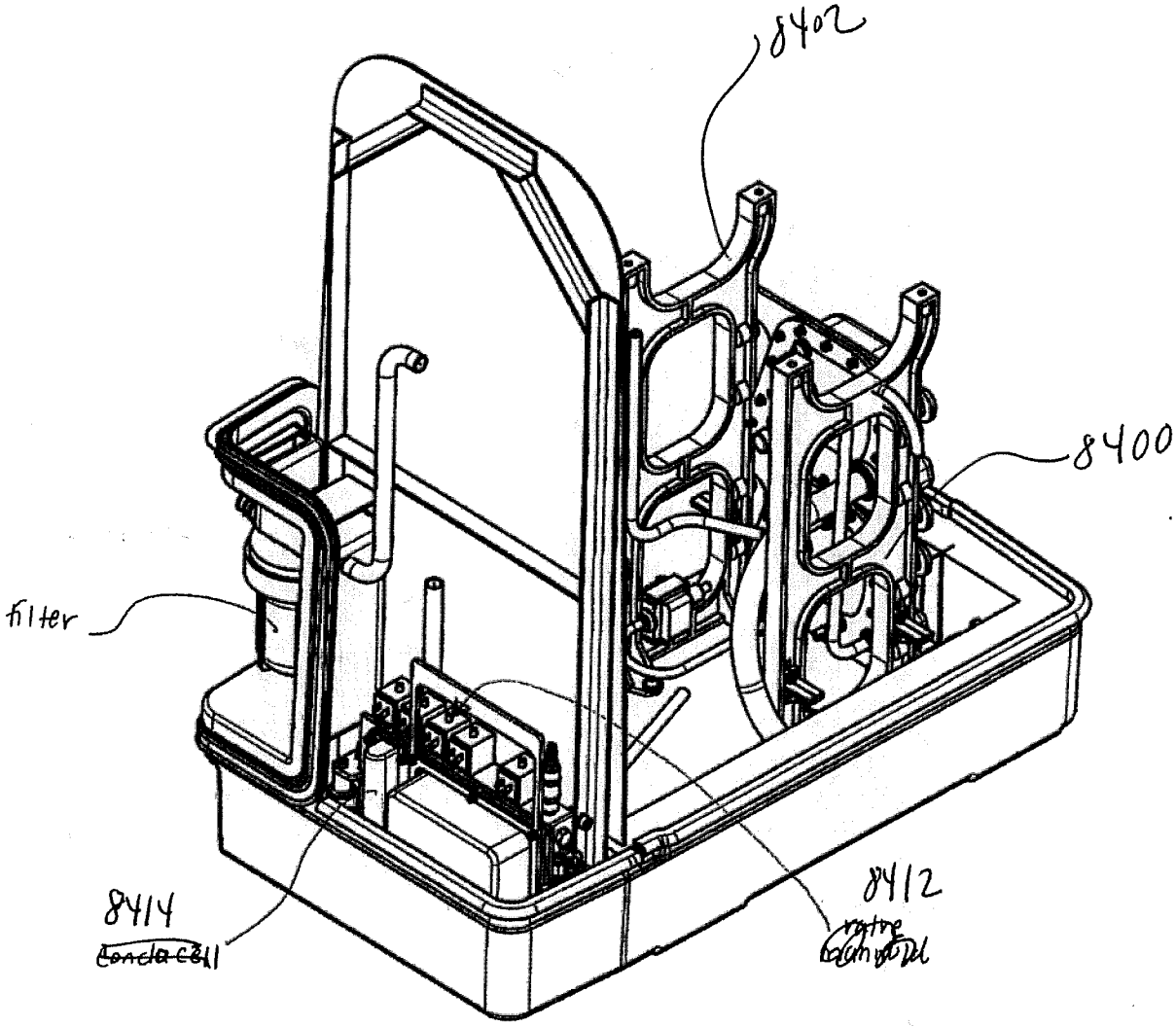



FIG. 84C

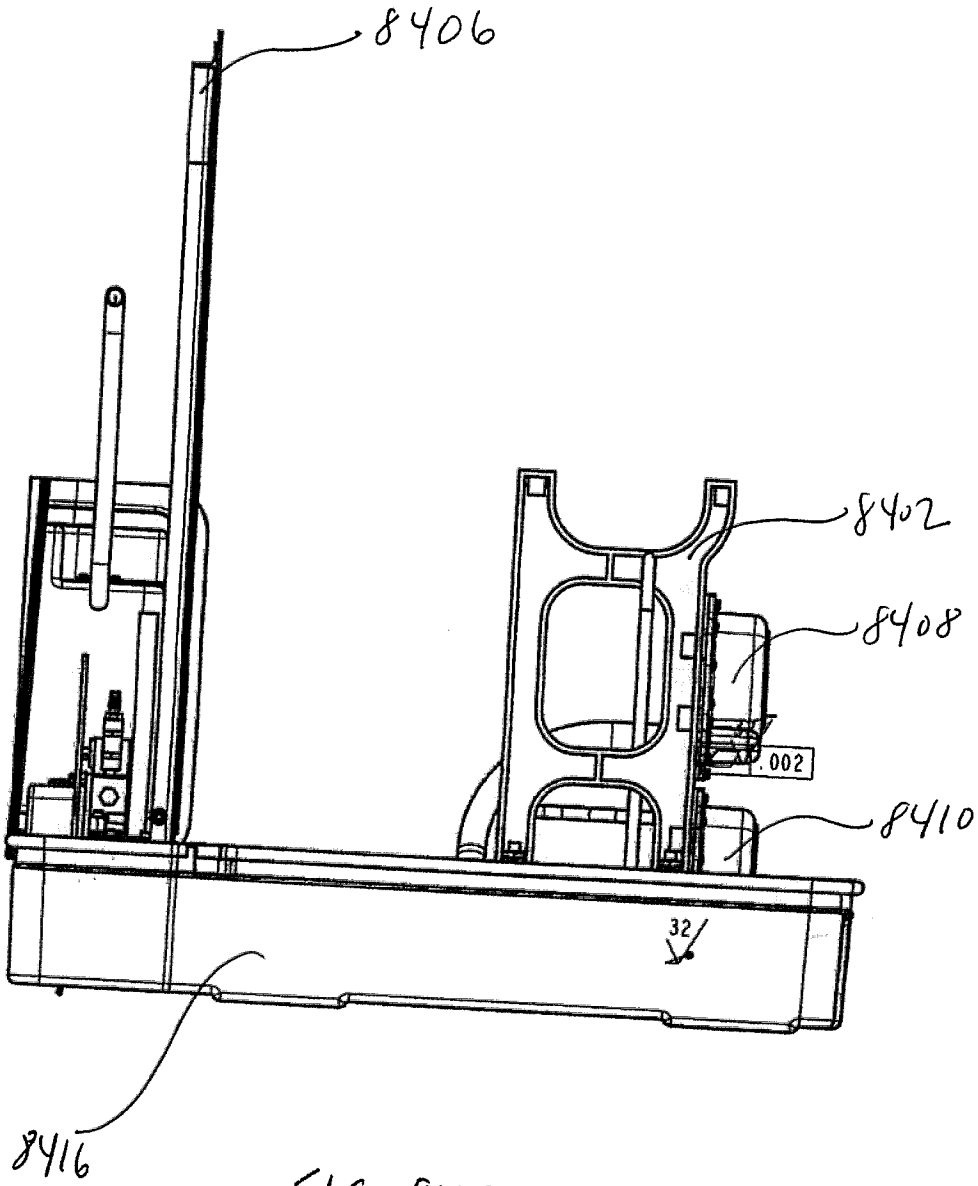



FIG. 84D

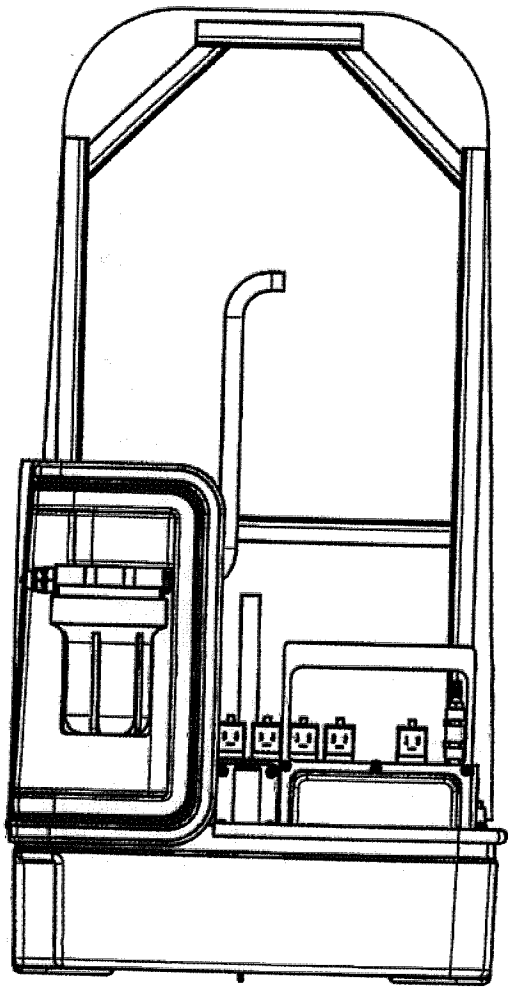


FIG. 84E

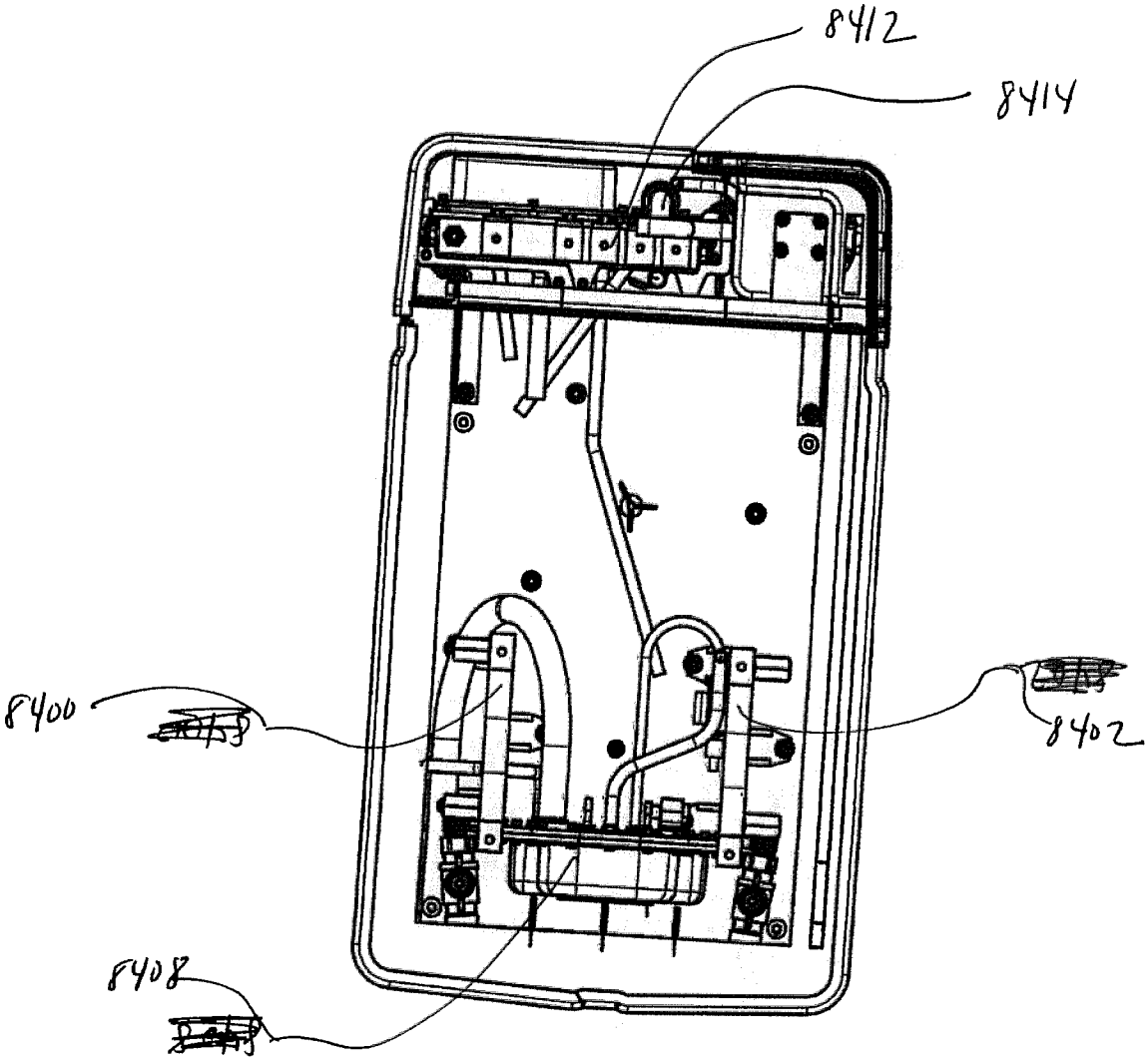



FIG. 84F

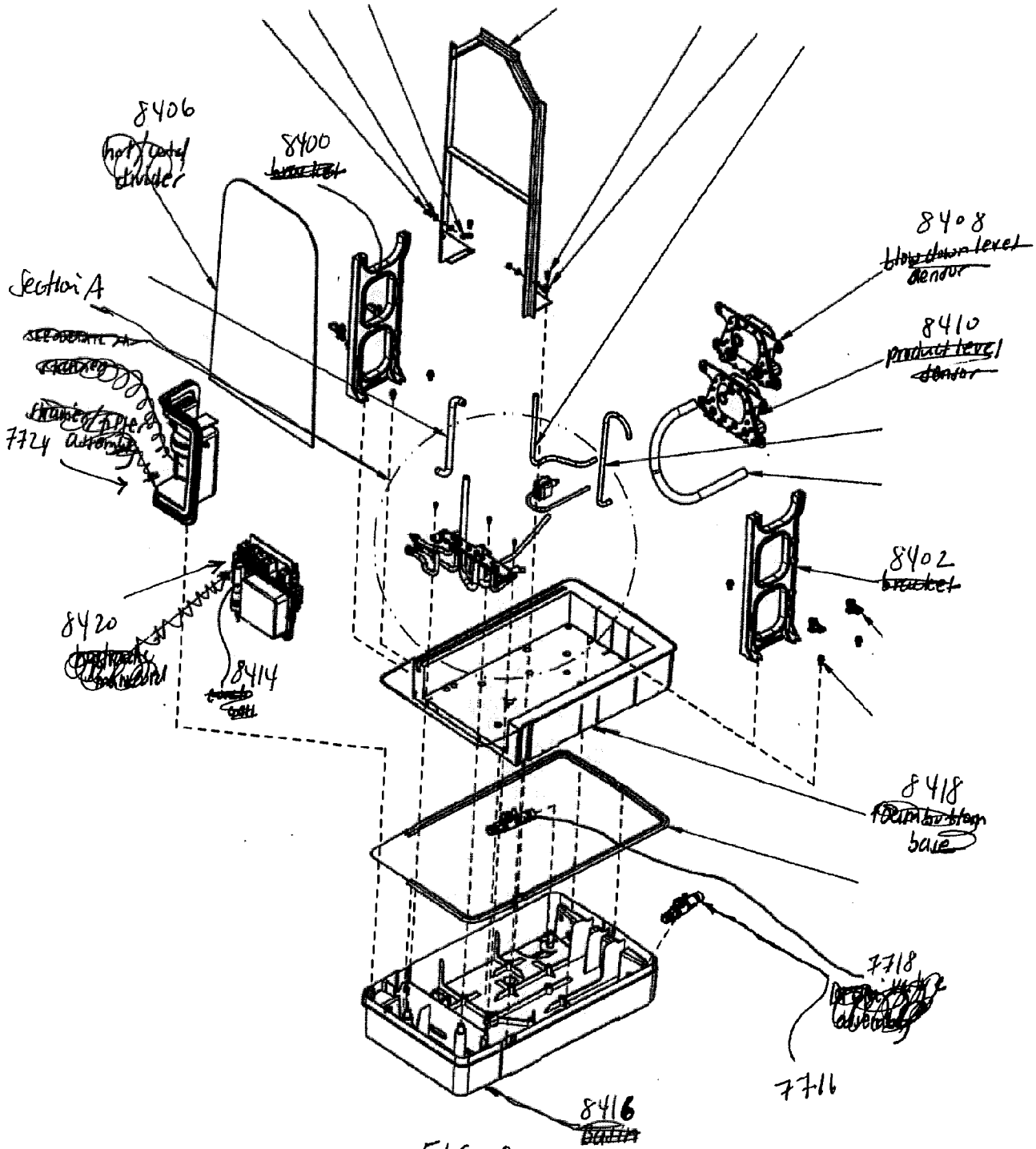

8406
8400
8408
8410
Section A
7724
8420
8414
8402
8418
7718
7716
8416

FIG. 85A

Detail of A

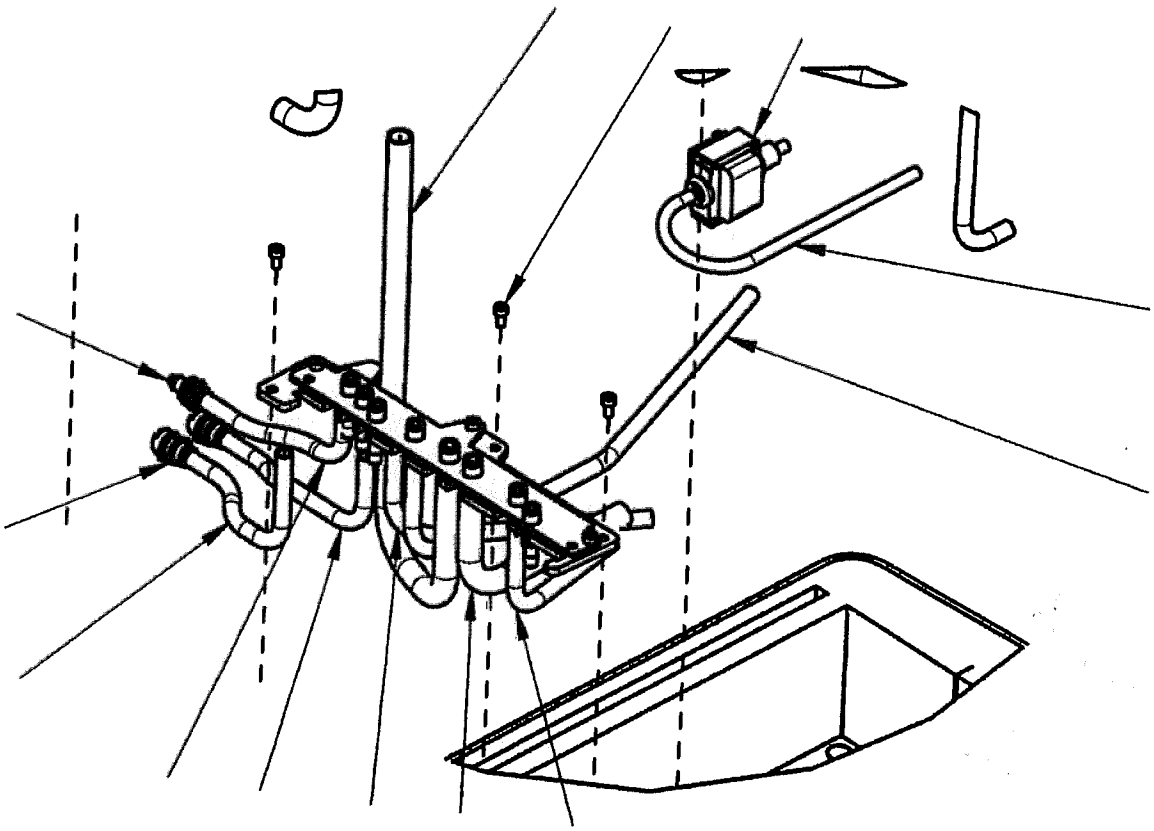


FIG. 85B

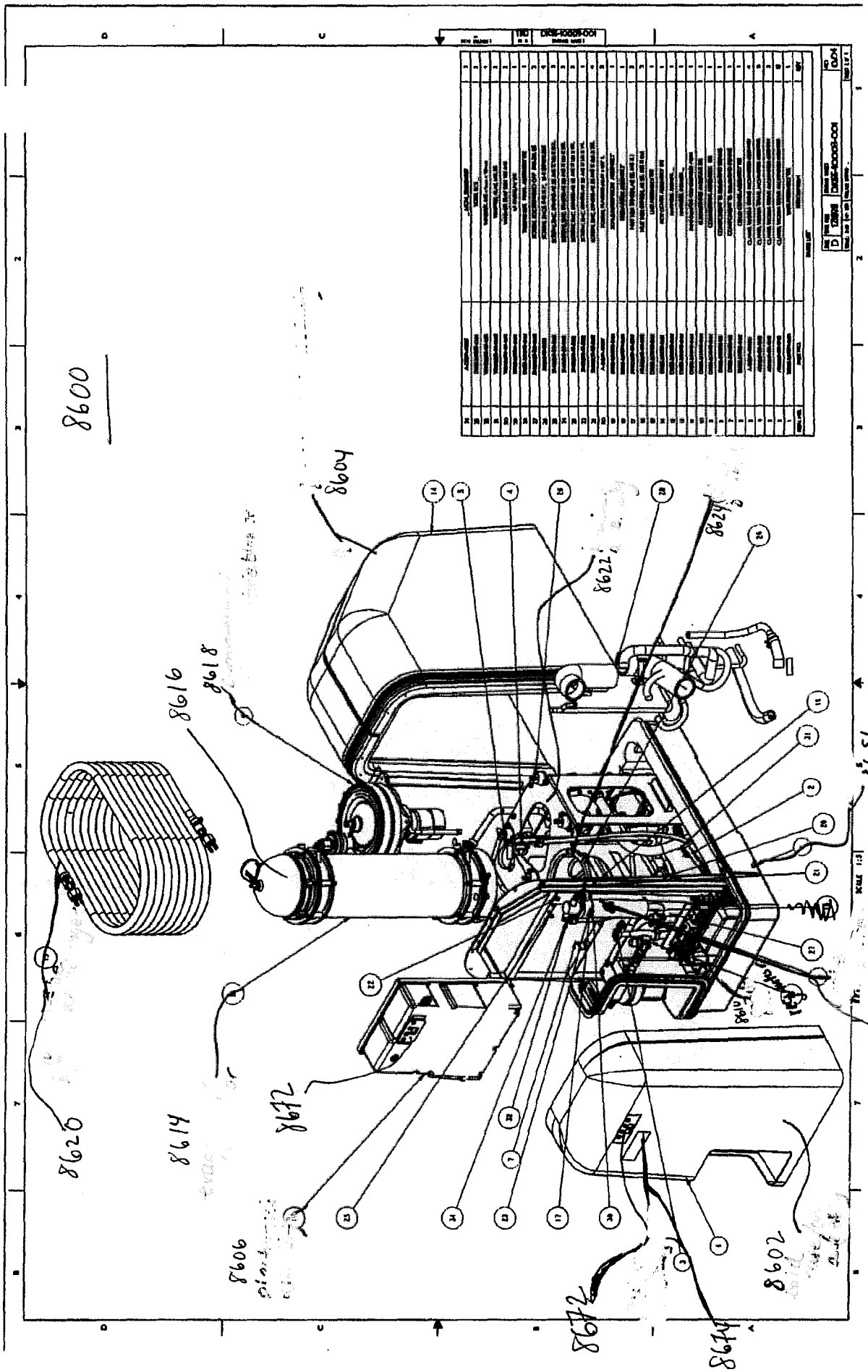

8600
8604
8622
8624
8616
8618
8656
8608
8620
8614
8612
8606
8602
8672
8674

FIG. 86

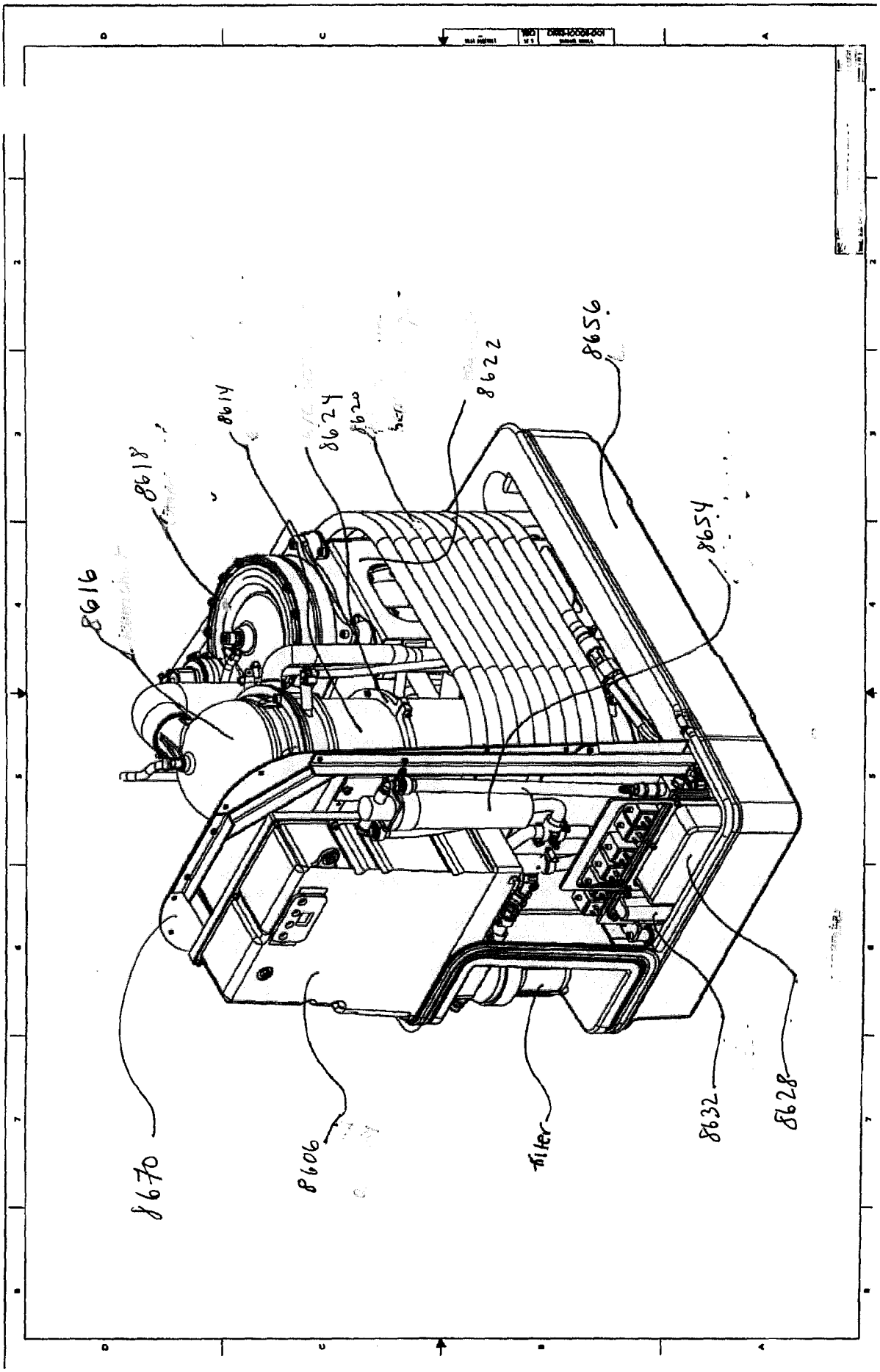

8616
8618
8614
8624
8620
8622
8656
8654
8670
8606
filter
8632
8628

FIG. 87A

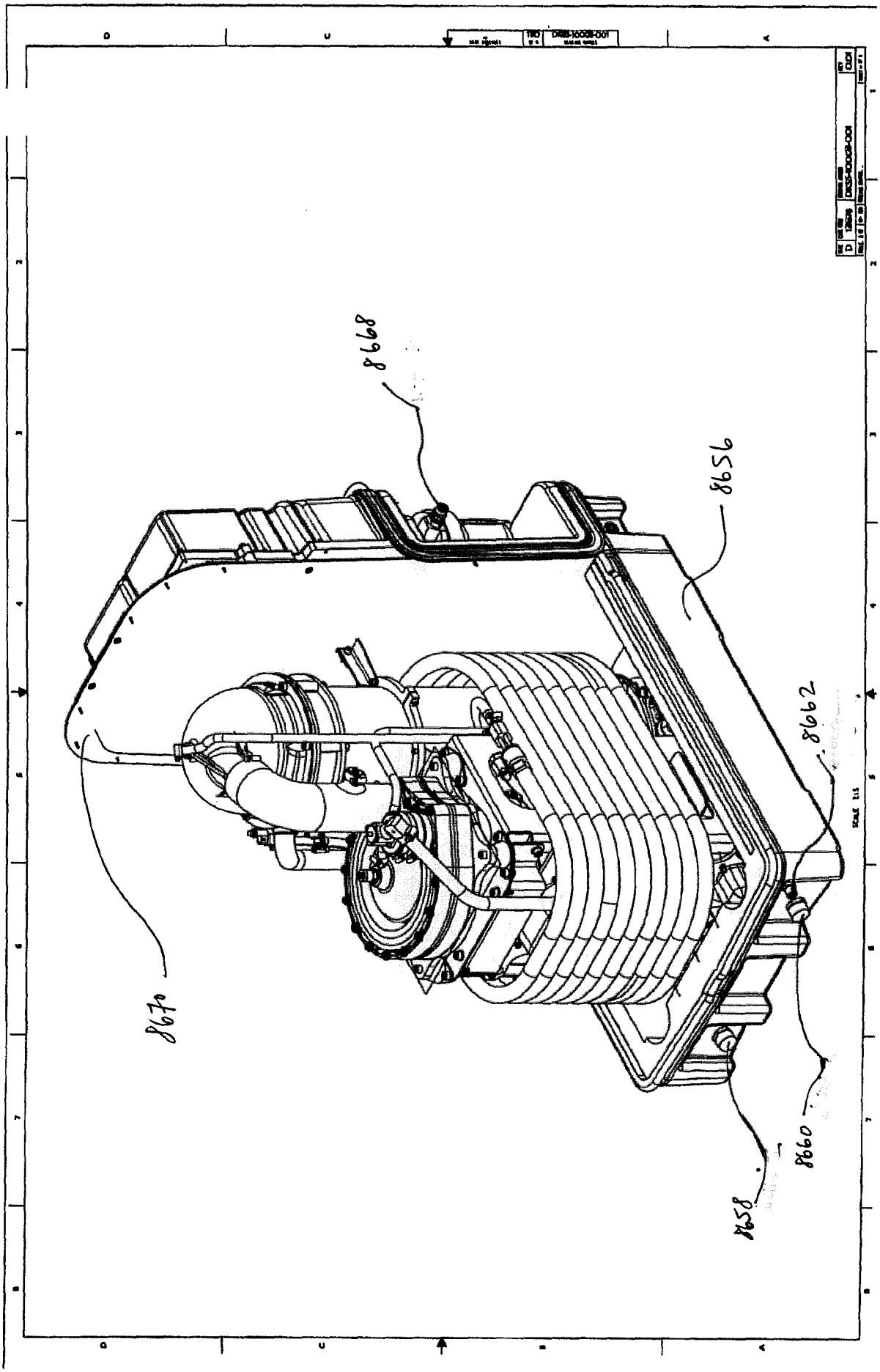



FIG. 87B

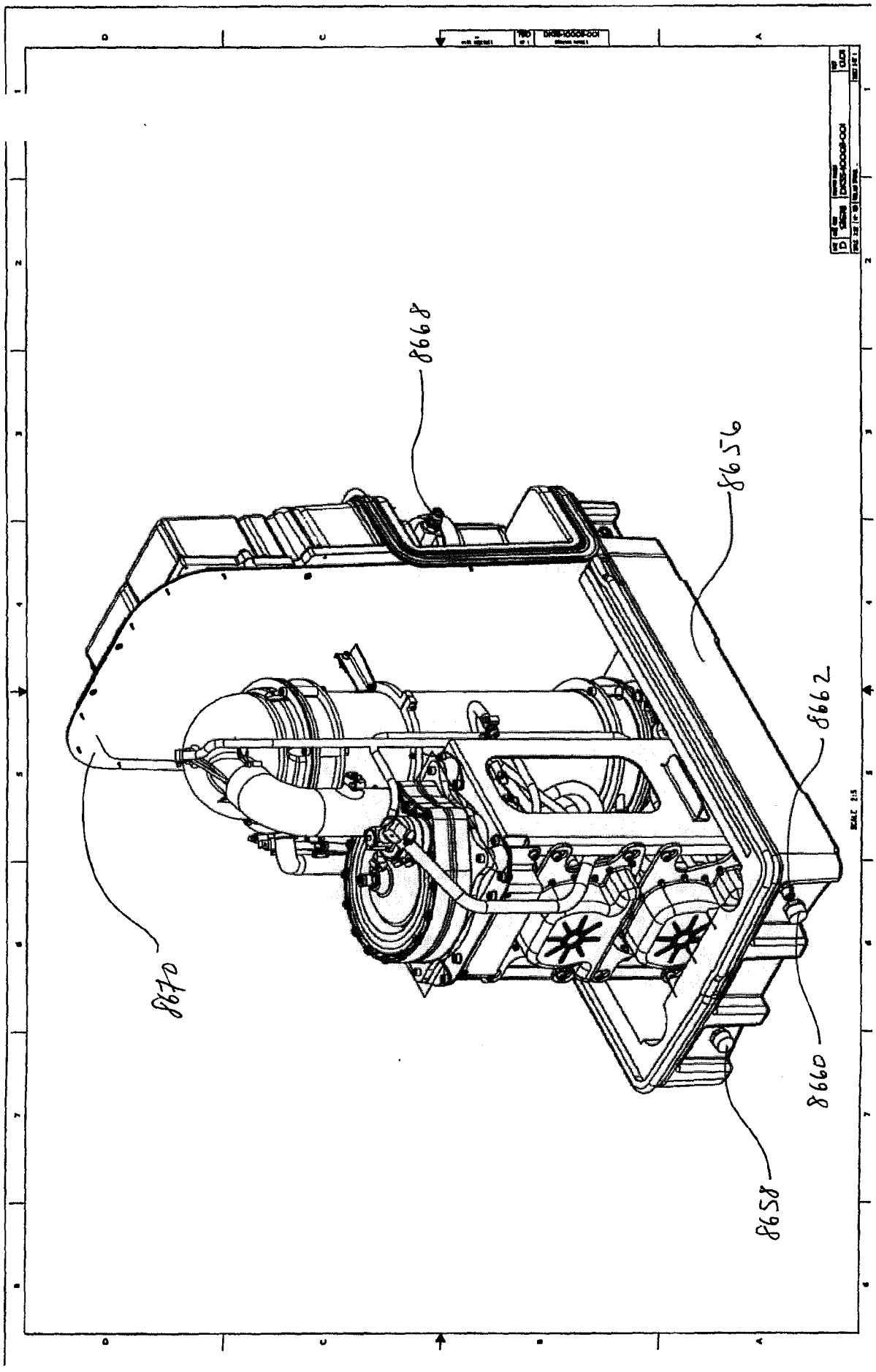



