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(54) **METAL HYDRIDE AIR CONDITIONER**

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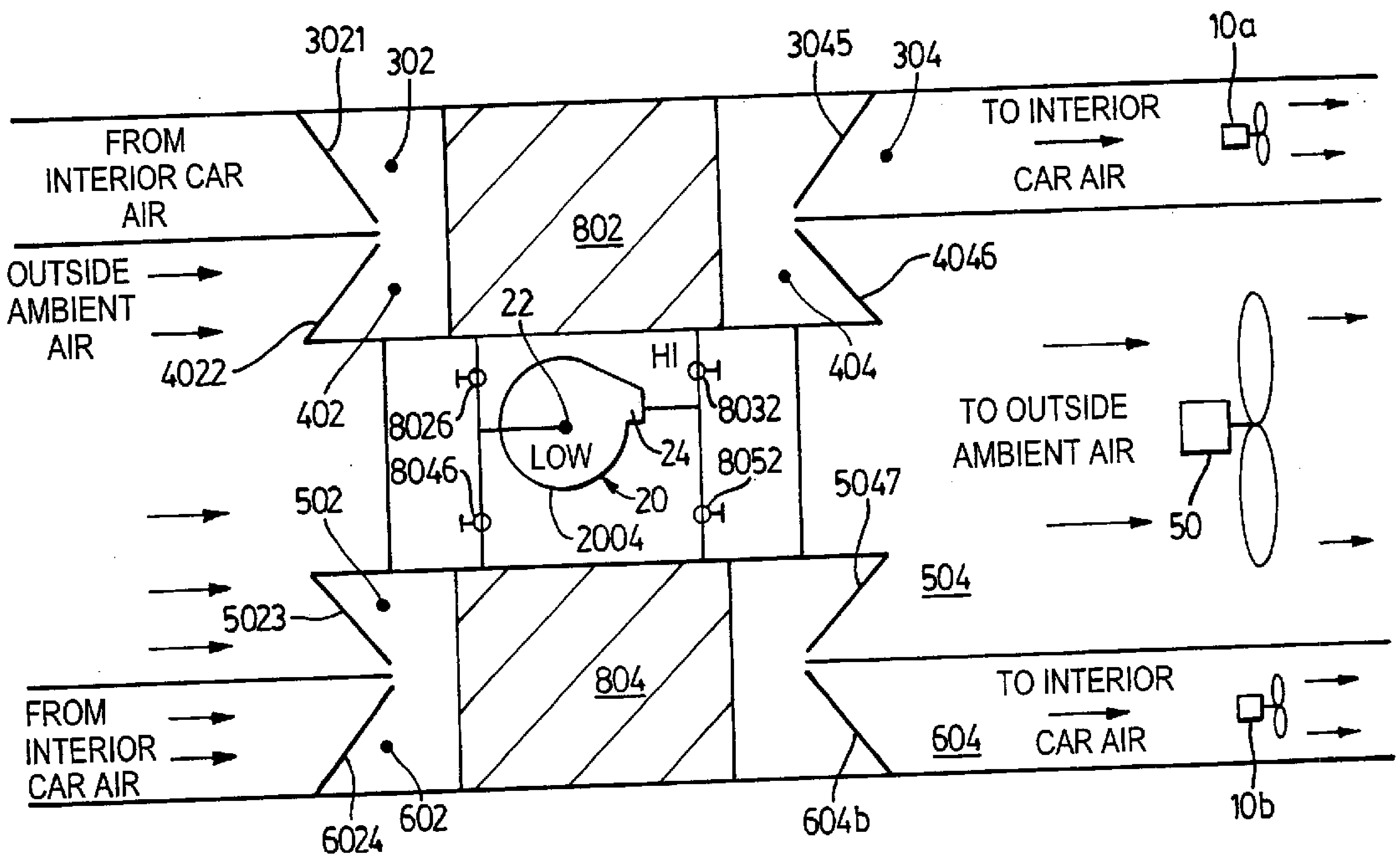
(57) **ABSTRACT**

A system for flowing gaseous fluid comprising: a collection container; compression machinery disposed within the collection container, and including an inlet, a fluid compression space, and an outlet, wherein the inlet is fluidly coupled to the outlet through the fluid compression space, and wherein the inlet is fluidly coupled to an inlet fluid conduit and the outlet is fluidly coupled to an outlet fluid conduit and each of the inlet and outlet fluid conduits extends through and externally of the container; wherein the collection container is configured for receiving gaseous fluid leakage flow from the compression space, and is fluidly coupled to the inlet of the compression machinery to facilitate flow of the received leaked gaseous fluid to the inlet of the compression machinery.