FIG. 87C

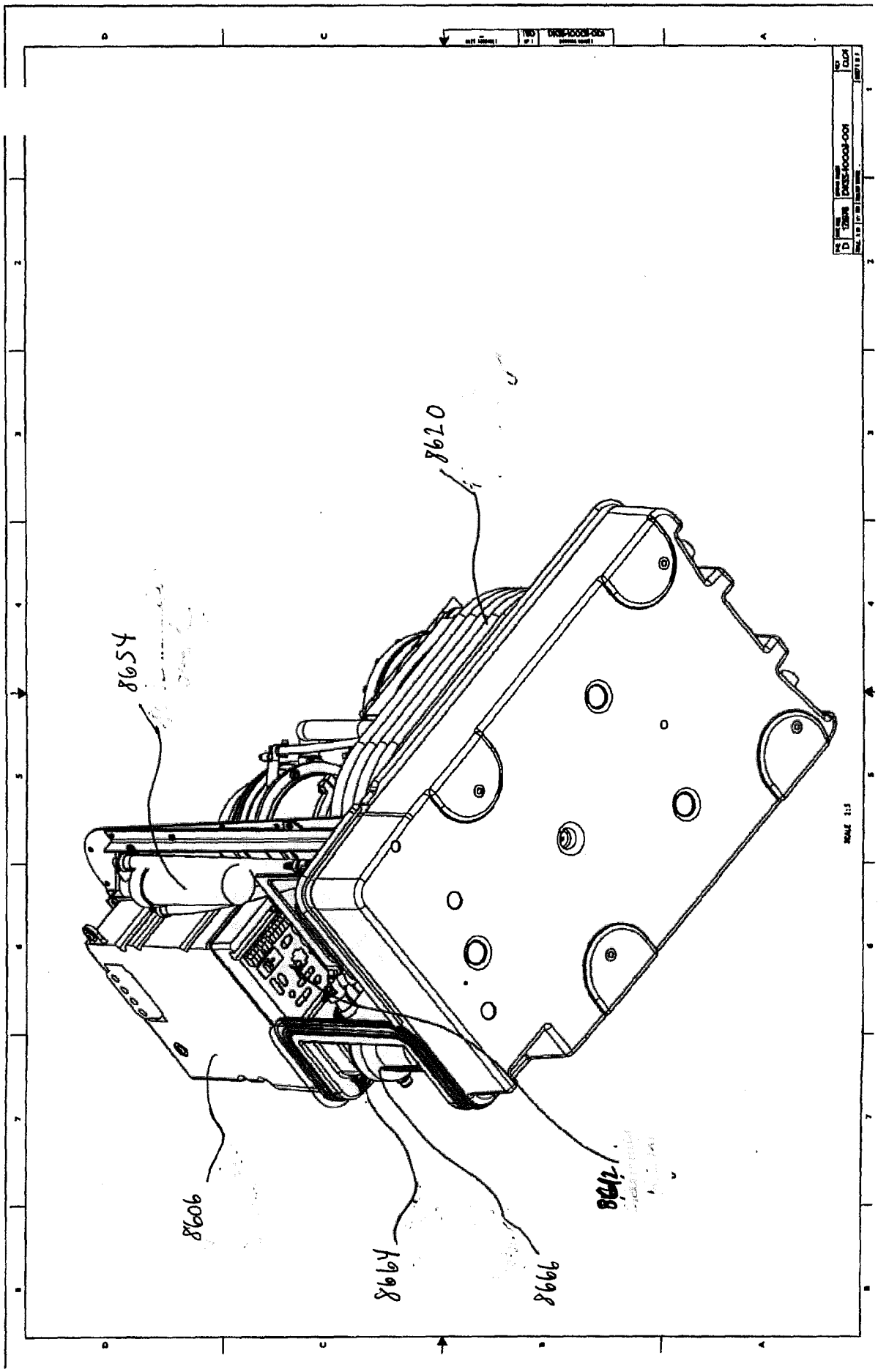



FIG. 87D

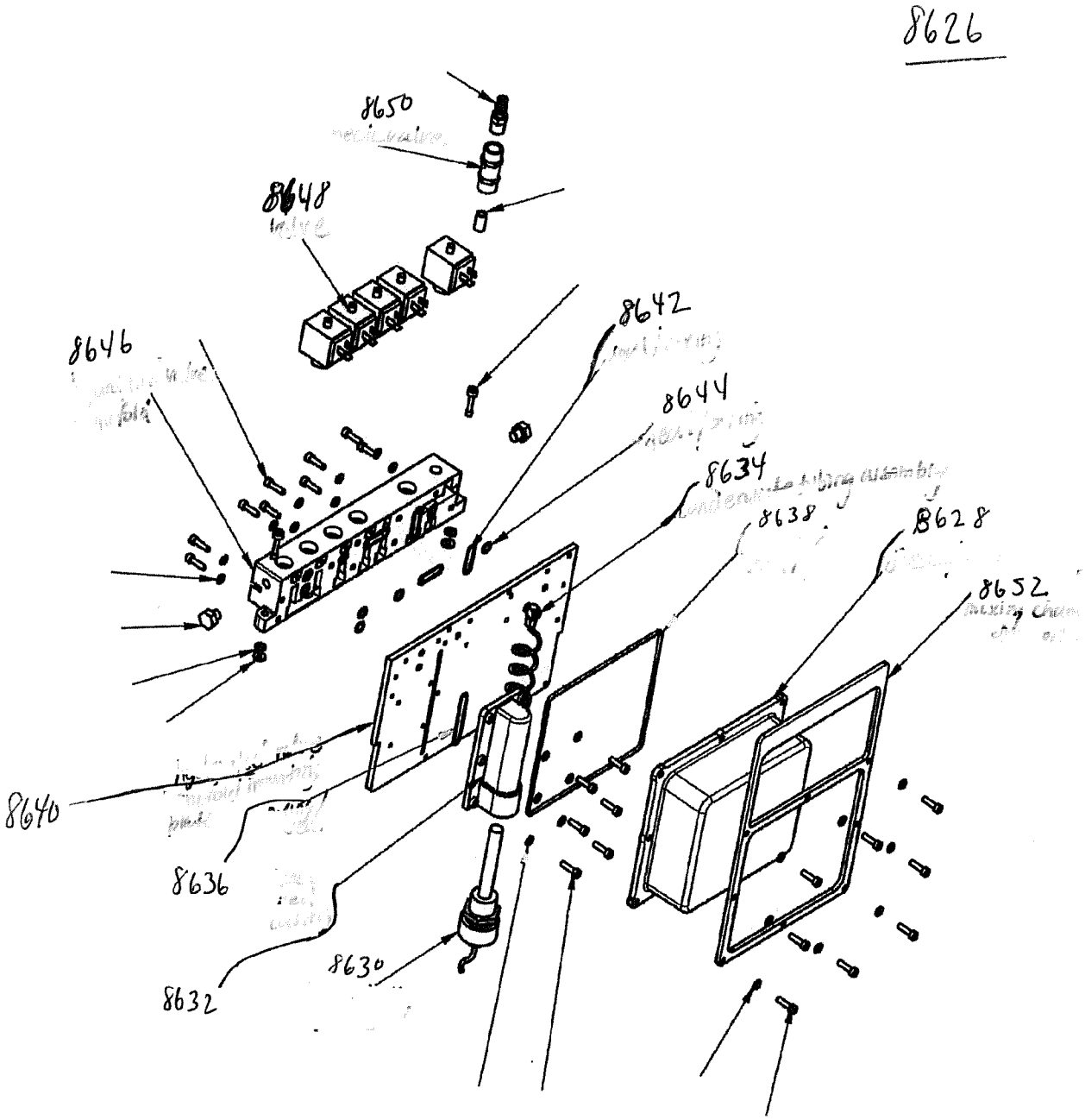

8626
8650
8648
8646
8642
8644
8634
8638
8628
8652
8640
8636
8630
8632

FIG. 88

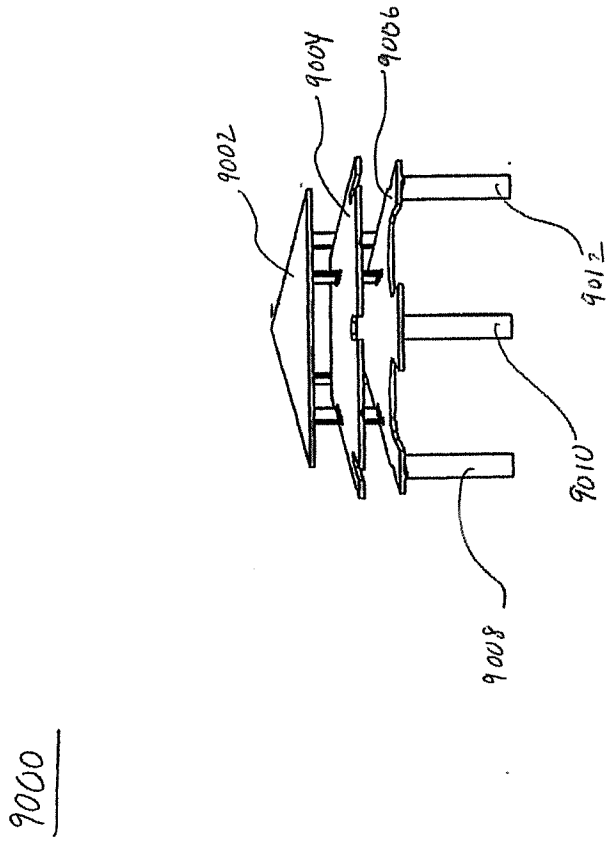



FIG. 90A

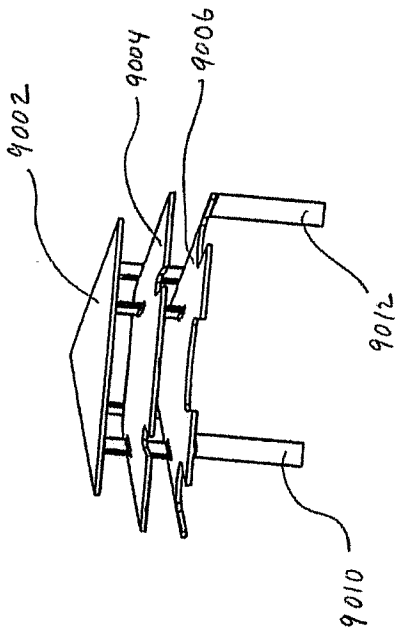
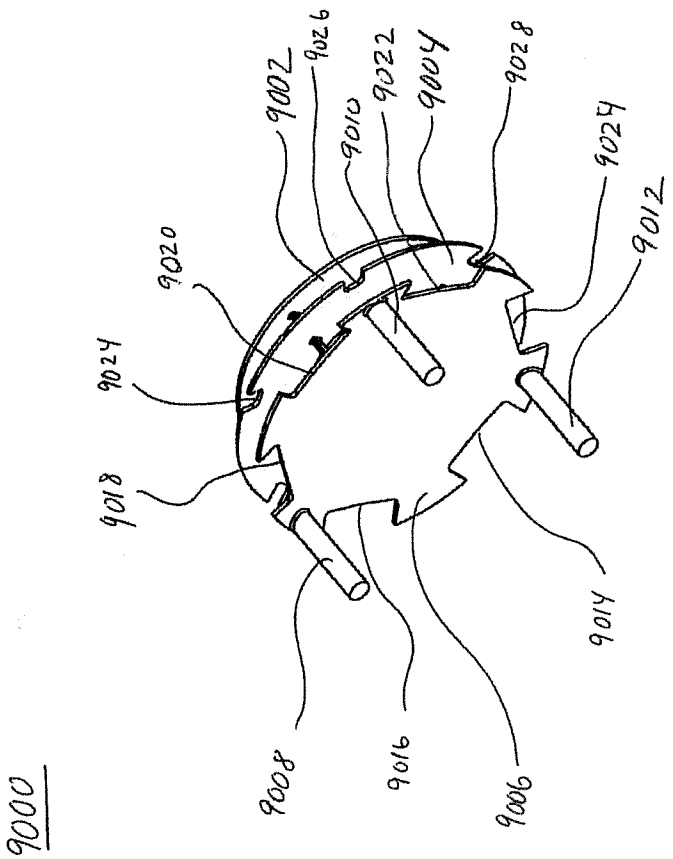



FIG. 90B


9000
9002
9026
9010
9022
9004
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9012
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9024
9018
9014
9008
9016
9006

FIG. 90C

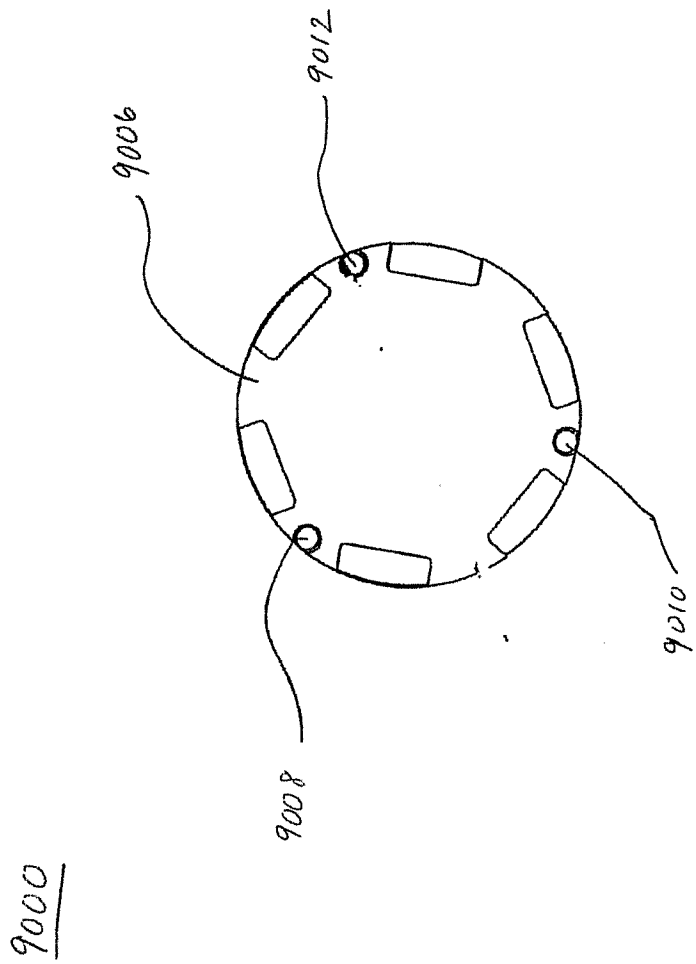
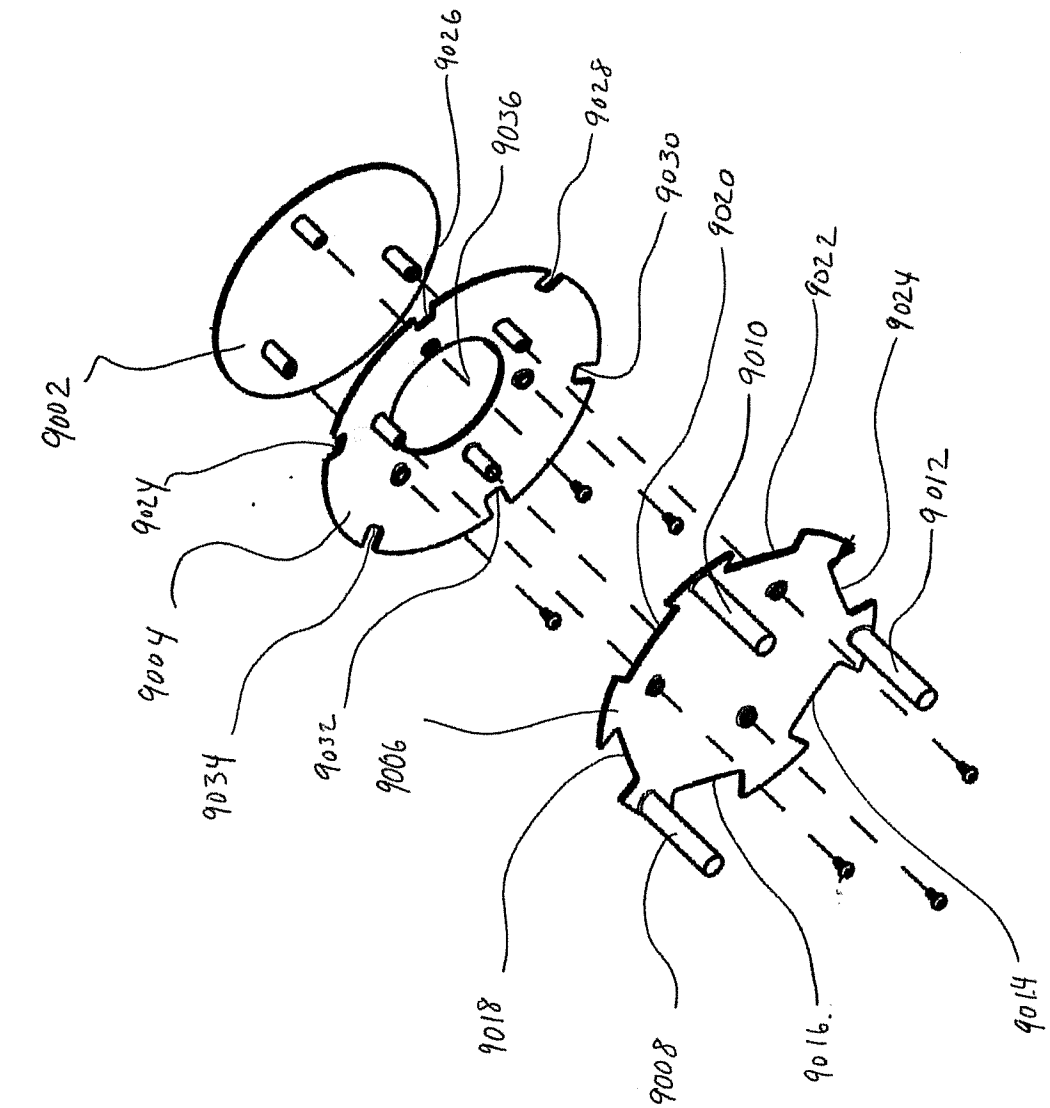



FIG. 90D


9000
9002
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9030
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9036

FIG. 90E

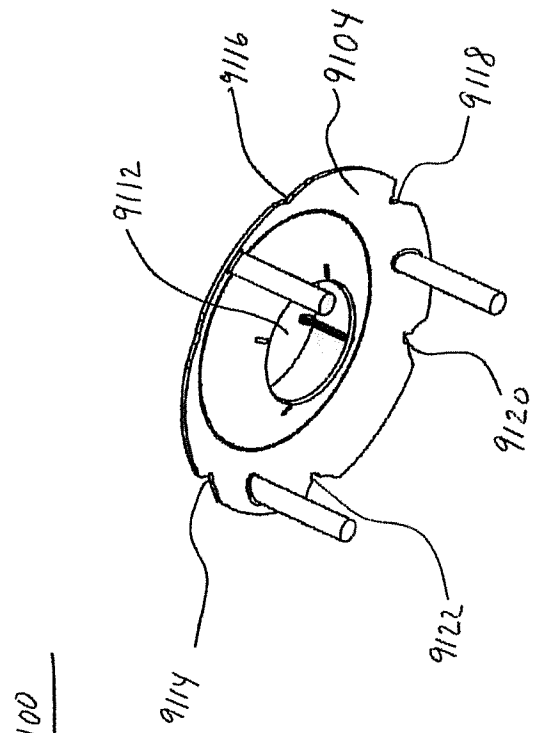



FIG. 91A

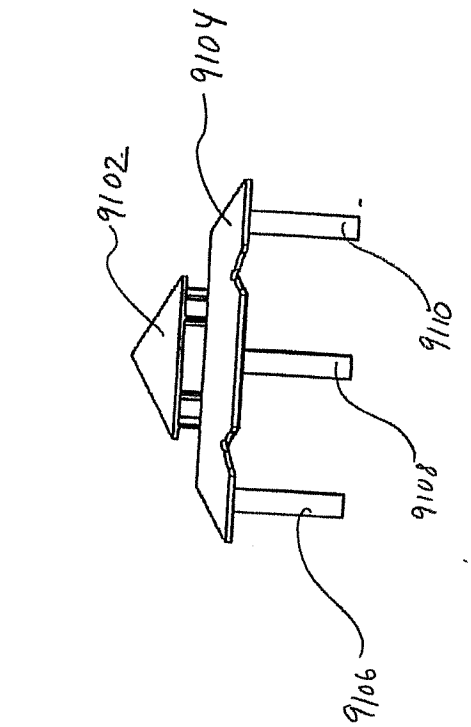



FIG. 91B

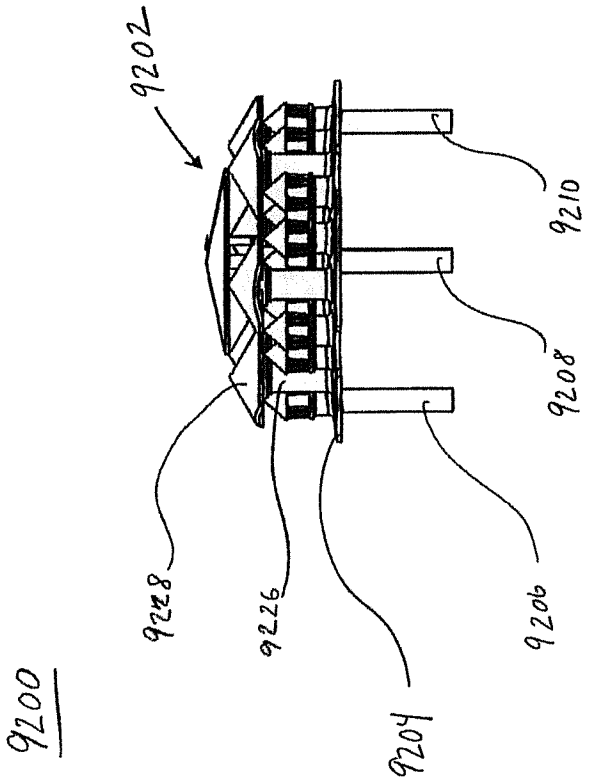
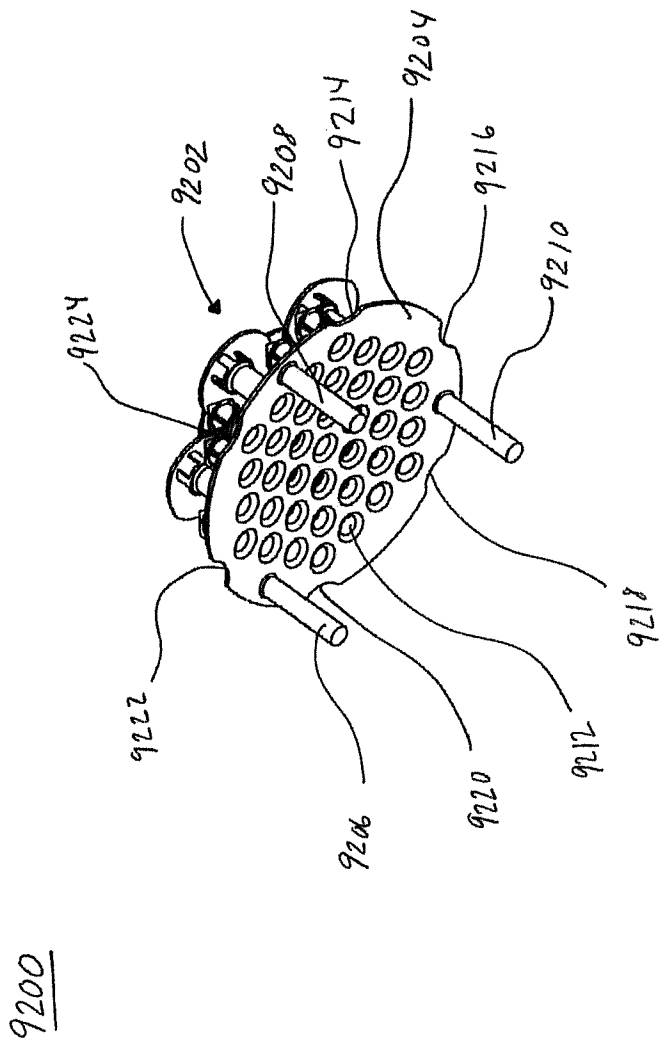



FIG. 92A


9200
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9204
9206
9208
9210
9212
9214
9216
9218
9220
9222
9224

FIG. 92B

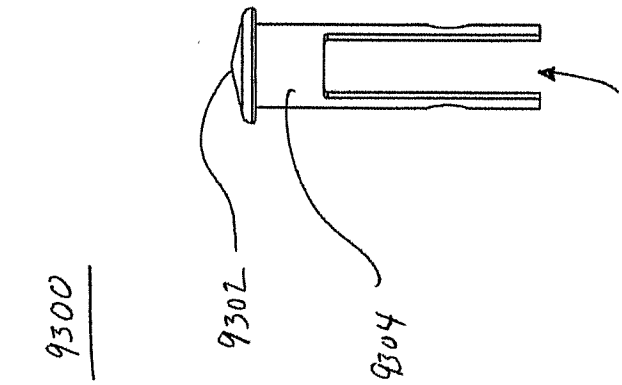



FIG. 93B

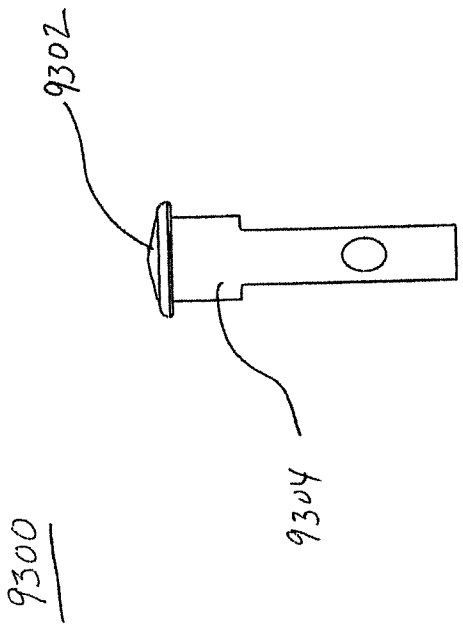



FIG. 93A

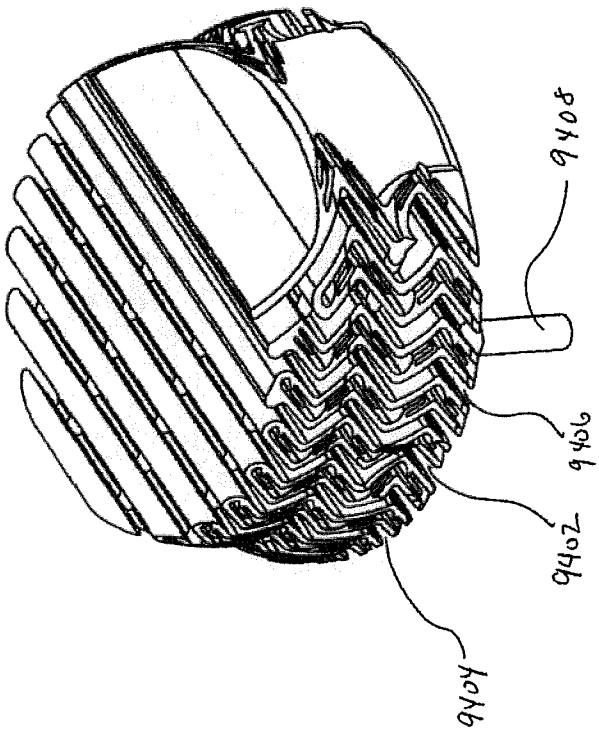



FIG. 94

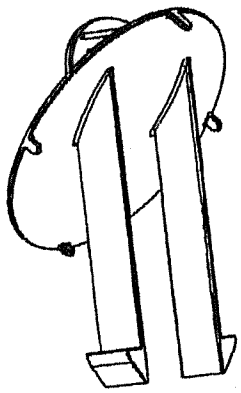


FIG. 95B

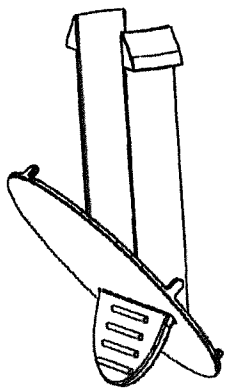


FIG. 95A

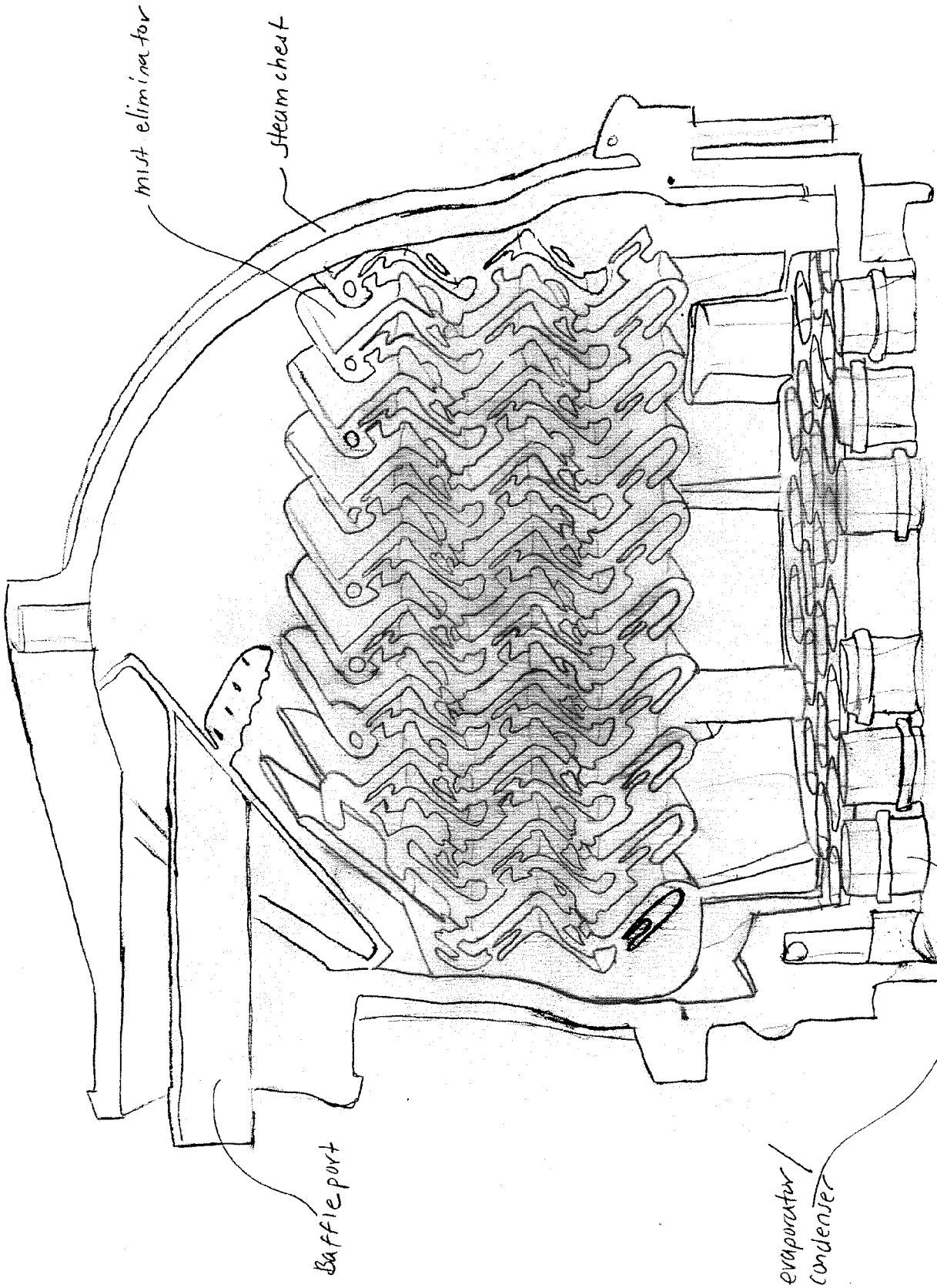

mist eliminator
steam chest
baffle port
evaporator / condenser

FIG. 96

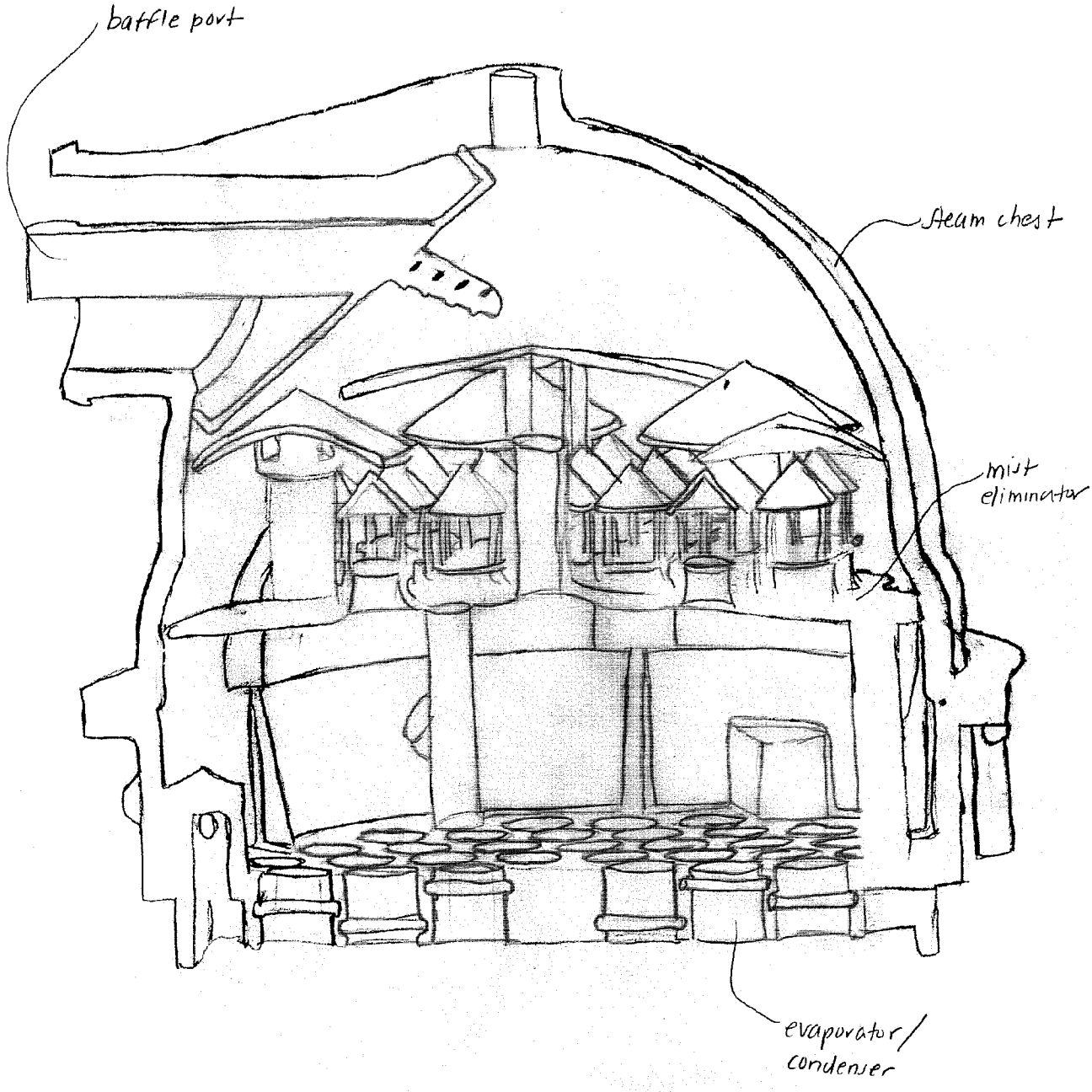
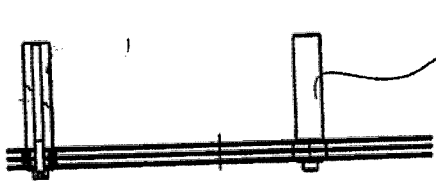
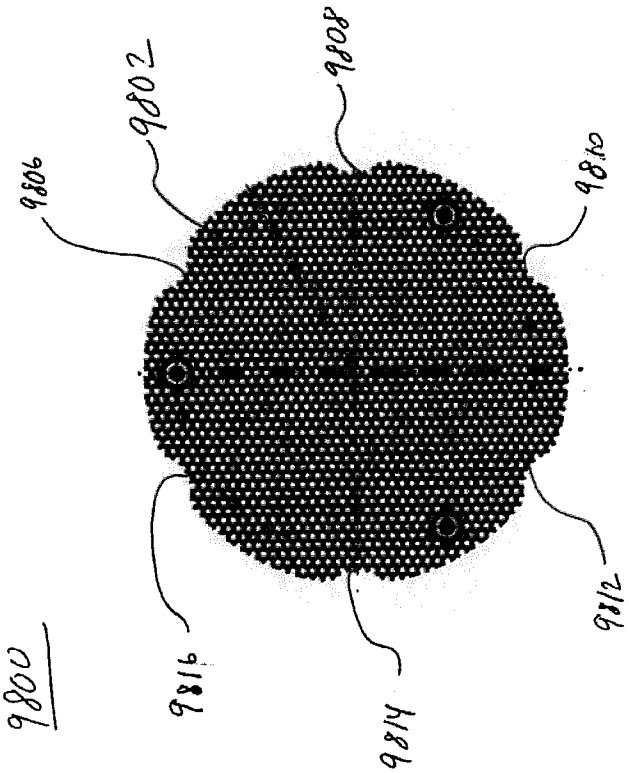

baffle port
steam chest
mist eliminator
evaporator/ condenser

FIG. 97




9800

FIG. 98B




9800

FIG. 98A

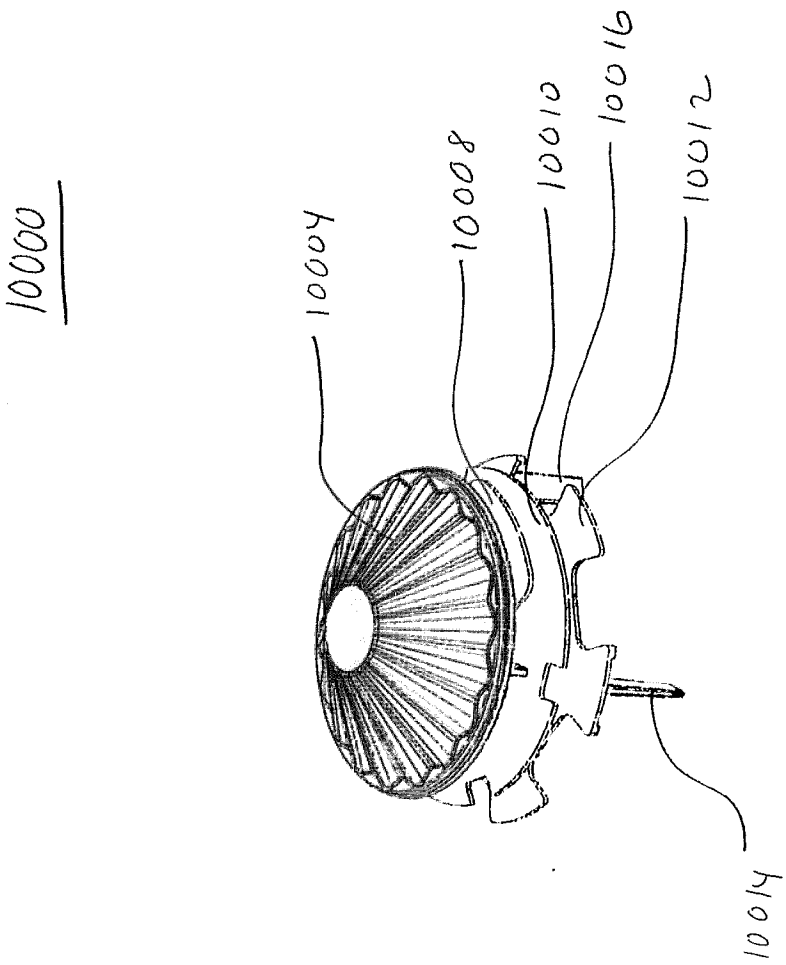



FIG. 99A

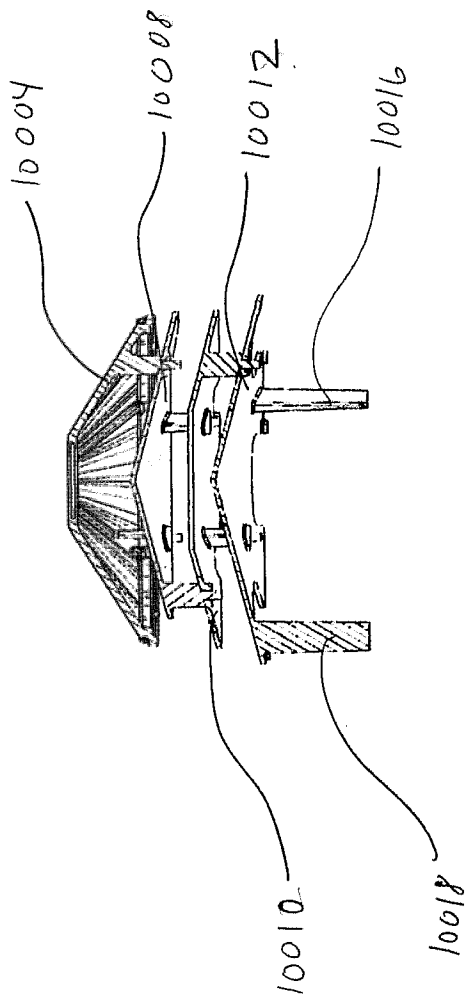



FIG. 99B

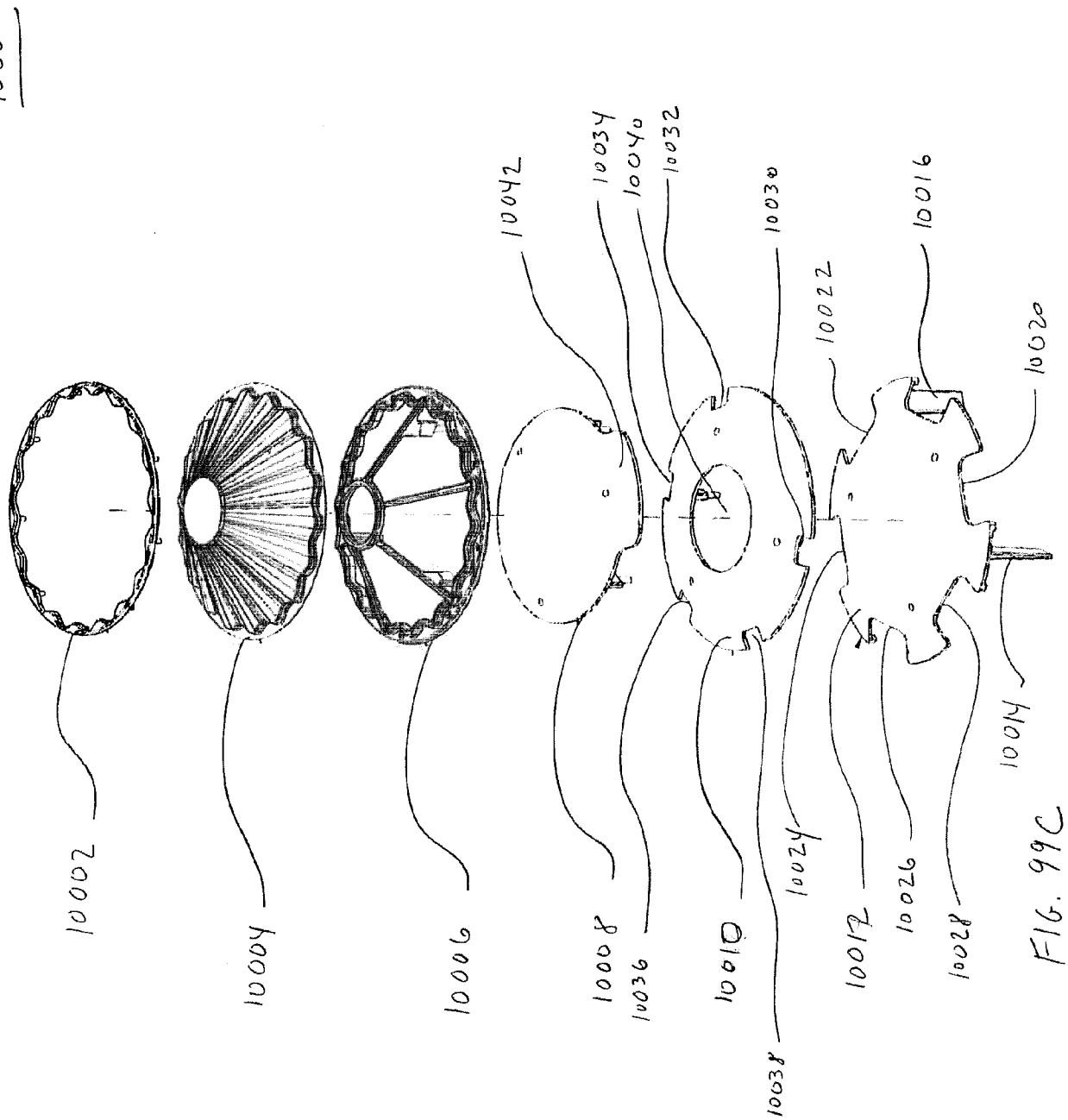

10000
10002
10004
10006
10042
10034
10040
10032
10030
10022
10016
10020
10014
10008
10036
10010
10038
10024
10012
10026
10028