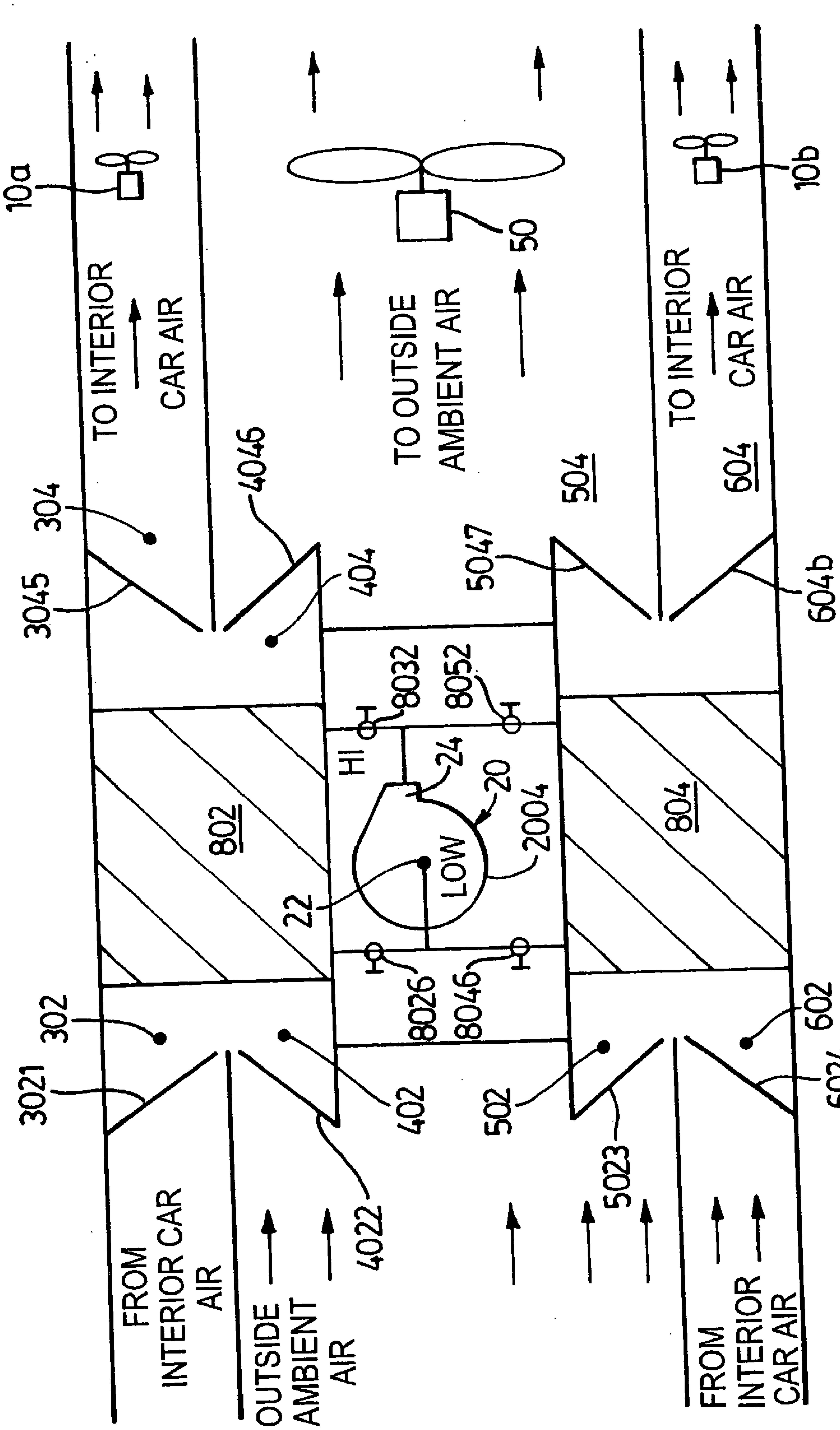

10a
TO INTERIOR
CAR AIR
TO OUTSIDE
AMBIENT AIR
50
TO INTERIOR
CAR AIR
10b
304
3045
4046
404
504
5047
604
604b
8032
8052
HI
24
20
2004
802
804
LOW
22
8026
8046
302
3021
402
4022
502
5023
602
6024
FROM
INTERIOR CAR
AIR
OUTSIDE
AMBIENT
AIR
FROM
INTERIOR
CAR AIR