FIG. 99C

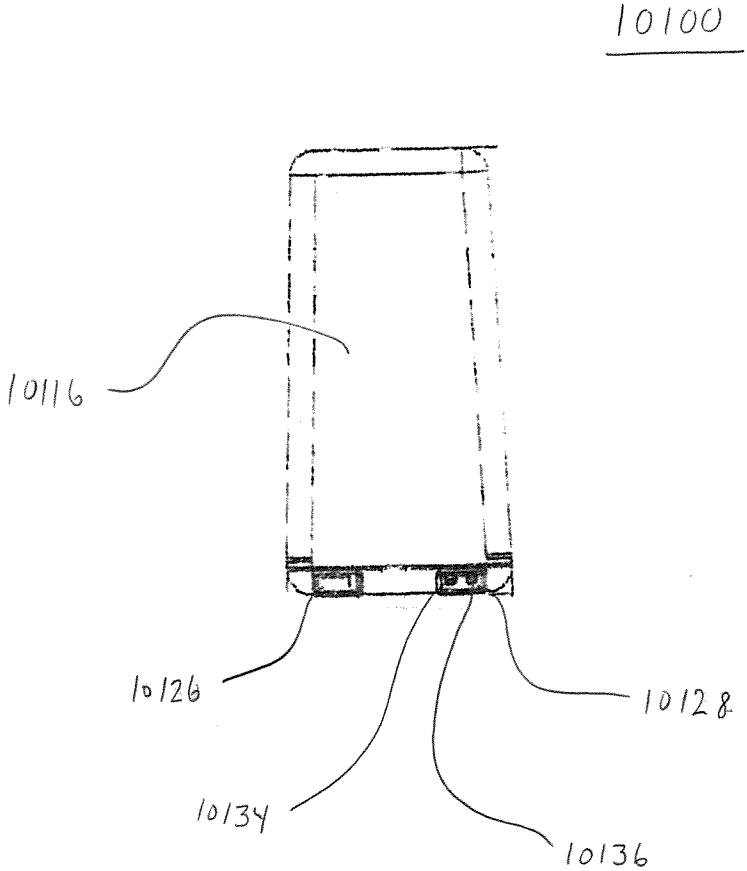



FIG. 100A

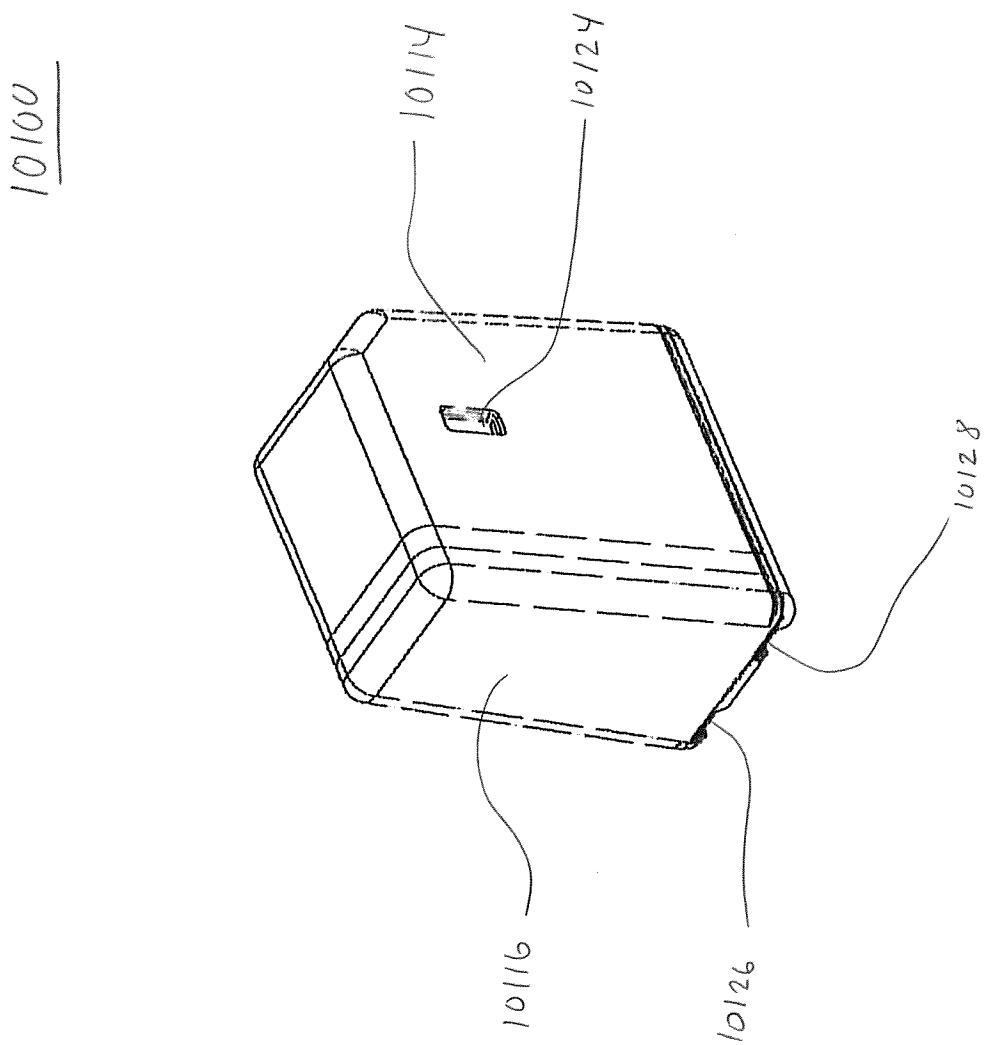



FIG. 100B

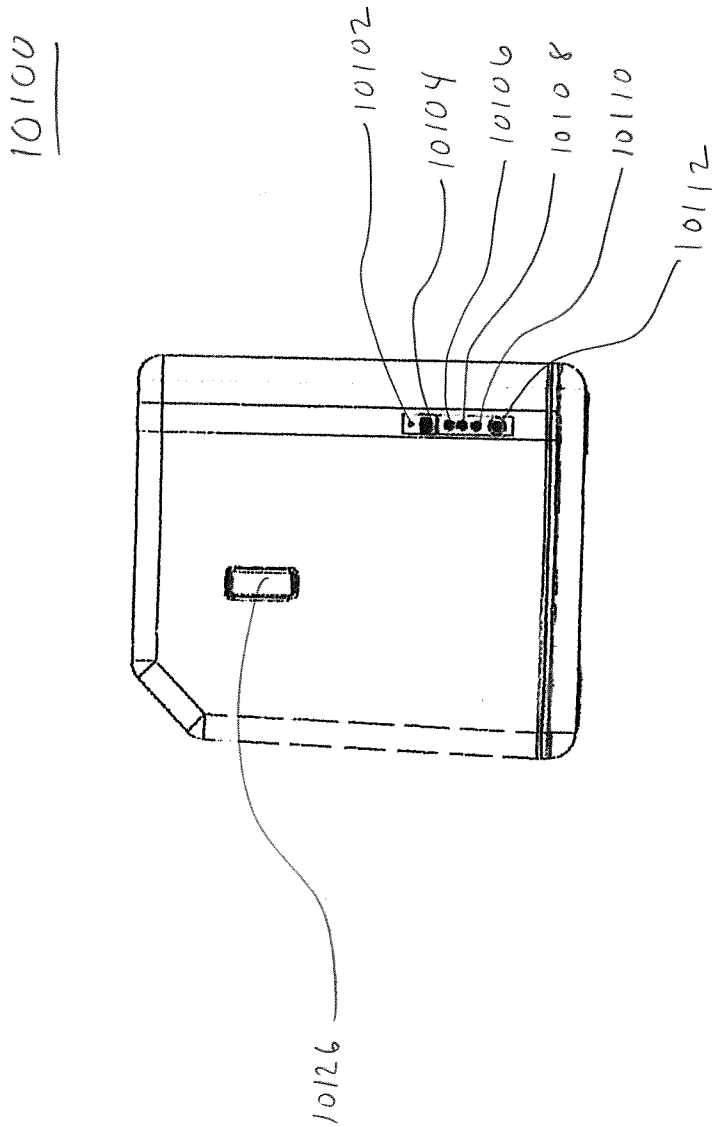



FIG. 100C

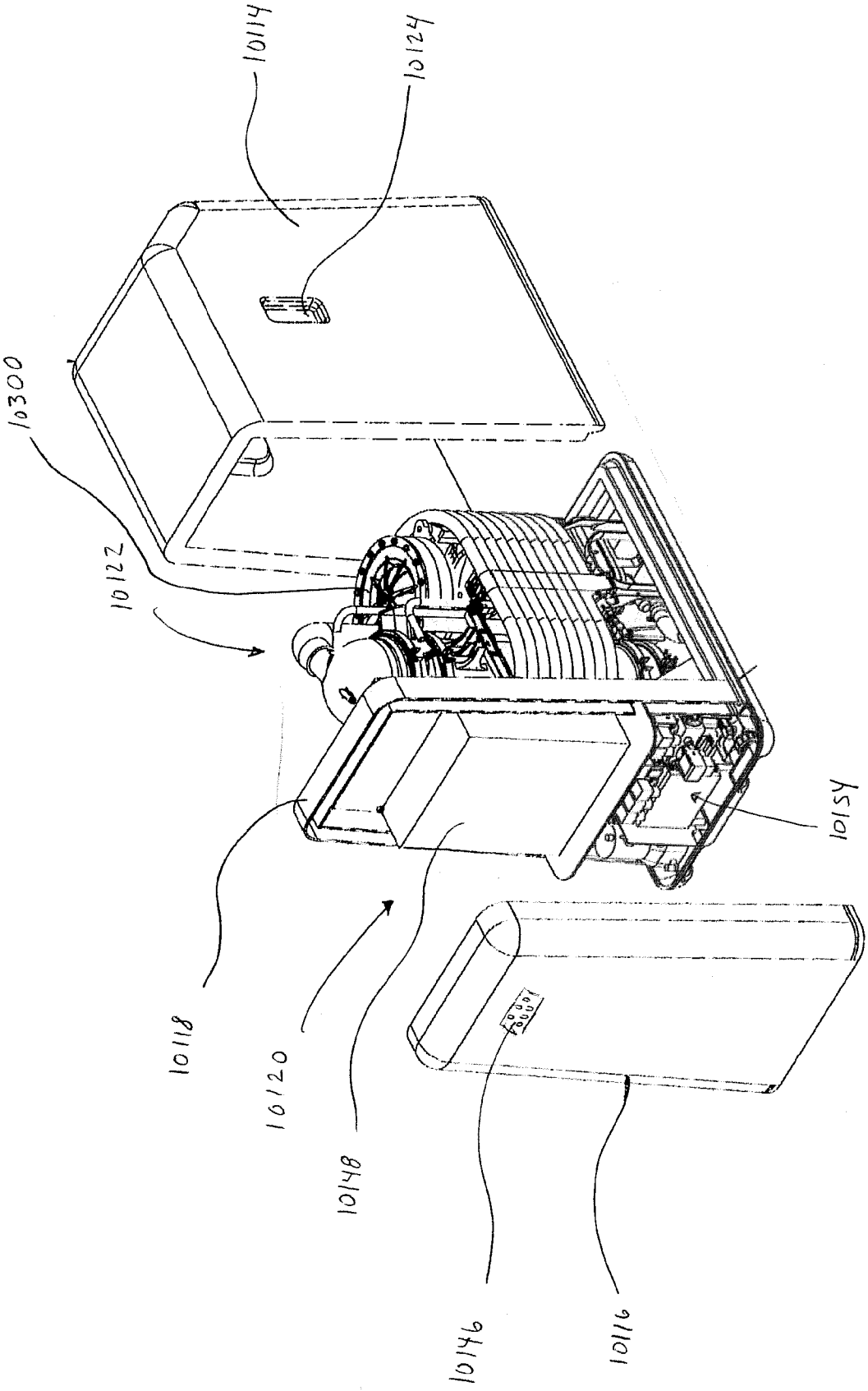

10114
10124
10300
10122
10118
10120
10148
10146
10116
1015Y

FIG. 101

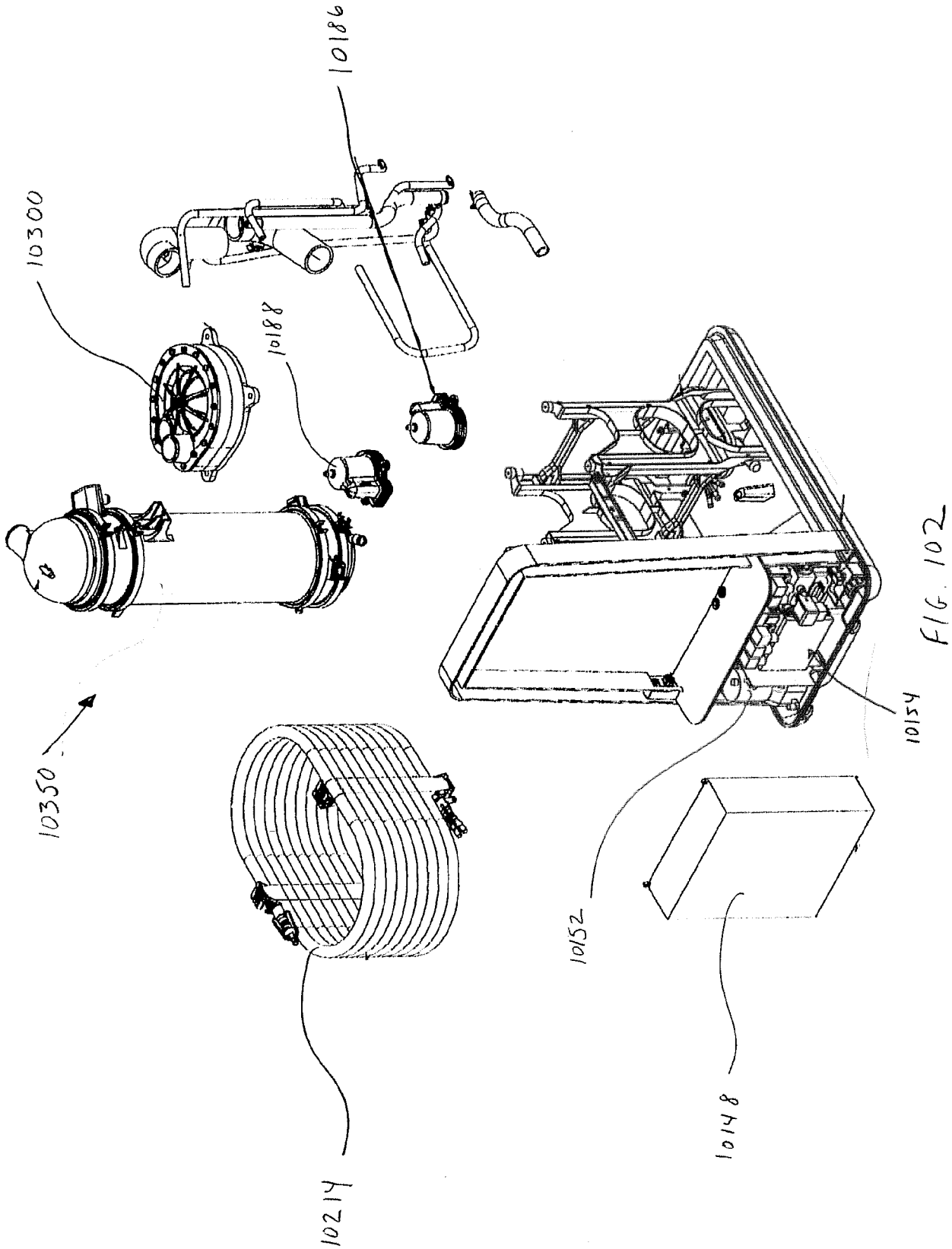



FIG. 102

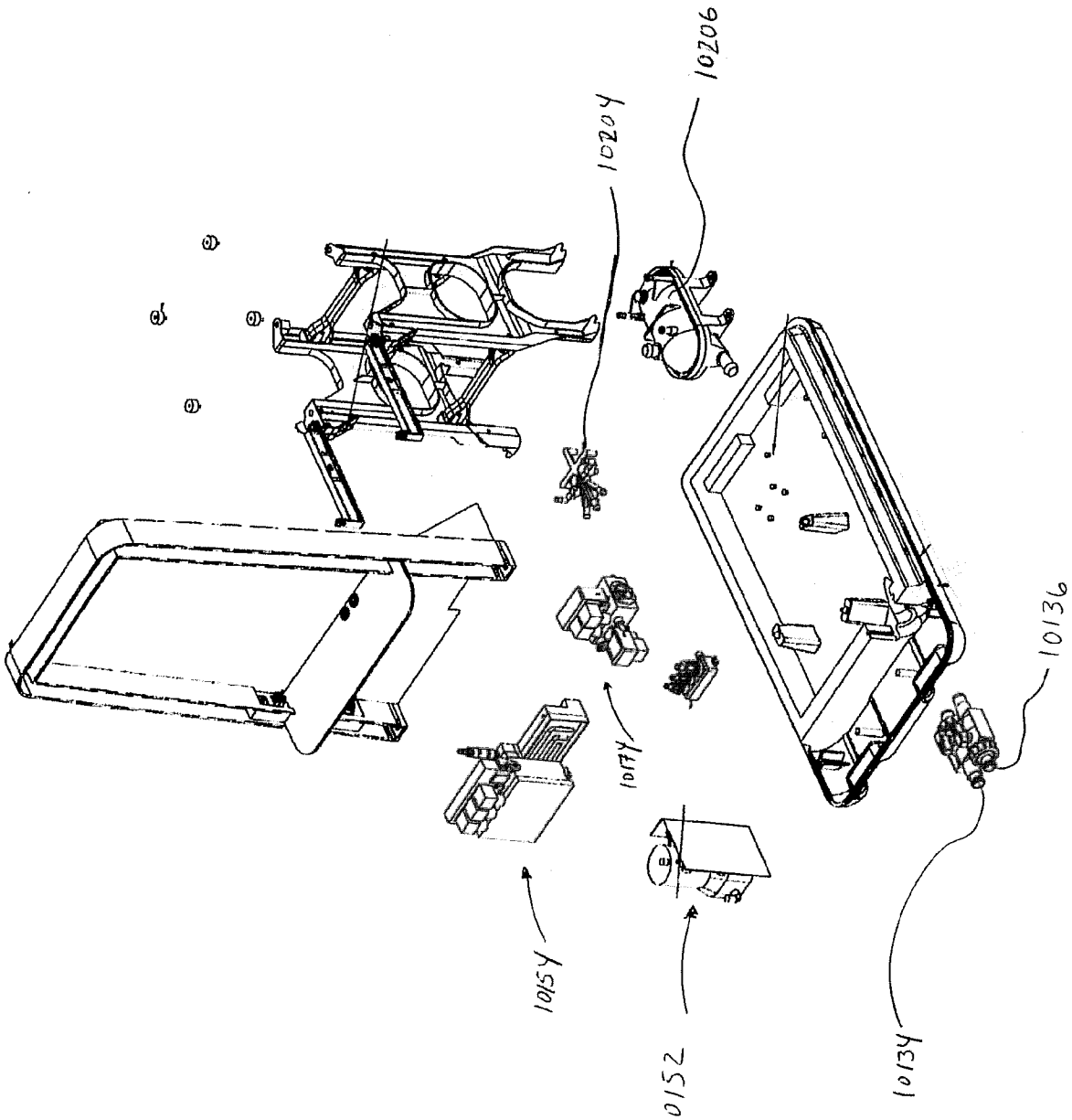



FIG. 103

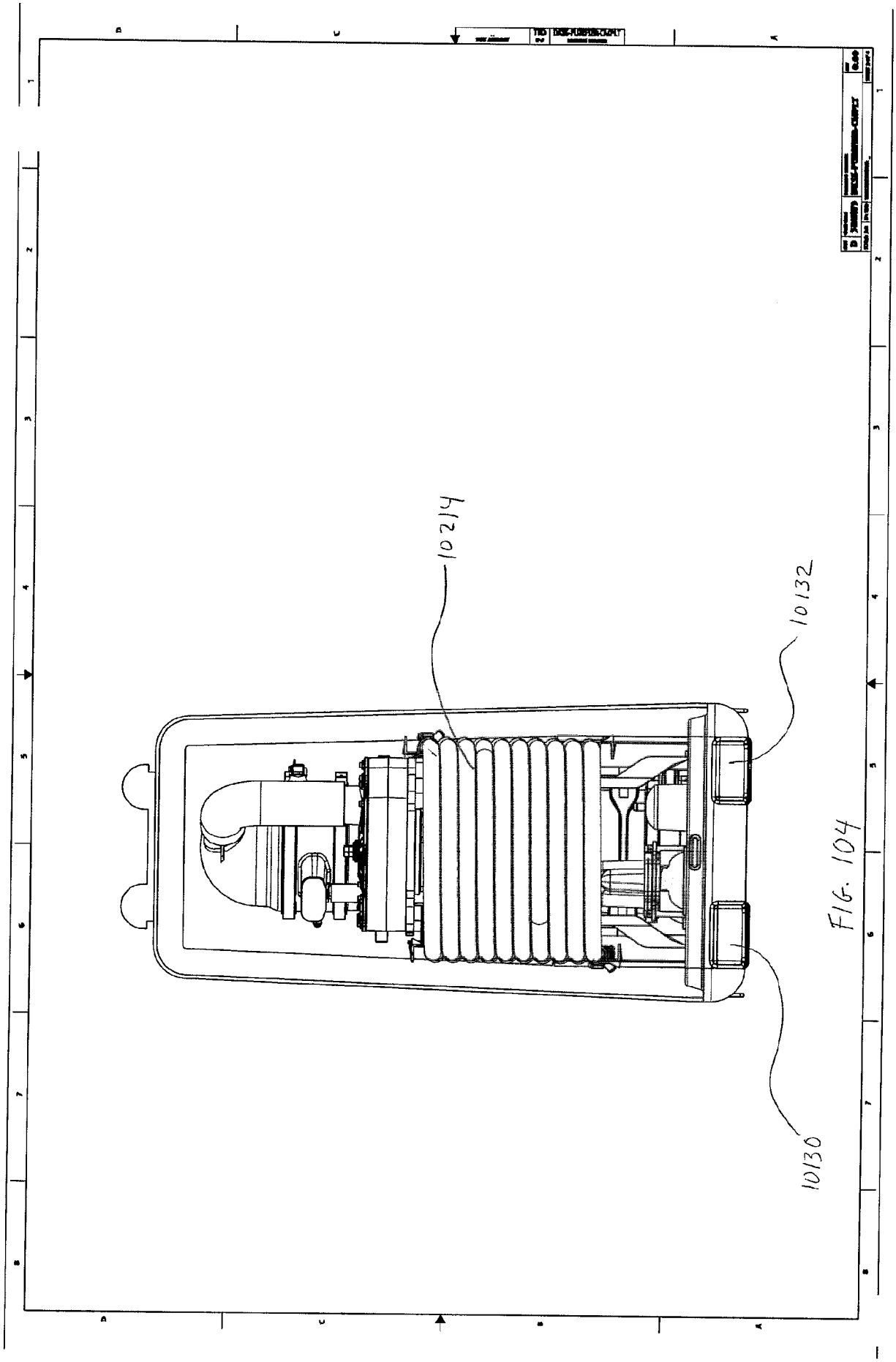



FIG. 104

10138

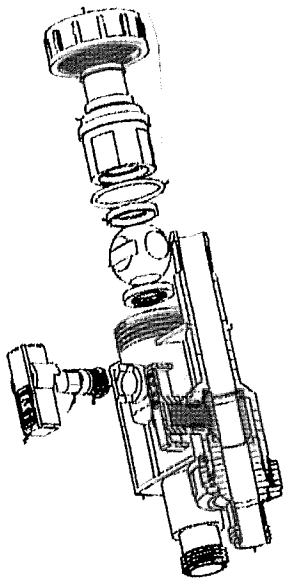


FIG. 105

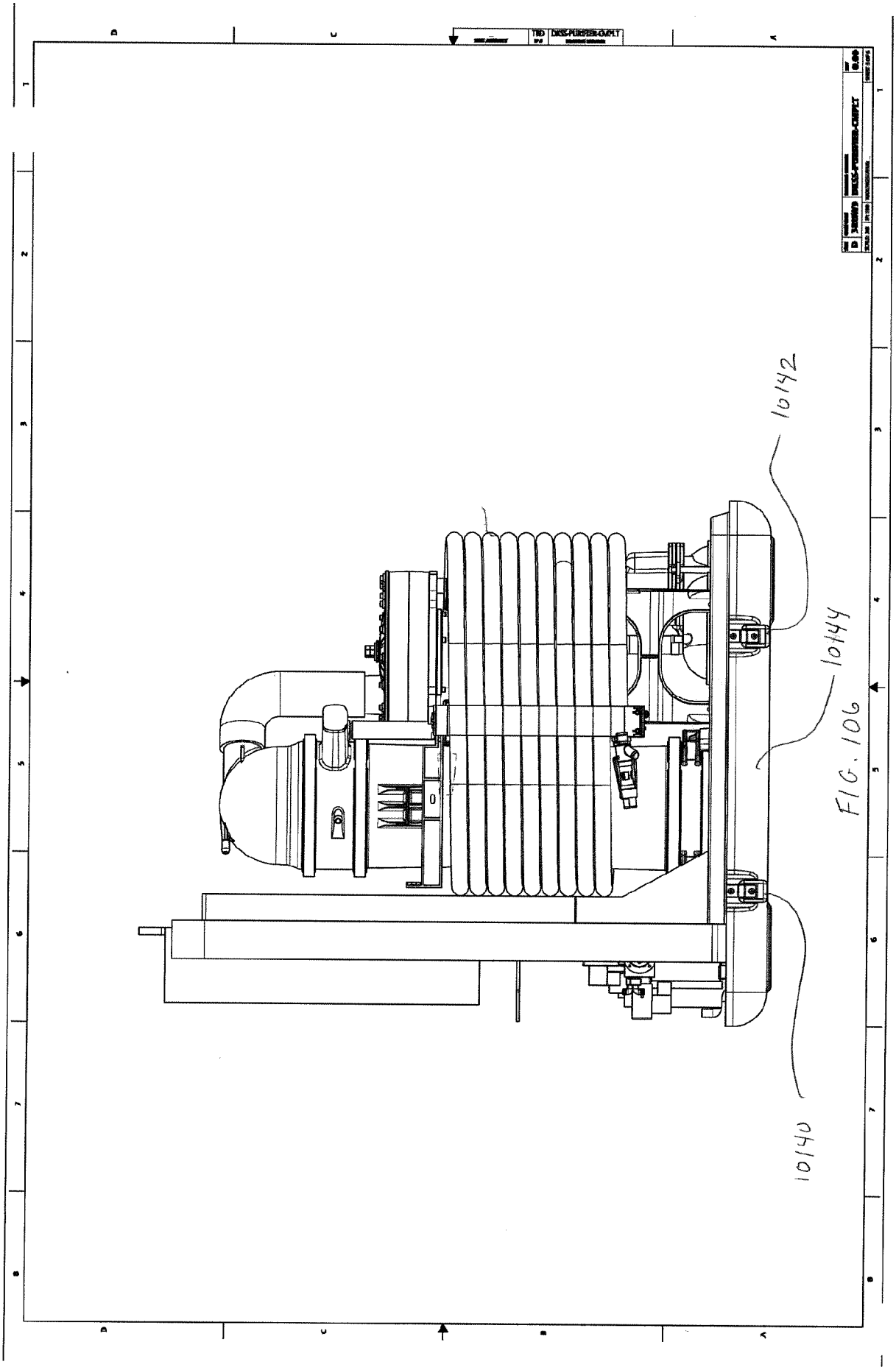



FIG. 106

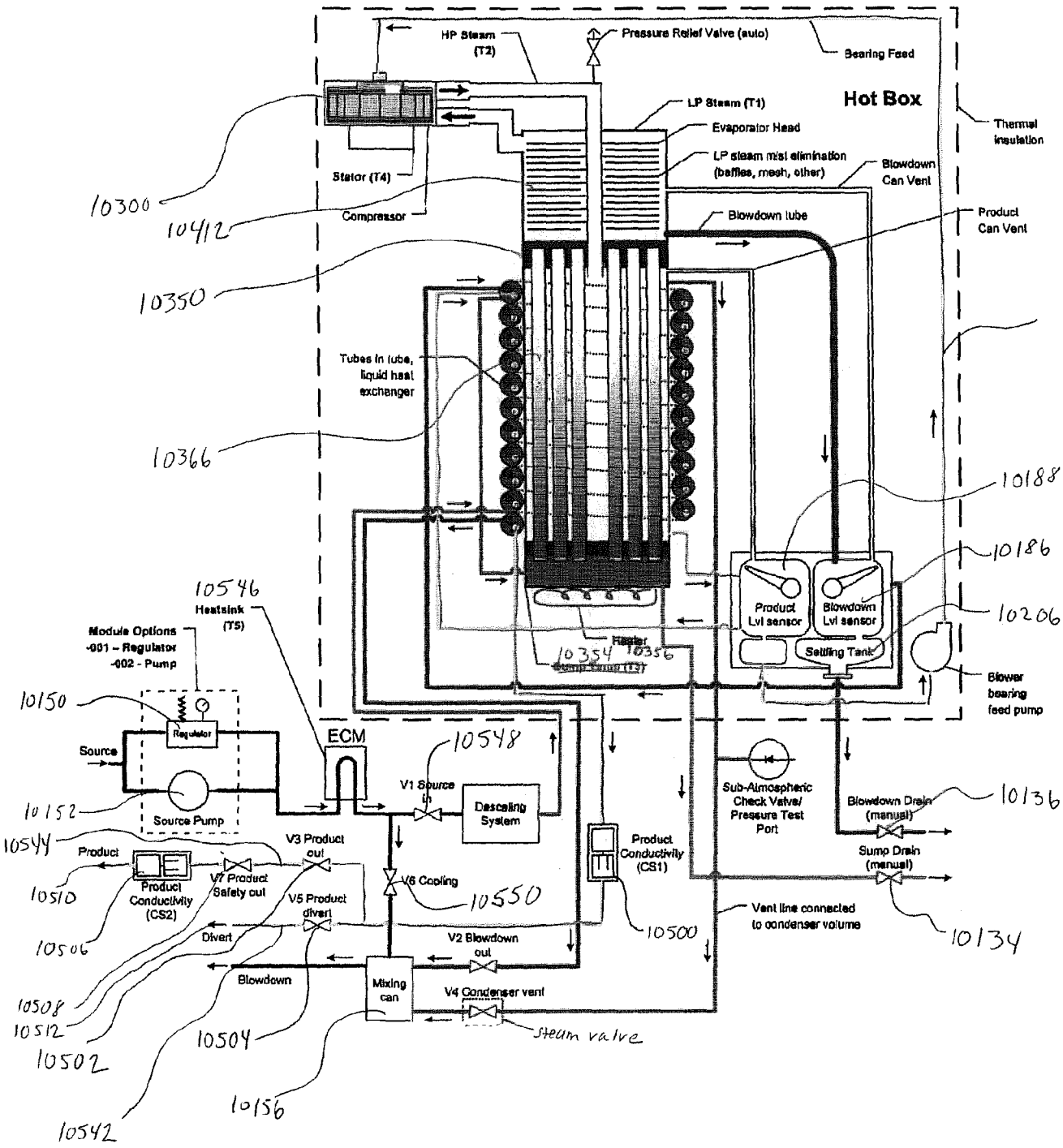

HP Steam (T2)
Pressure Relief Valve (auto)
Bearing Feed
Hot Box
LP Steam (T1)
Evaporator Head
LP steam mist elimination (baffles, mesh, other)
Blowdown Can Vent
Thermal insulation
Stator (T4)
Compressor
Blowdown tube
Product Can Vent
10300
10412
10350
Tubes in tube, liquid heat exchanger
10366
10188
10186
10206
Product Lvl sensor
Blowdown Lvl sensor
Settling Tank
Heater
10354
10356
Blower bearing feed pump
10546
Heatsink (T5)
Module Options
-001 – Regulator
-002 - Pump
10150
Regulator
Source
ECM
10548
V1 Source In
Descaling System
10152
Source Pump
10544
Product
V3 Product out
V7 Product Safety out
Product Conductivity (CS2)
10510
10506
V5 Product divert
V6 Cooling
10550
Divert
V2 Blowdown out
Blowdown
Mixing can
V4 Condenser vent
steam valve
10508
10512
10502
10504
10156
10542
Sub-Atmospheric Check Valve/ Pressure Test Port
Blowdown Drain (manual)
10136
Sump Drain (manual)
Product Conductivity (CS1)
10500
Vent line connected to condenser volume
10134

FIG. 107

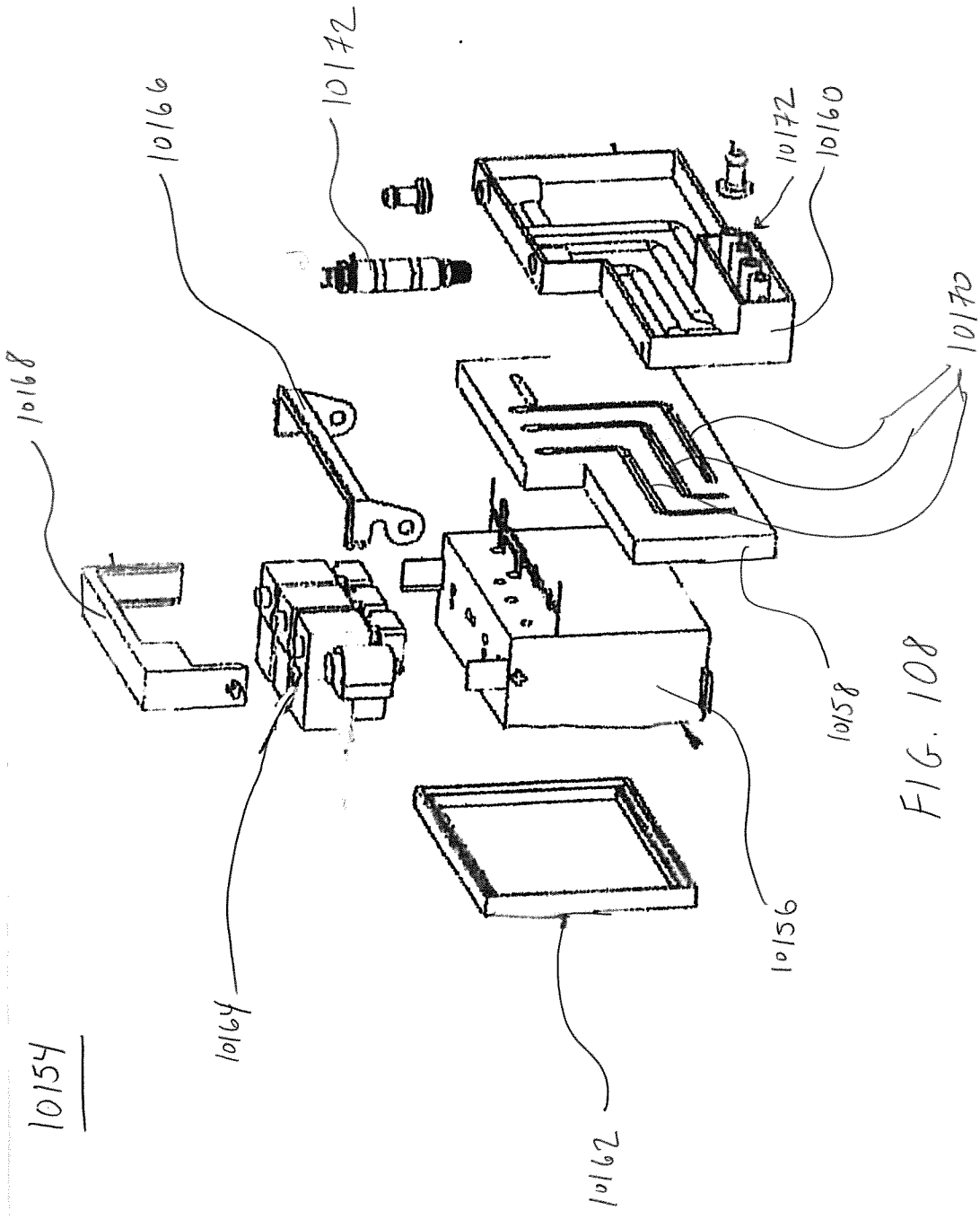

10154
10156
10158
10160
10162
10164
10166
10168
10170
10172
10172

FIG. 108

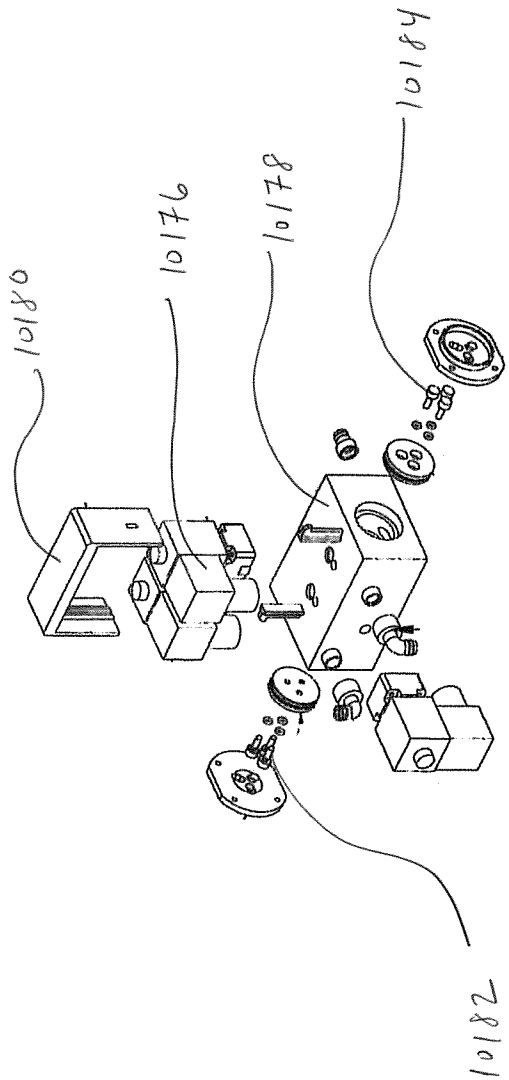



FIG. 109

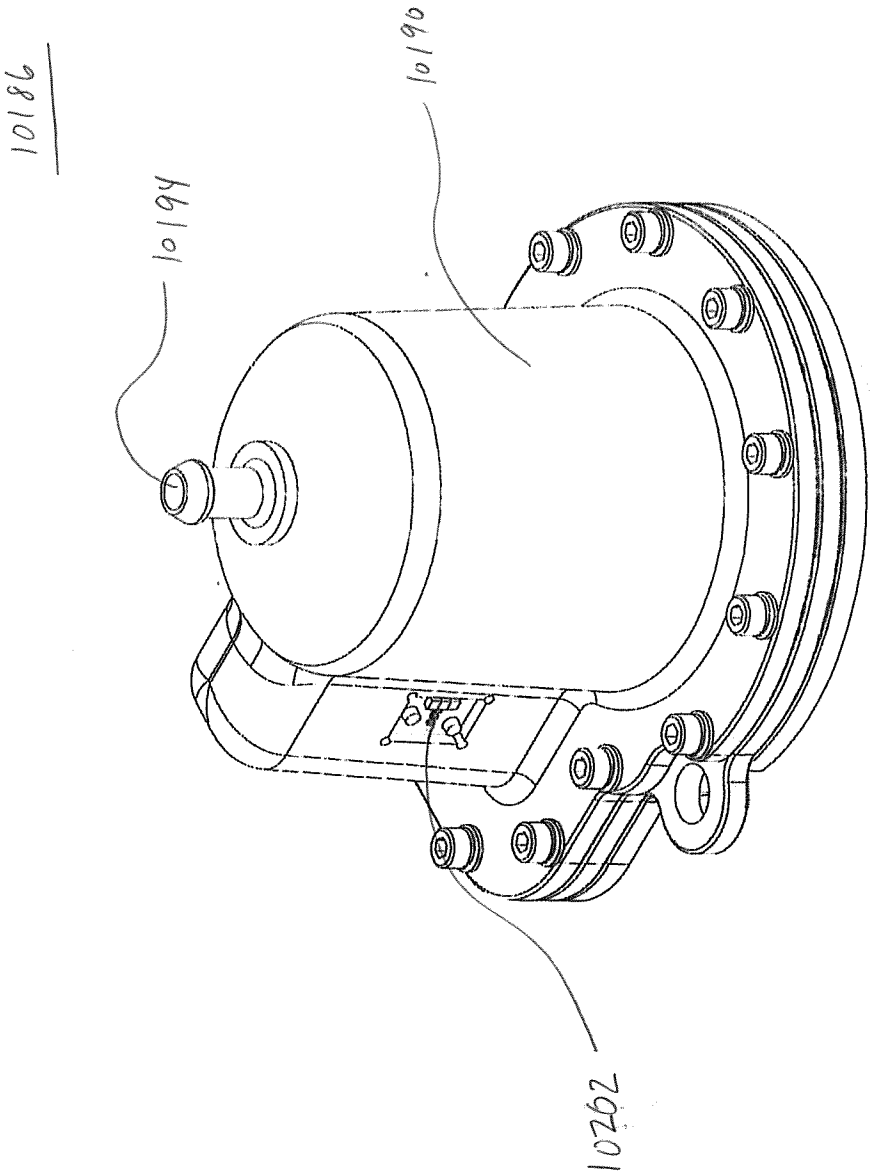



FIG. 110

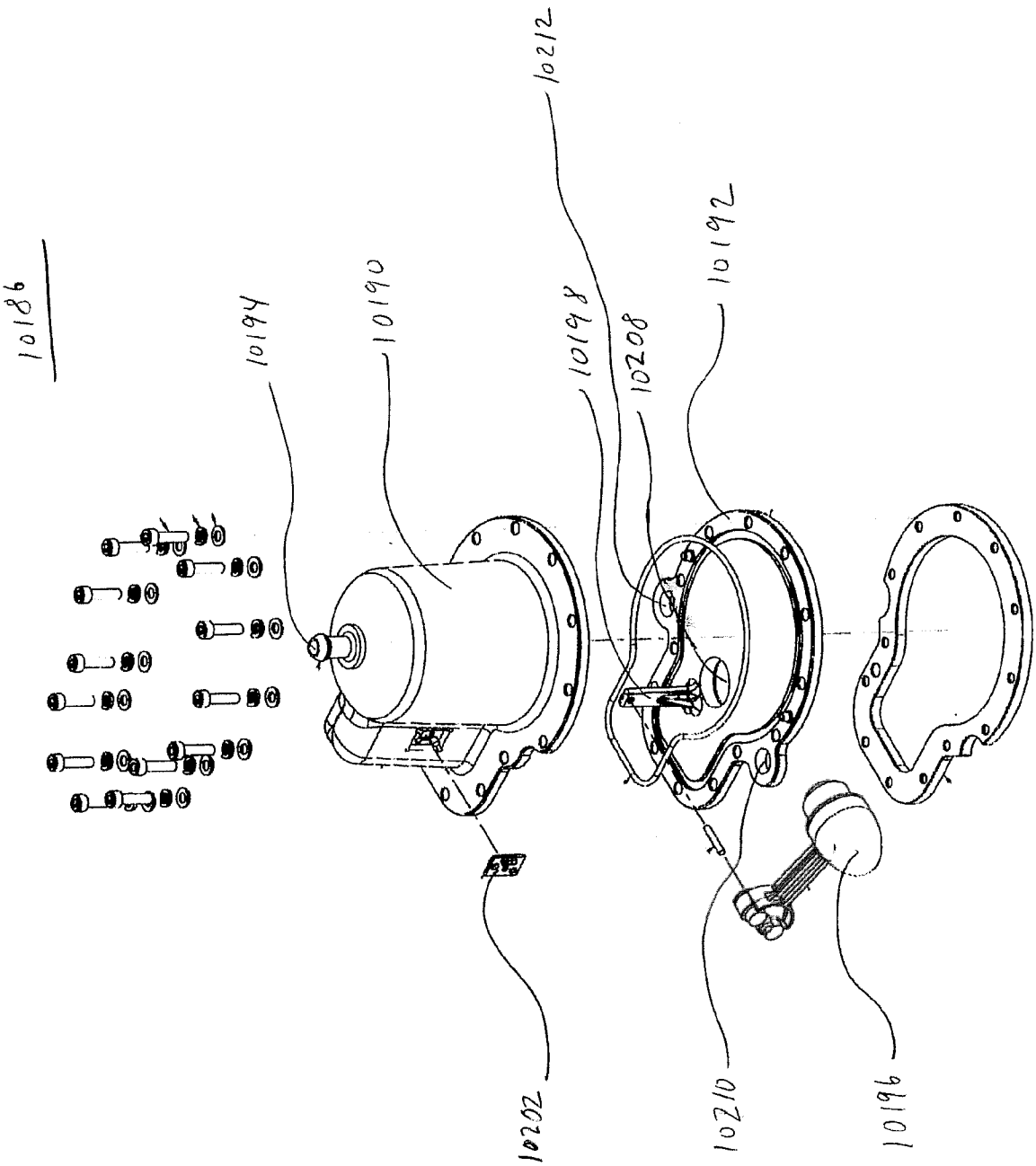

10186
10194
10190
10212
10198
10208
10192
10202
10210
10196

FIG. 111

10186

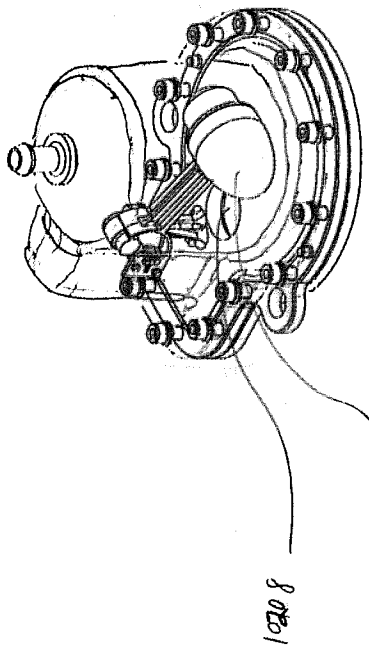



FIG. 112

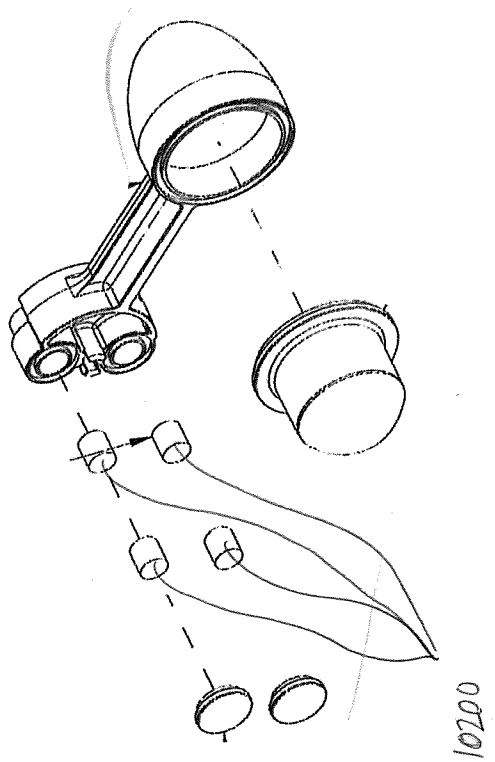



FIG. 113

10214

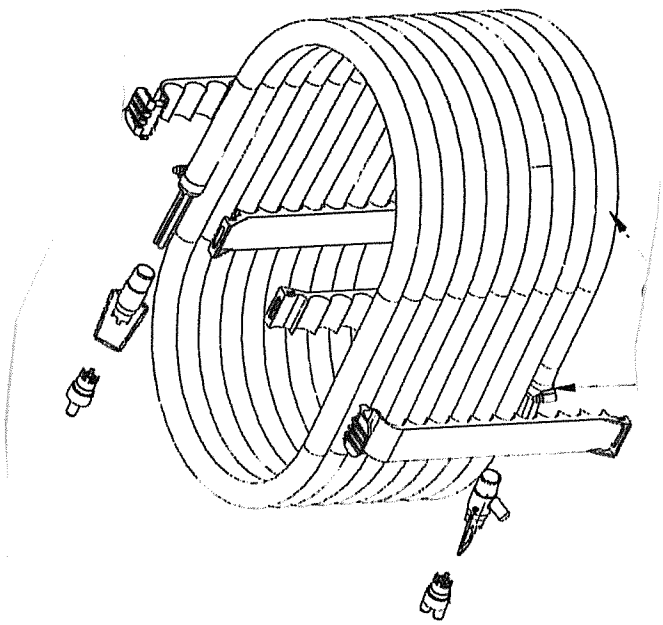


FIG. 114

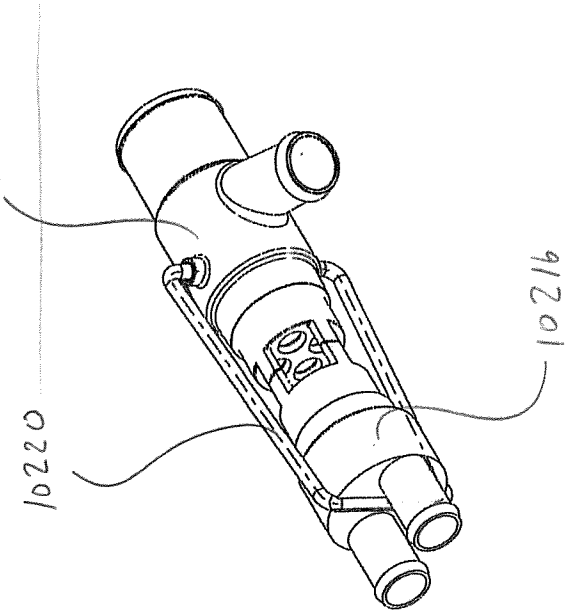



FIG. 115B

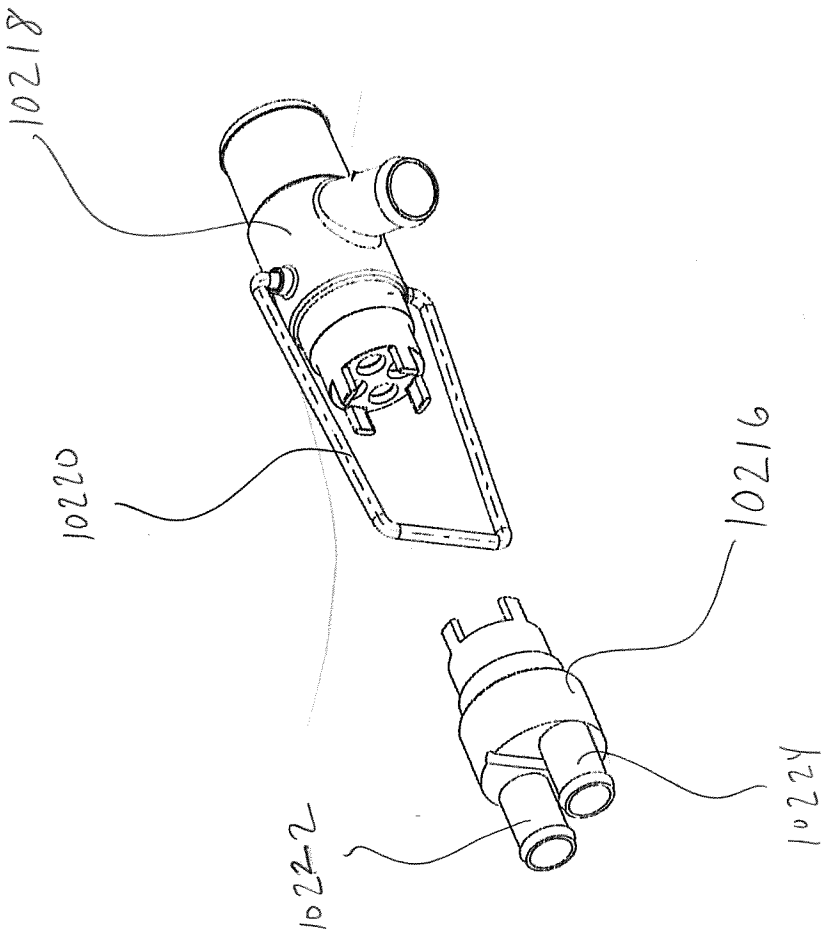



FIG. 115A

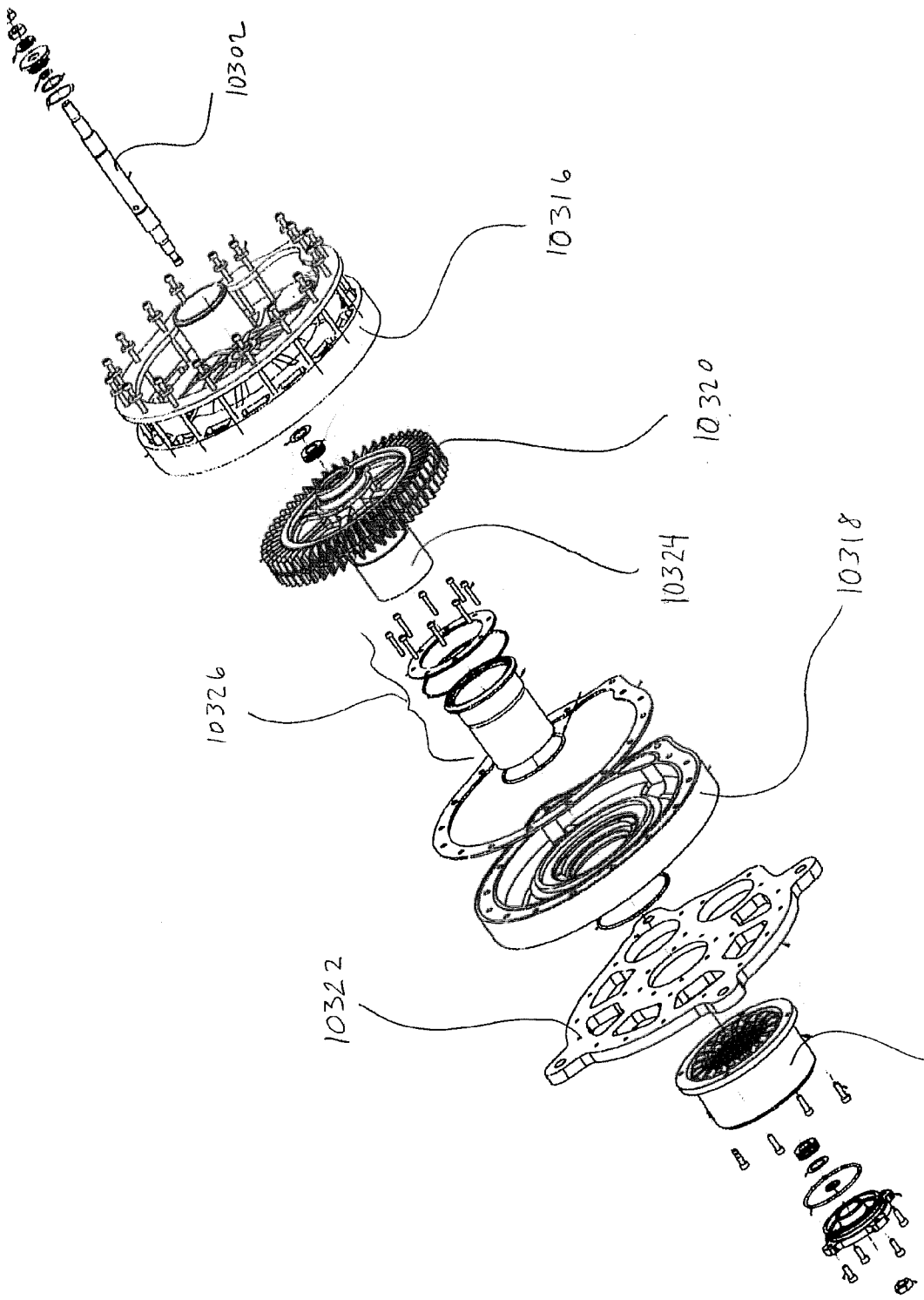



FIG. 116