FIG. 1

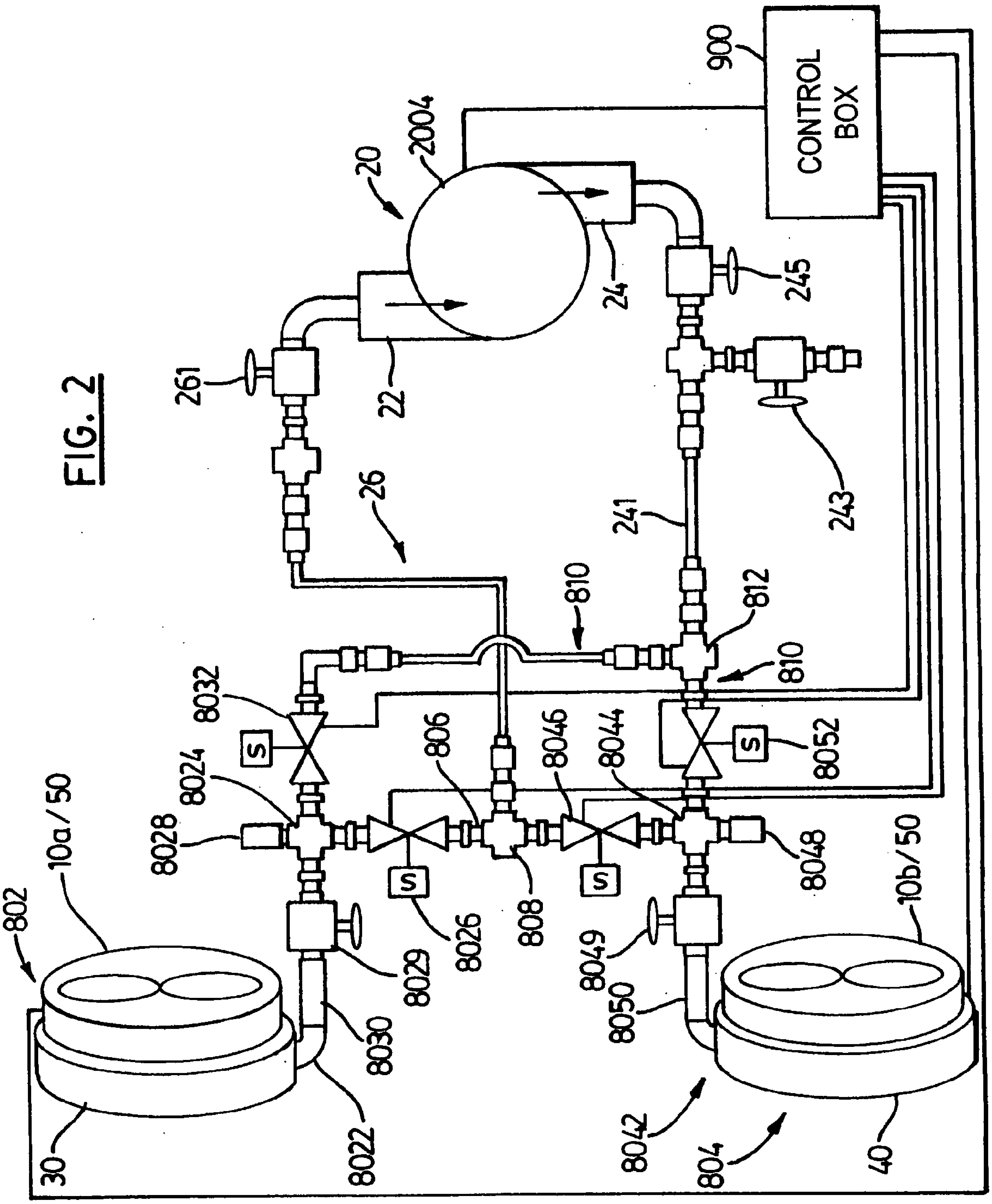

CONTROL BOX
900
20
2004
22
24
245
261
26
241
243
810
812
8032
8024
8028
806
808
8046
8044
8052
8026
8029
8030
8022
8048
8049
8050
8042
804
802
10a/50
10b/50
30
40
S