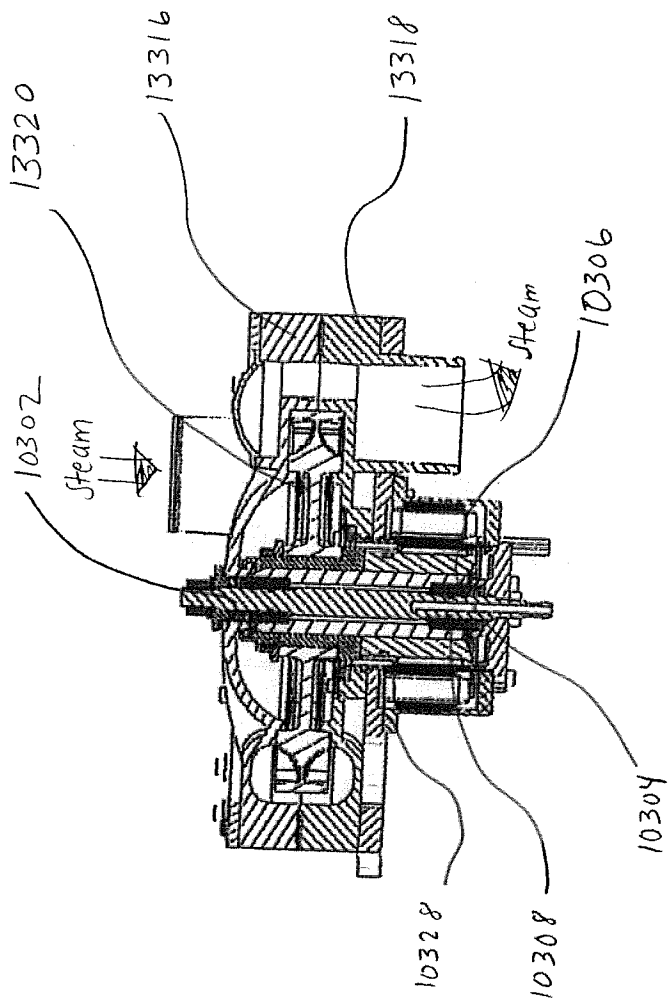

13320
13316
13318
10306
steam
steam
10302
10304
10308
10328

FIG. 117

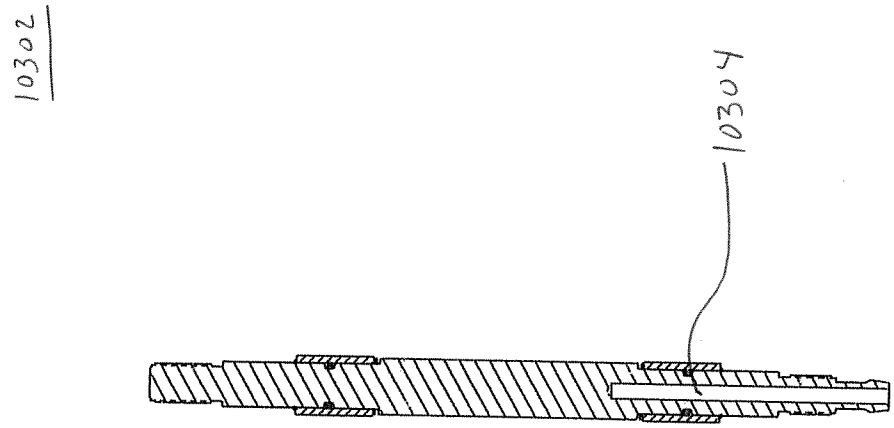



FIG. 118B

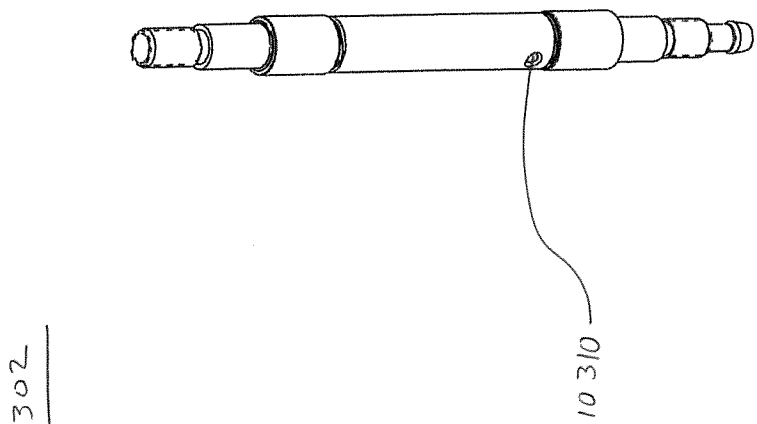



FIG. 118A

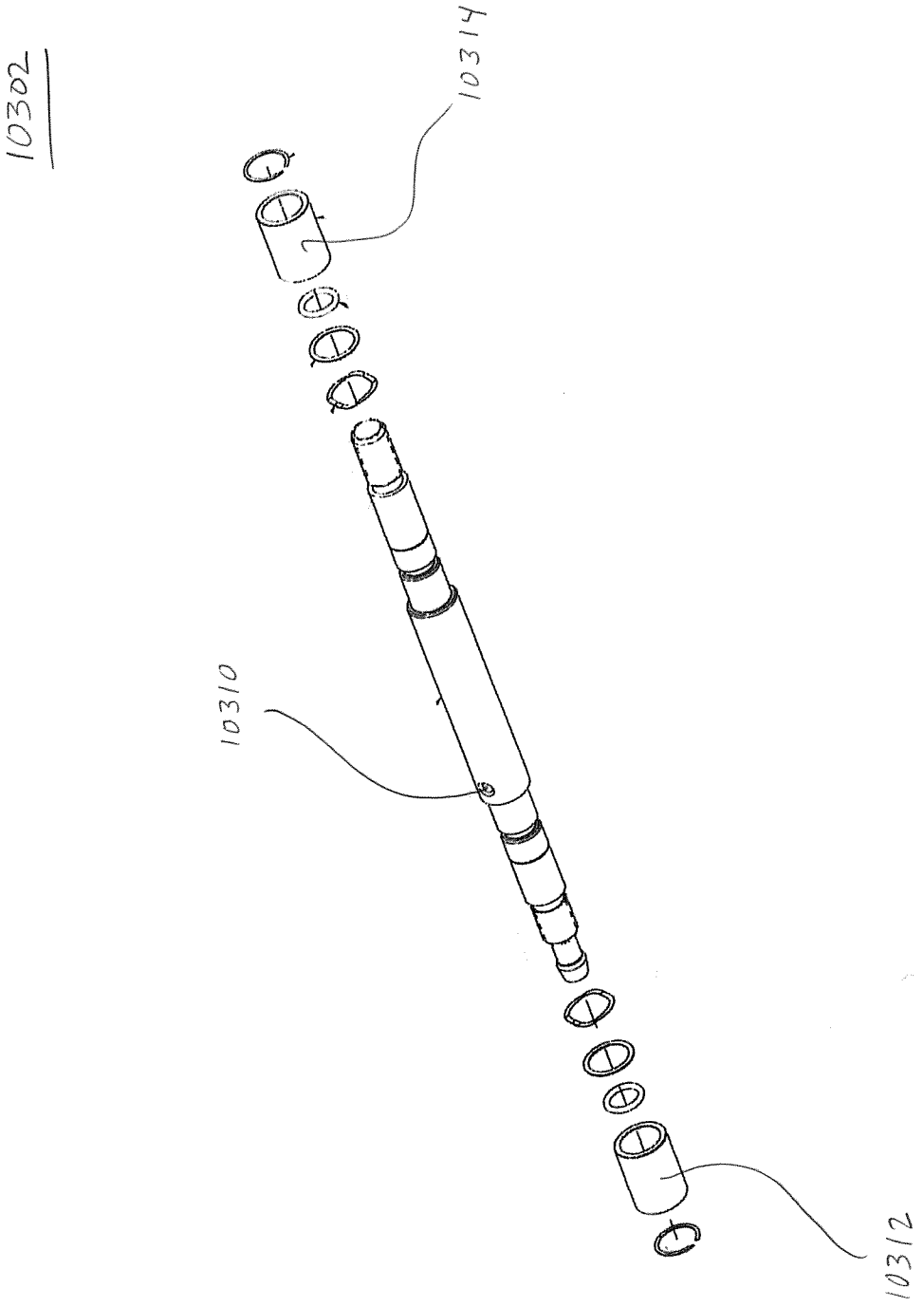



FIG. 119

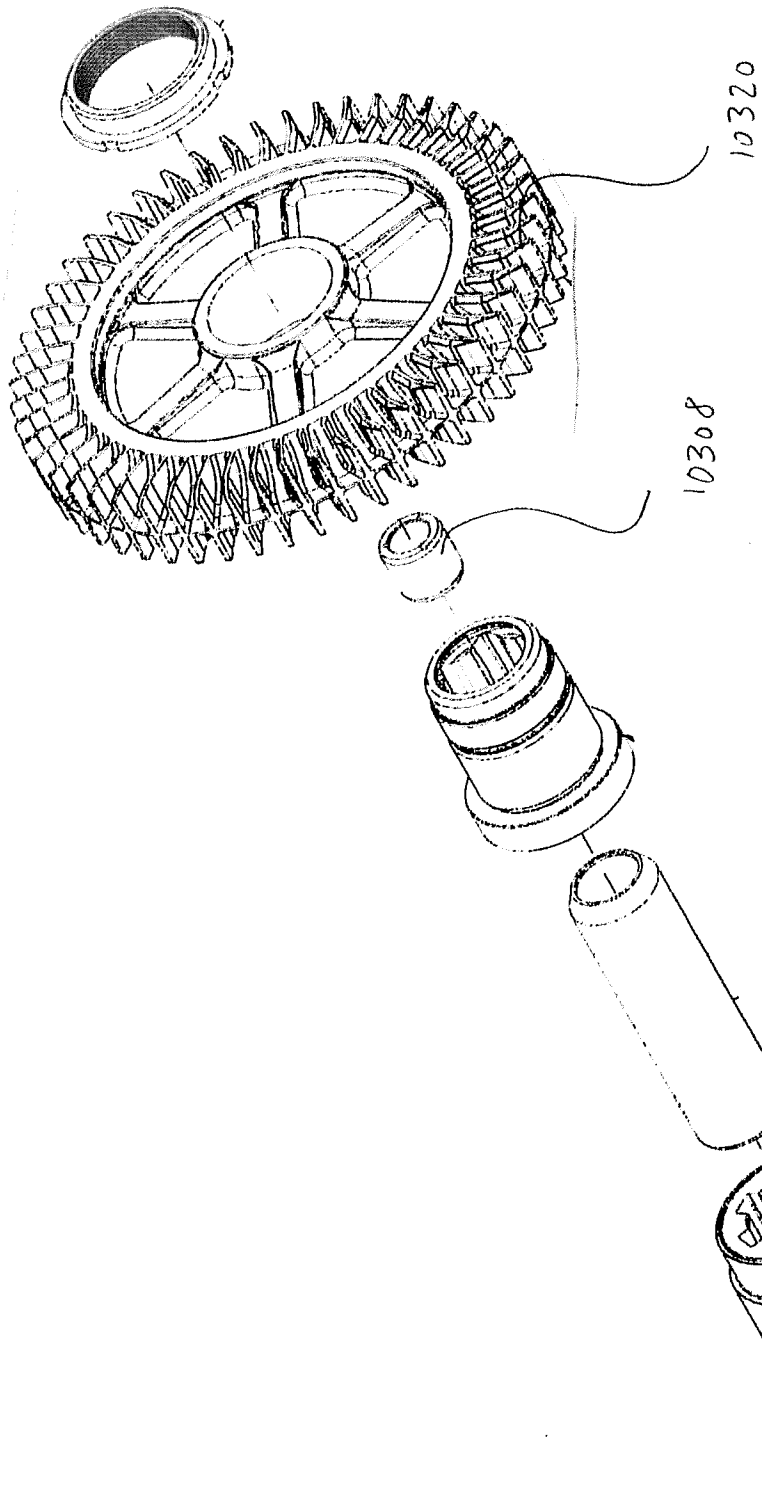



FIG. 120

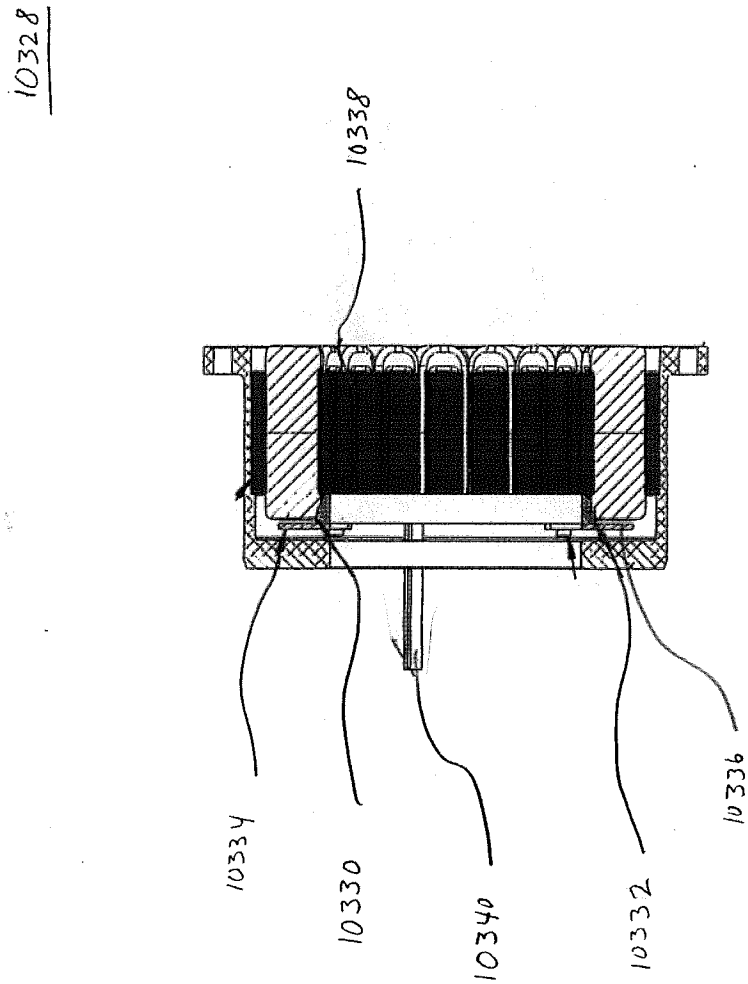



FIG. 12I

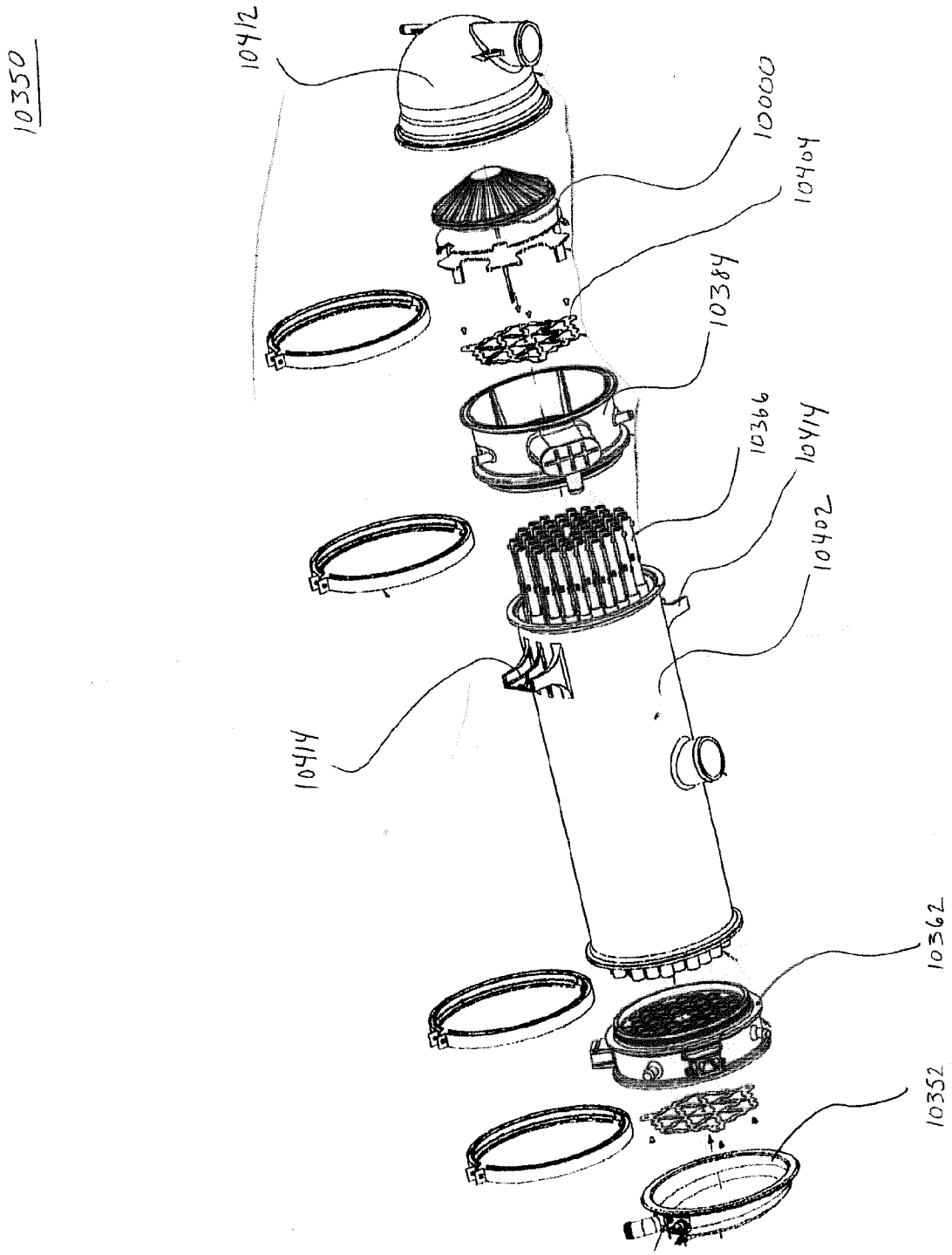

10350
10412
10000
10404
10384
10366
10414
10402
10414
10362
10352

FIG. 122

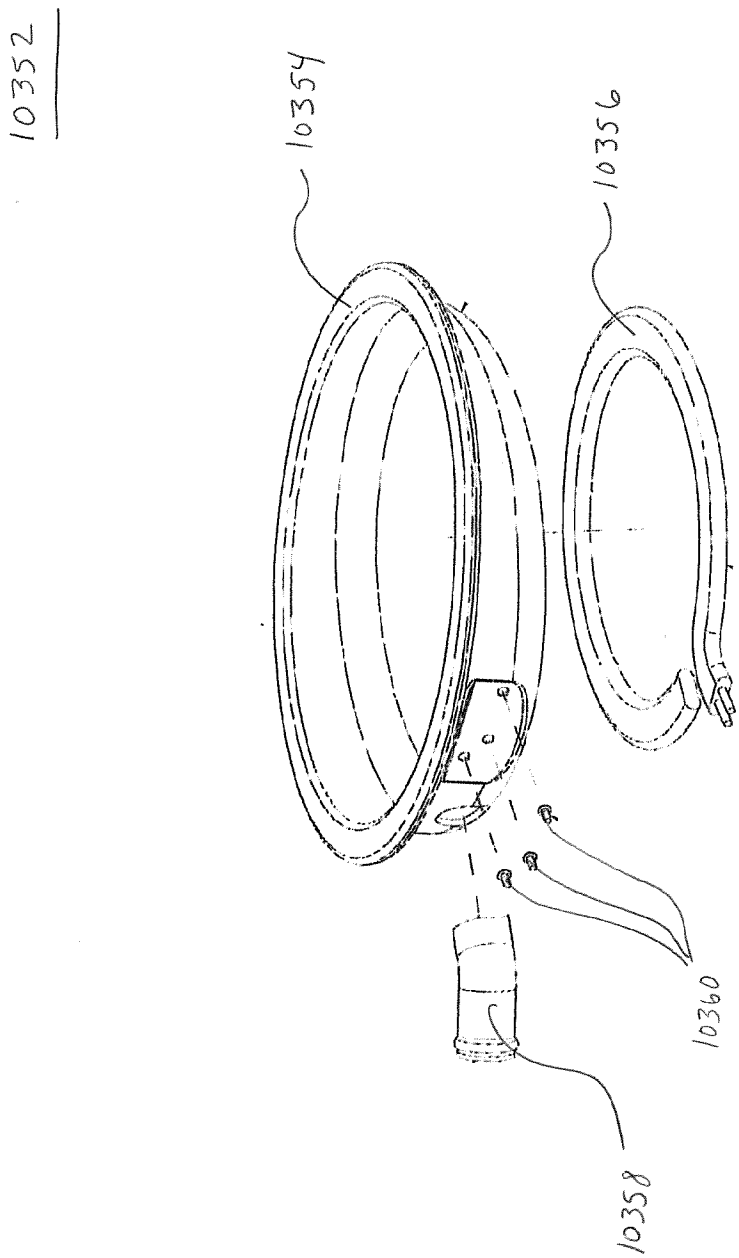



FIG. 123

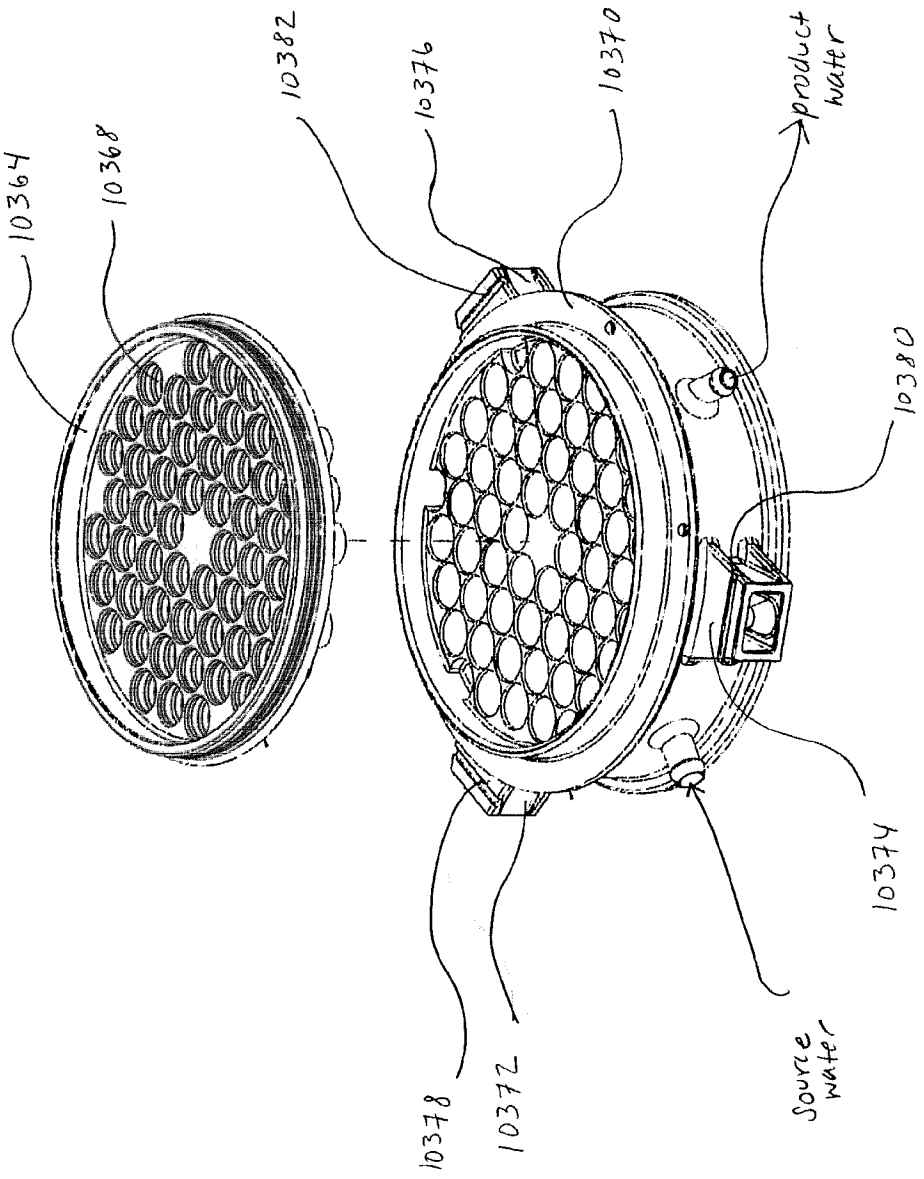

10362
10364
10368
10382
10376
10370
product water
10380
10374
source water
10372
10378

FIG. 124.

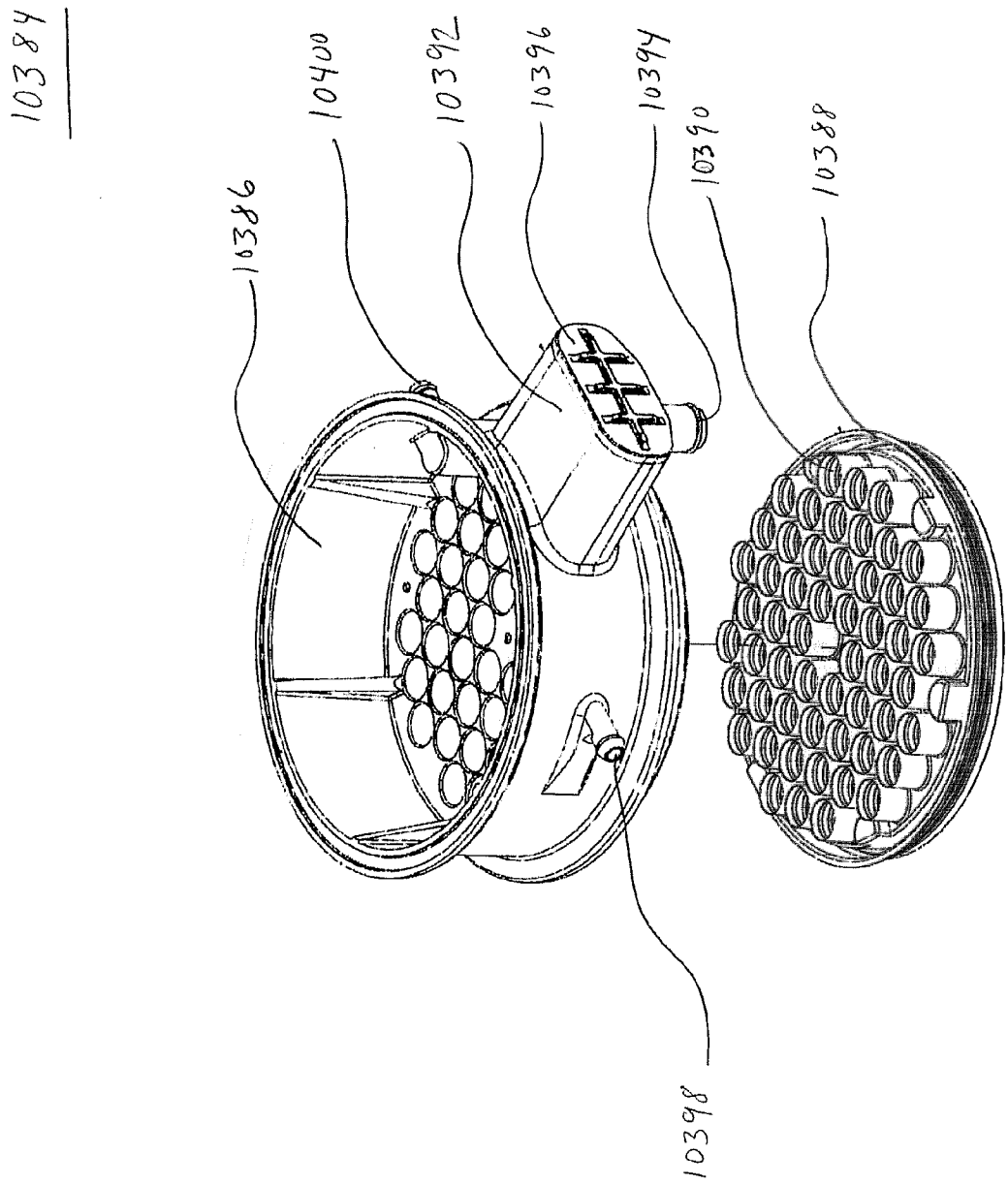



FIG. 12SA

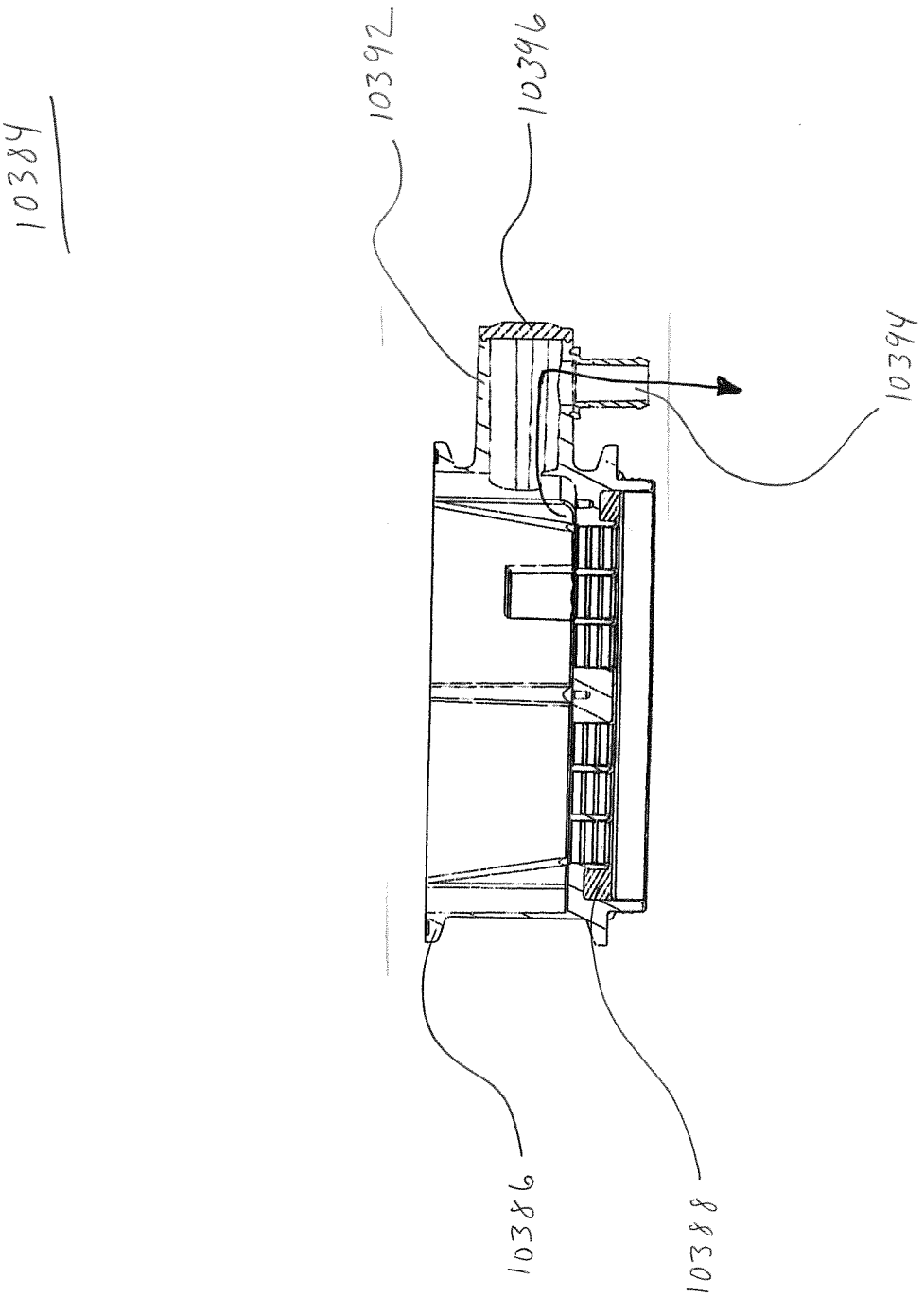



FIG. 125B

10350

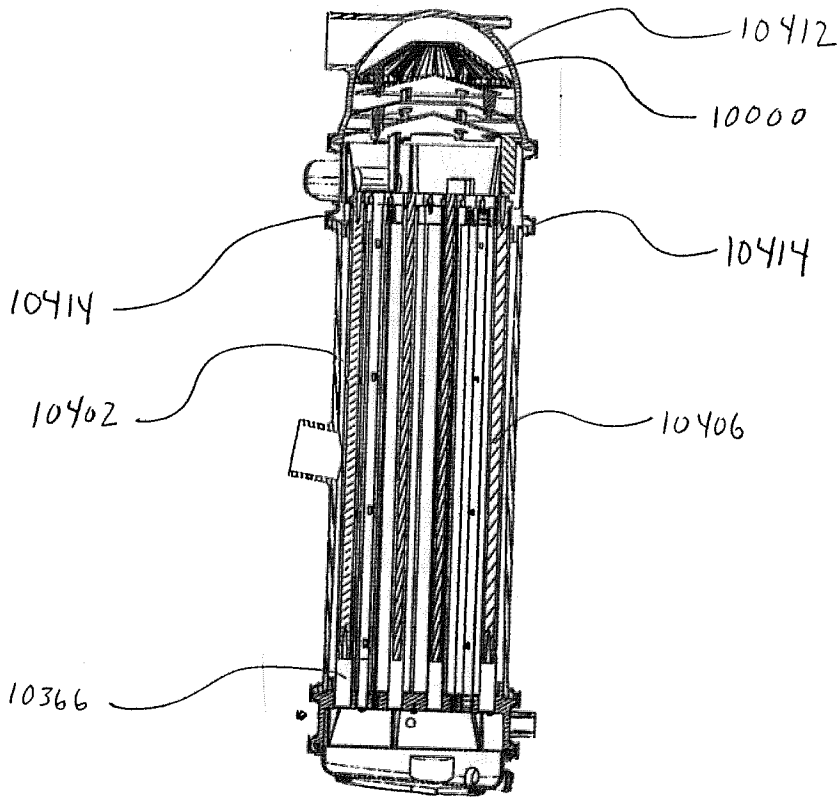



FIG. 126

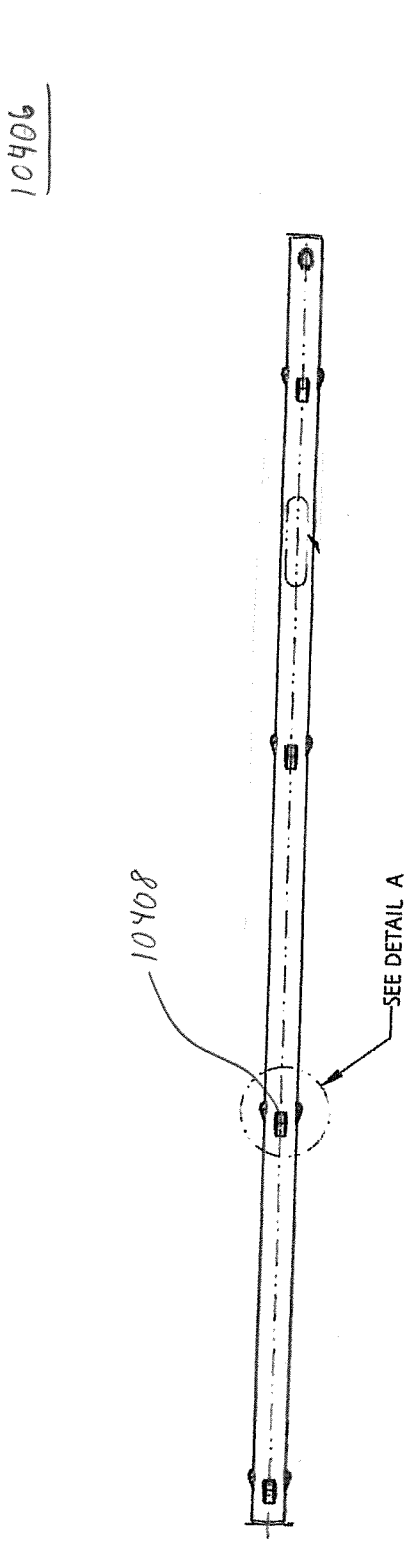



FIG. 127A

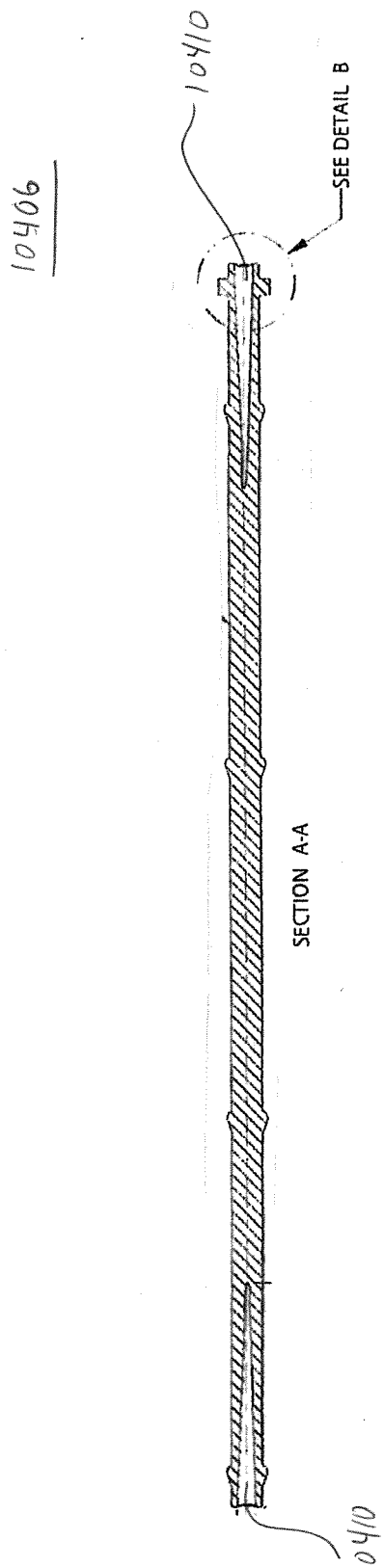



FIG. 127B

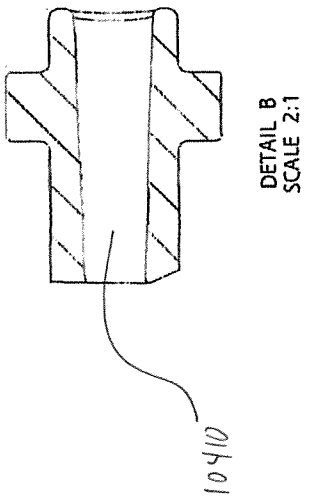



FIG. 128B

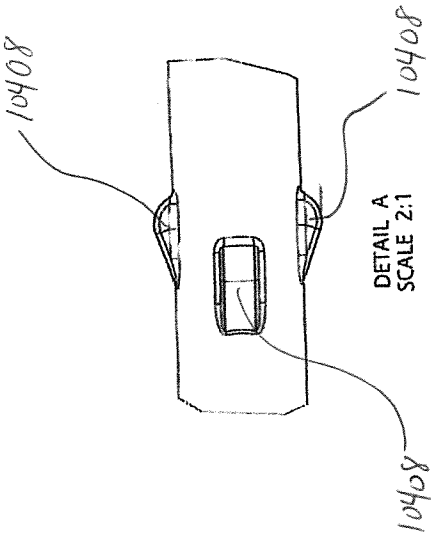



FIG. 128A

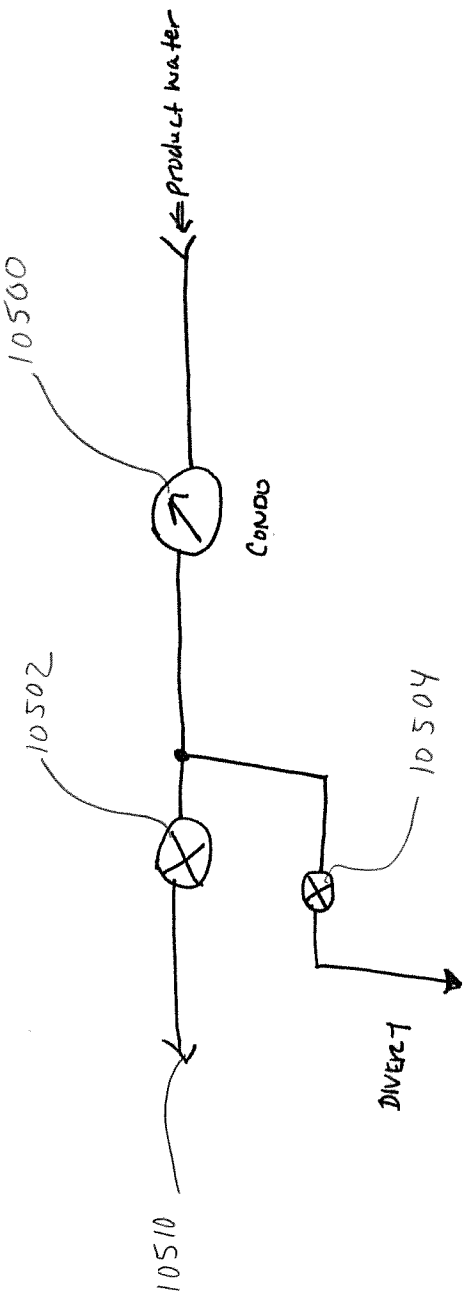



FIG. 129

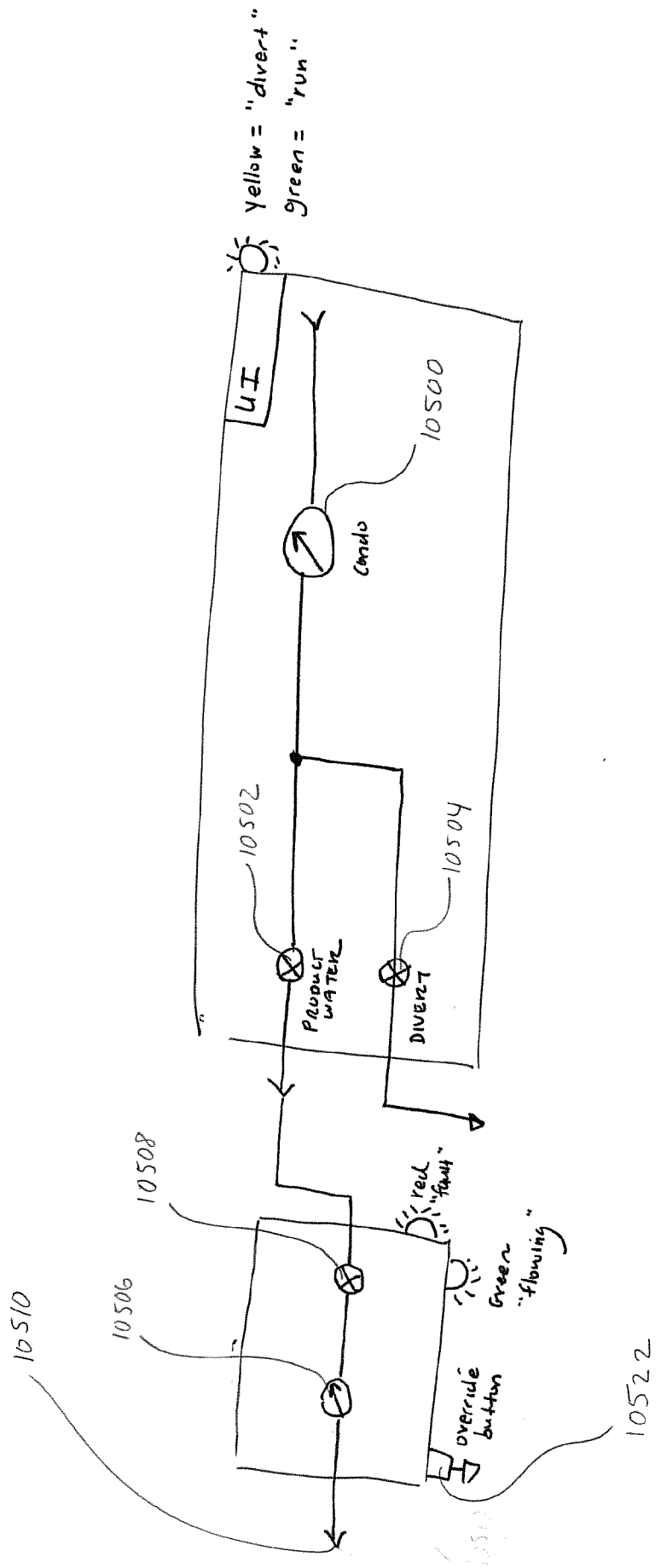

Yellow = "divert"
Green = "run"
UI
10500
Condo
10502
10504
PRIORITY WATER
DIVERT
10508
red "fault"
green "flowing"
10506
10510
override button
10522

FIG. 130

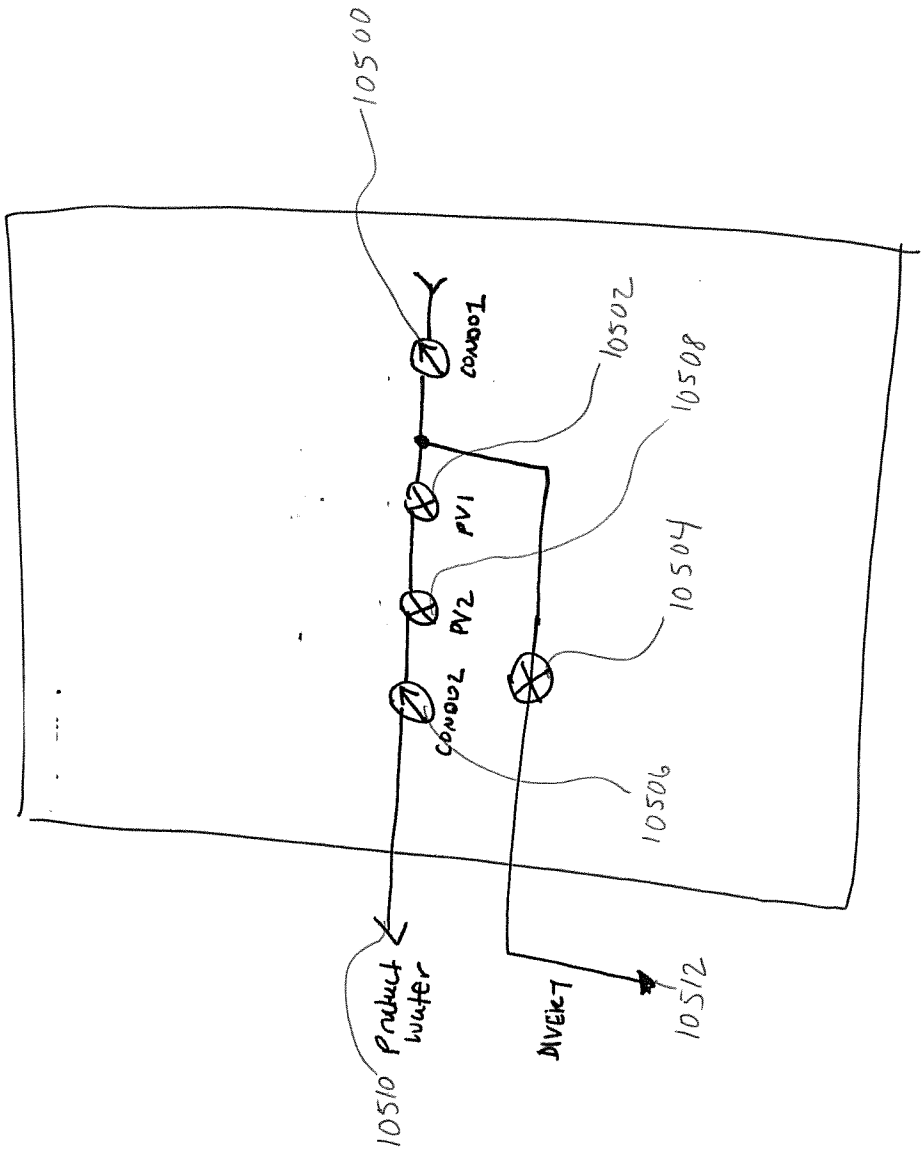

10500
CONDO1
10502
10508
PV1
PV2
10504
CONDO2
10506
Product water
DIVERT
10512
10510

FIG. 131

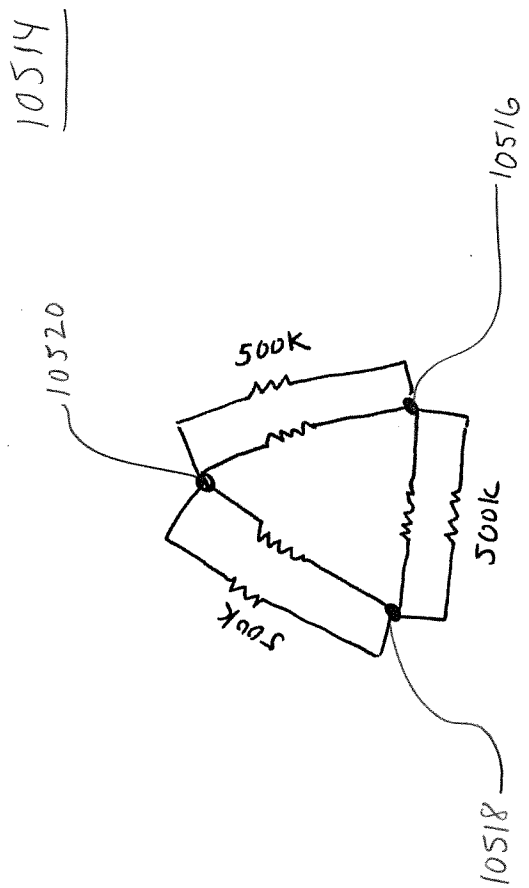

10514
10520
500K
10516
500K
500K
10518
Compare resistance
any resistance < threshold = FAULT

FIG. 132

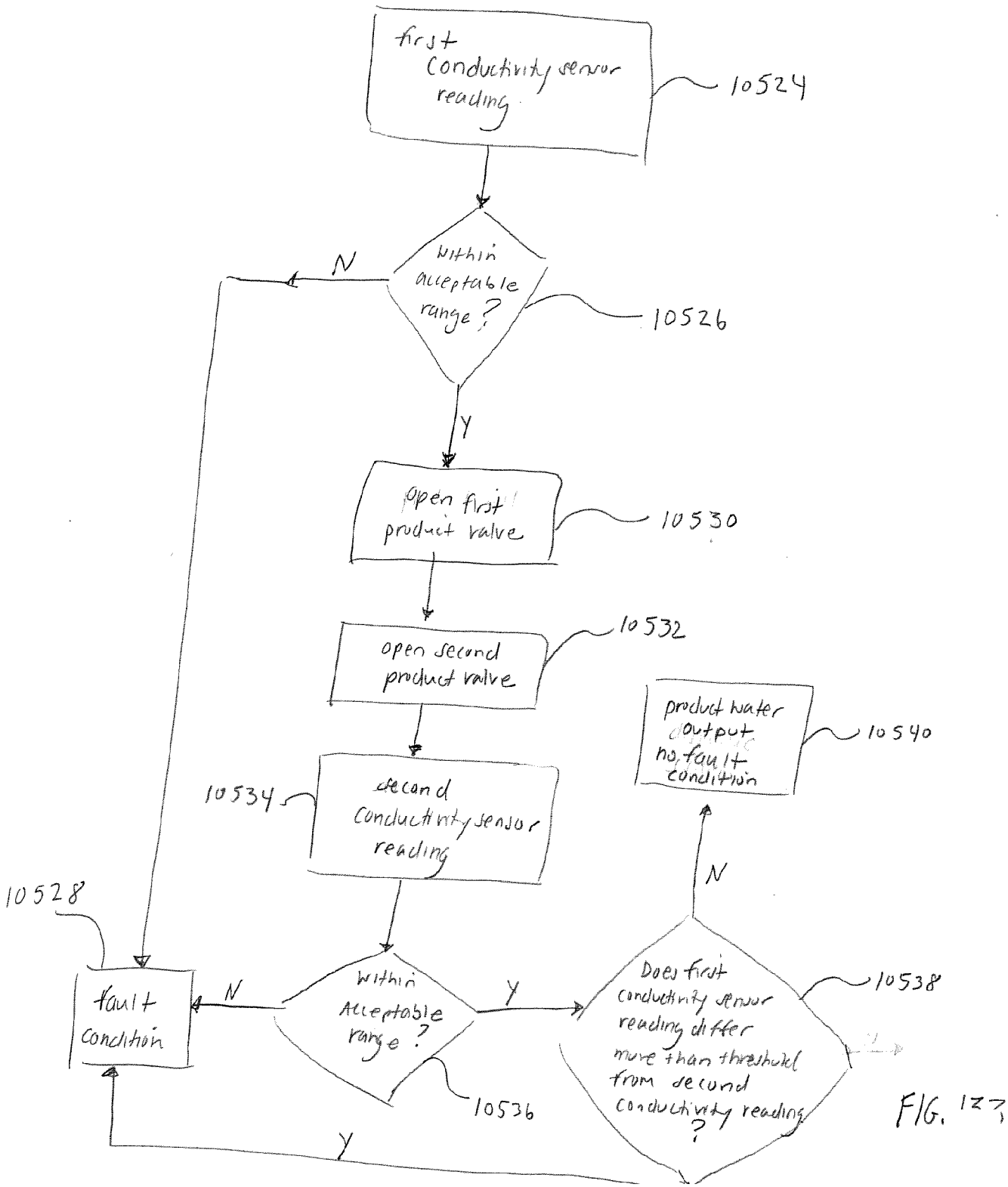

first Conductivity sensor reading
10524
within acceptable range?
10526
N
Y
open first product valve
10530
open second product valve
10532
second Conductivity sensor reading
10534
product water output no fault condition
10540
10528
fault condition
within Acceptable range?
10536
Does first conductivity sensor reading differ more than threshold from second conductivity reading?
10538
N
Y
Y

FIG. 127

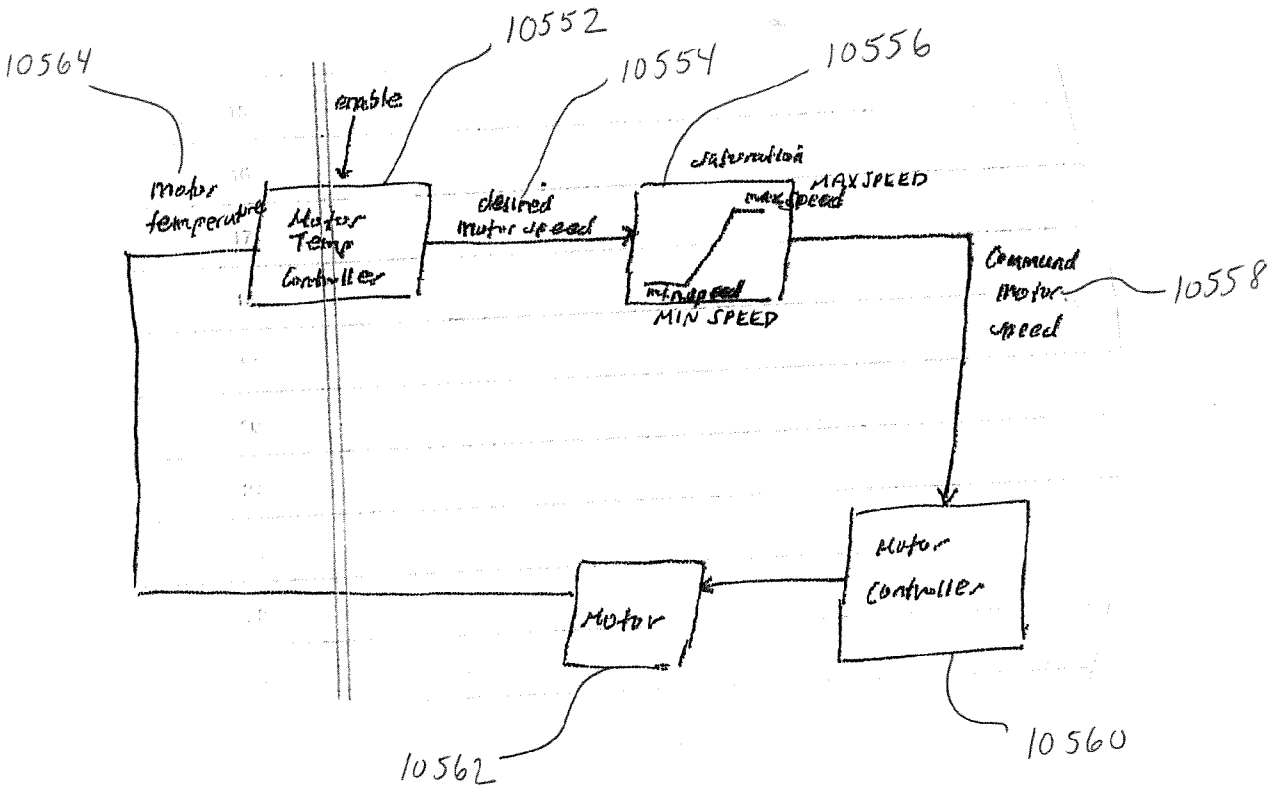

10564
10552
10554
10556
enable
motor temperature
Motor Temp Controller
desired motor speed
saturation
MAX SPEED
max speed
min speed
MIN SPEED
Command Motor speed
10558
Motor Controller
Motor
10562
10560

FIG. 134

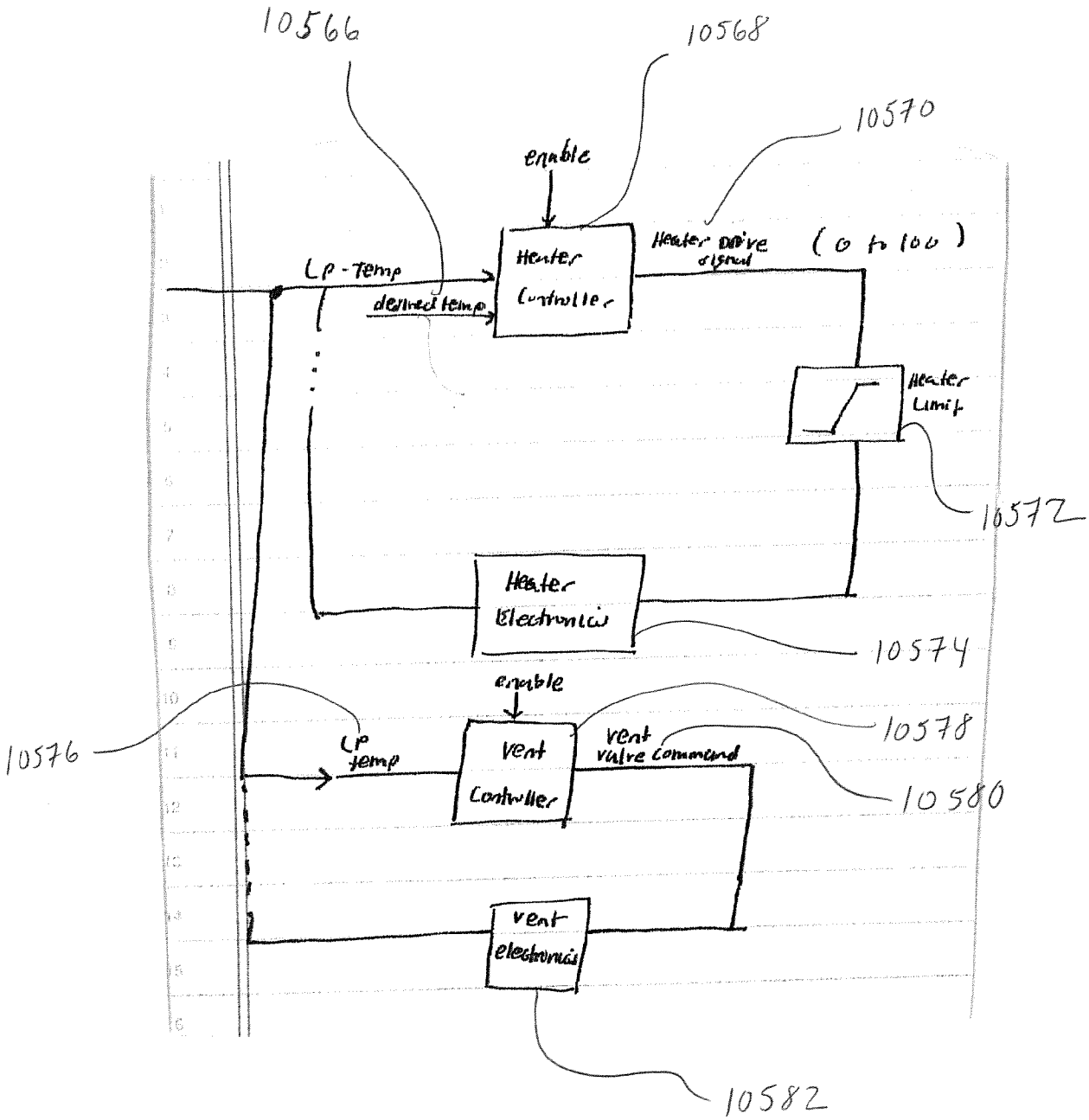

10566
10568
10570
enable
Heater Drive signal
(0 to 100)
Lp - Temp
desired temp
Heater Controller
Heater Limit
10572
Heater Electronics
10574
enable
10576
Lp temp
Vent Controller
vent valve command
10578
10580
vent electronics
10582

FIG. 135

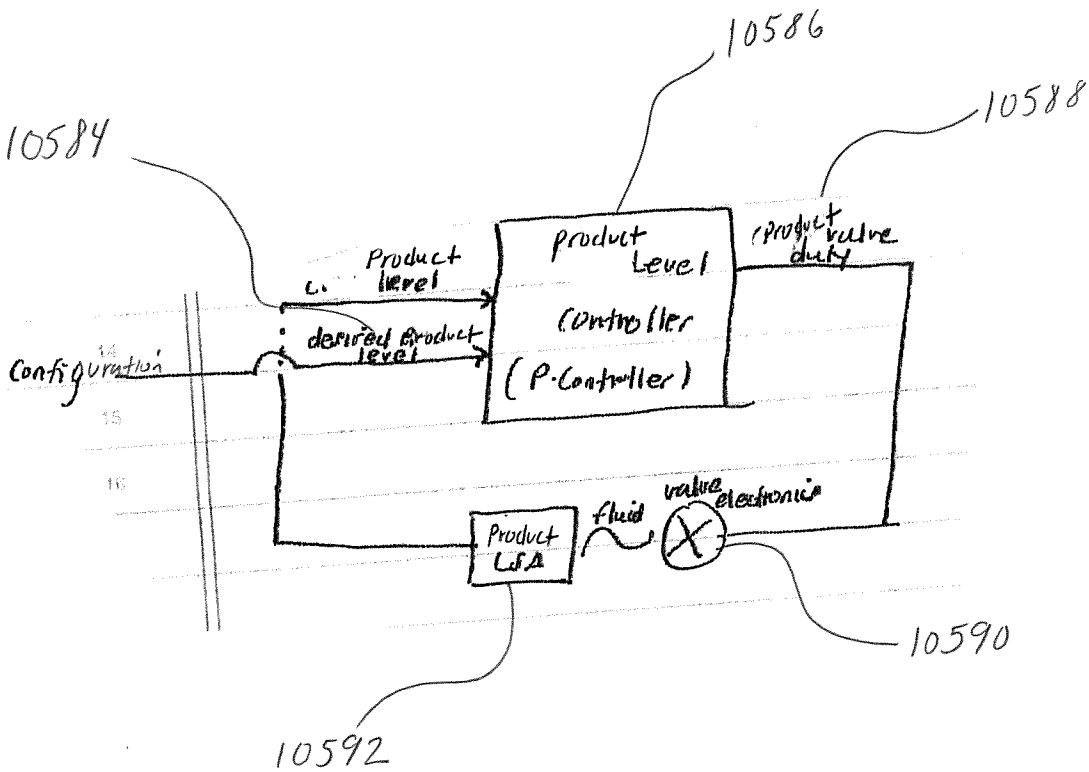

10586
10588
10584
Product Level
Product valve duty
Product level
desired product level
Configuration
Product Level Controller (P-Controller)
valve electronics
fluid
Product LOA
10590
10592

FIG. 136

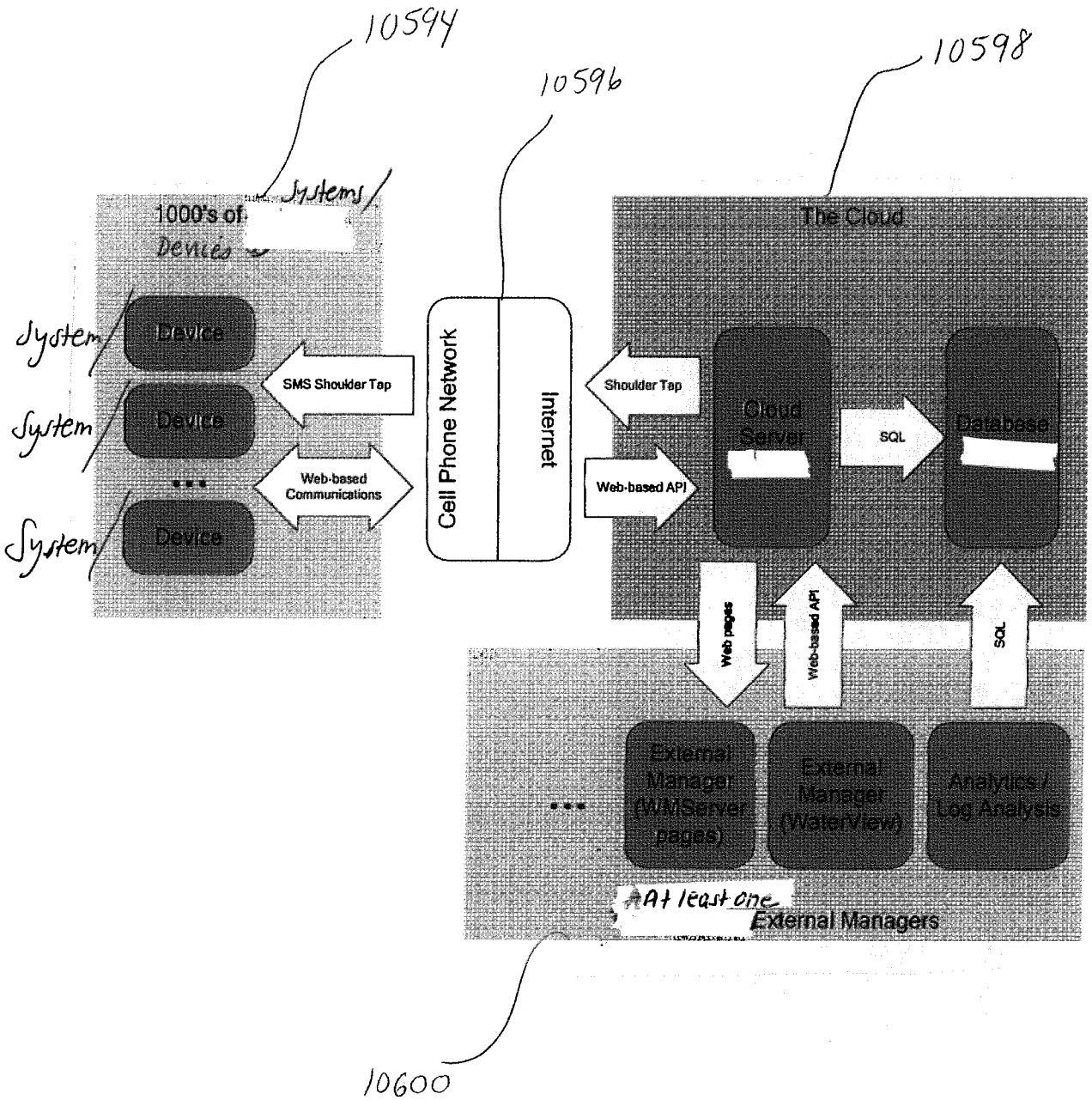

10594
10596
10598
1000's of Systems
Devices
System
Device
System
Device
System
Device
SMS Shoulder Tap
Web-based Communications
Cell Phone Network
Internet
Shoulder Tap
Web-based API
The Cloud
Cloud Server
SQL
Database
Web pages
Web-based API
SQL
External Manager (WMServer pages)
External Manager (WaterView)
Analytics / Log Analysis
At least one External Managers
10600

FIG. 137

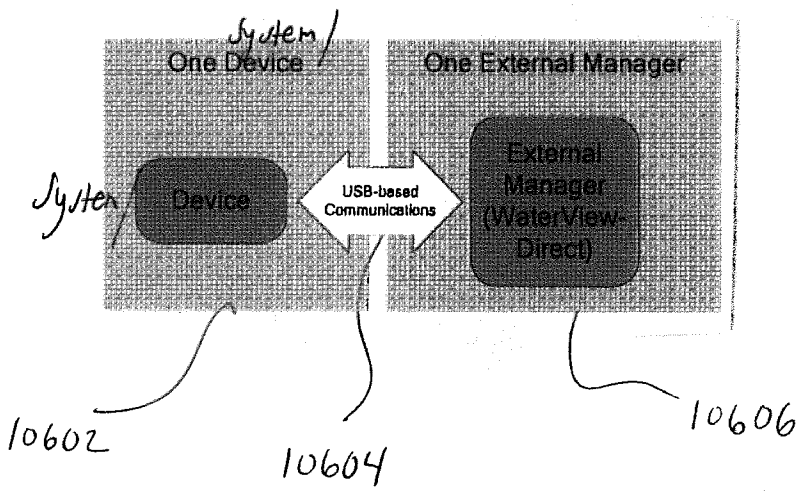

System
One Device
One External Manager
System
Device
USB-based Communications
External Manager (WaterView-Direct)
10602
10604
10606

FIG. 138

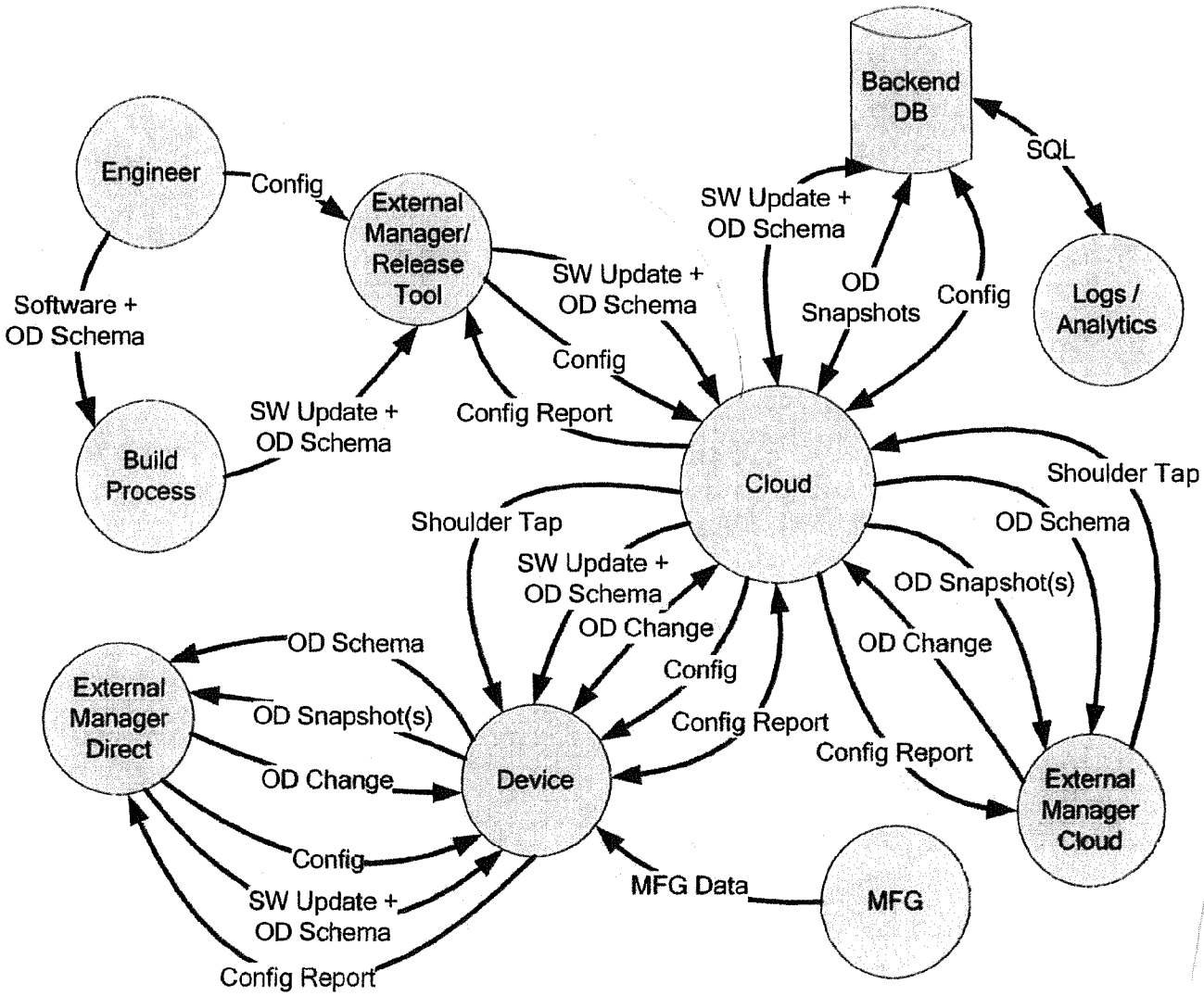

Backend DB
SQL
Engineer
Config
External Manager/ Release Tool
SW Update + OD Schema
OD Snapshots
Config
Logs / Analytics
Software + OD Schema
SW Update + OD Schema
Config
Build Process
SW Update + OD Schema
Config Report
Cloud
Shoulder Tap
Shoulder Tap
OD Schema
SW Update + OD Schema
OD Snapshot(s)
OD Change
OD Schema
Config
OD Change
External Manager Direct
OD Snapshot(s)
Config Report
Config Report
External Manager Cloud
OD Change
Device
Config
SW Update + OD Schema
MFG Data
MFG
Config Report

FIG. 13.9

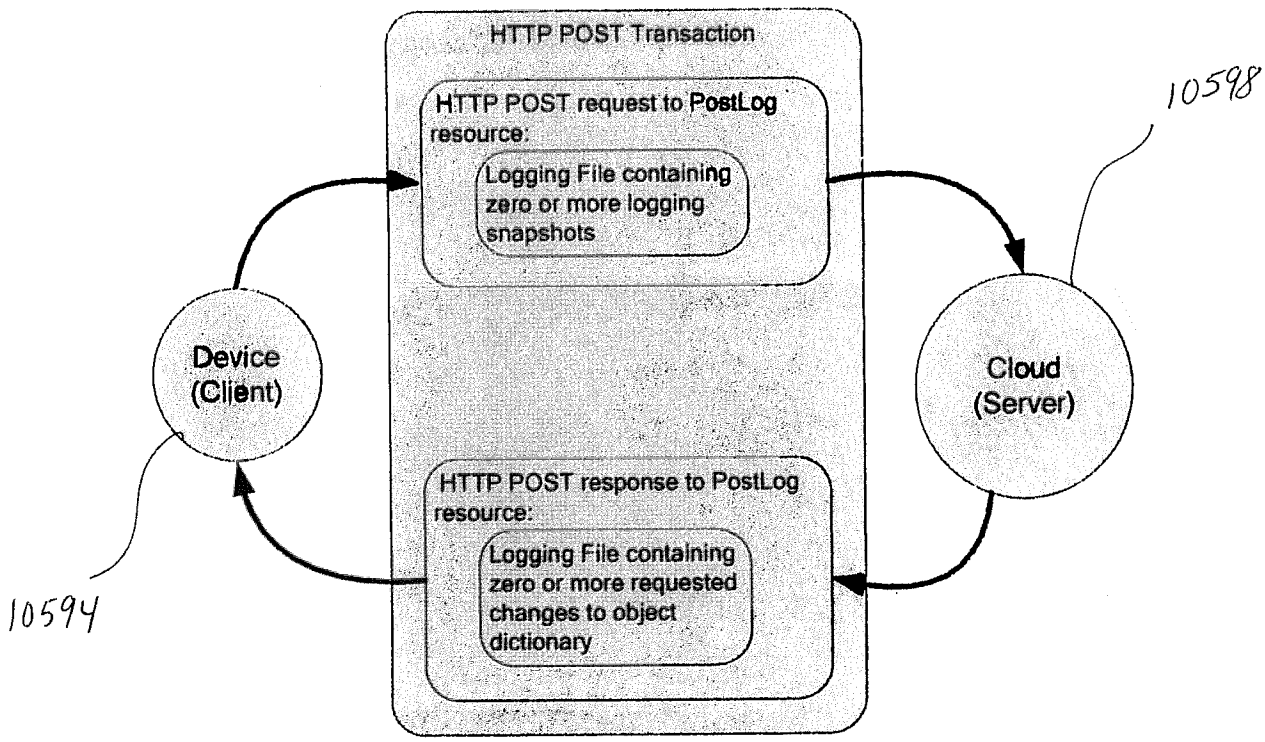

HTTP POST Transaction
HTTP POST request to PostLog resource:
Logging File containing zero or more logging snapshots
HTTP POST response to PostLog resource:
Logging File containing zero or more requested changes to object dictionary
Device (Client)
Cloud (Server)
10598
10594

FIG. 140

# INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/052335

A. CLASSIFICATION OF SUBJECT MATTER
INV. C02F1/00 C02F1/04 B01D1/00
ADD.

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)
B01D C02F

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | WO 2008/154435 A2 (DEKA PRODUCTS LP [US]; KAMEN DEAN [US]; LANGENFELD CHRISTOPHER C [US];) 18 December 2008 (2008-12-18)<br>abstract<br>page 57, line 21 - line 29<br>page 62, line 10 - line 20<br>page 112, line 31 - page 113, line 7<br>page 113, line 21 - line 33<br>----- | 1-20 |
| A | WO 2006/029540 A1 (DECTRON [CA])<br>23 March 2006 (2006-03-23)<br>abstract; figures<br>page 5, paragraph 12<br>page 12, paragraph 1036<br>----- | 1-20 |

-/--

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

[X] See patent family annex.

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

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 18 December 2013 | 03/01/2014 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016 | Lapeyrère, Jean |

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

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | US 5 729 987 A (MILLER JOEL V [US])<br>24 March 1998 (1998-03-24)<br>abstract; figures<br>column 4, line 30 - line 34<br>column 4, line 45 - line 55<br>----- | 1-20 |
| A | US 4 428 328 A (RATLIFF RICHARD L [US])<br>31 January 1984 (1984-01-31)<br>abstract; figures<br>column 3, line 40 - column 4, line 15<br>column 5, line 1 - line 11<br>column 5, line 34 - line 40<br>----- | 1-20 |

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2013/052335

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| WO 2008154435 A2 | 18-12-2008 | CA 2689931 A1 | 18-12-2008 |
| | | CN 101765563 A | 30-06-2010 |
| | | EP 2158161 A2 | 03-03-2010 |
| | | JP 2010528848 A | 26-08-2010 |
| | | KR 20100041747 A | 22-04-2010 |
| | | KR 20130082511 A | 19-07-2013 |
| | | US 2009025399 A1 | 29-01-2009 |
| | | WO 2008154435 A2 | 18-12-2008 |
| WO 2006029540 A1 | 23-03-2006 | CA 2579929 A1 | 23-03-2006 |
| | | US 2006060233 A1 | 23-03-2006 |
| | | US 2009235954 A1 | 24-09-2009 |
| | | WO 2006029540 A1 | 23-03-2006 |
| US 5729987 A | 24-03-1998 | NONE | |
| US 4428328 A | 31-01-1984 | NONE | |