FIG. 2

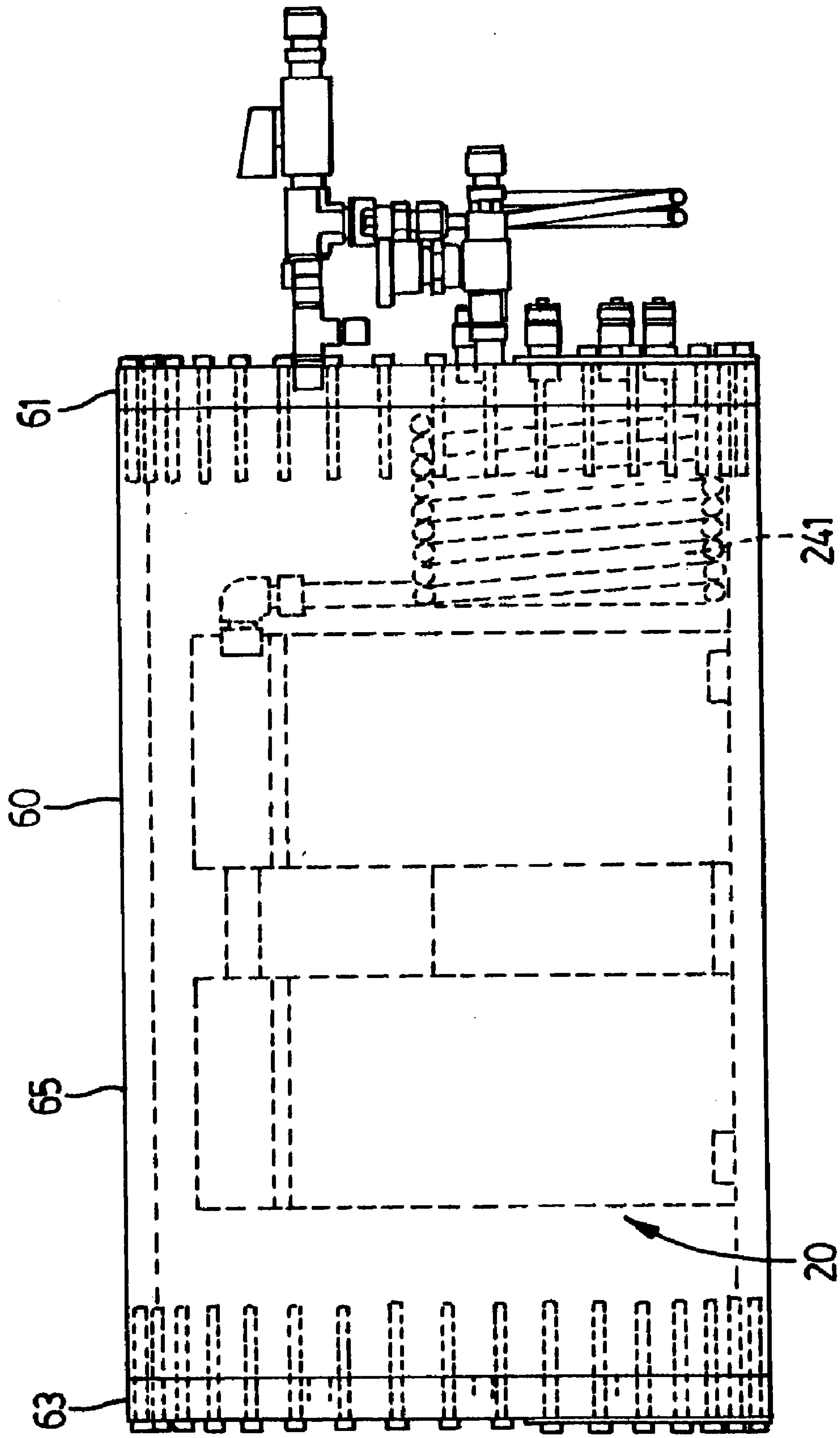


FIG. 3A

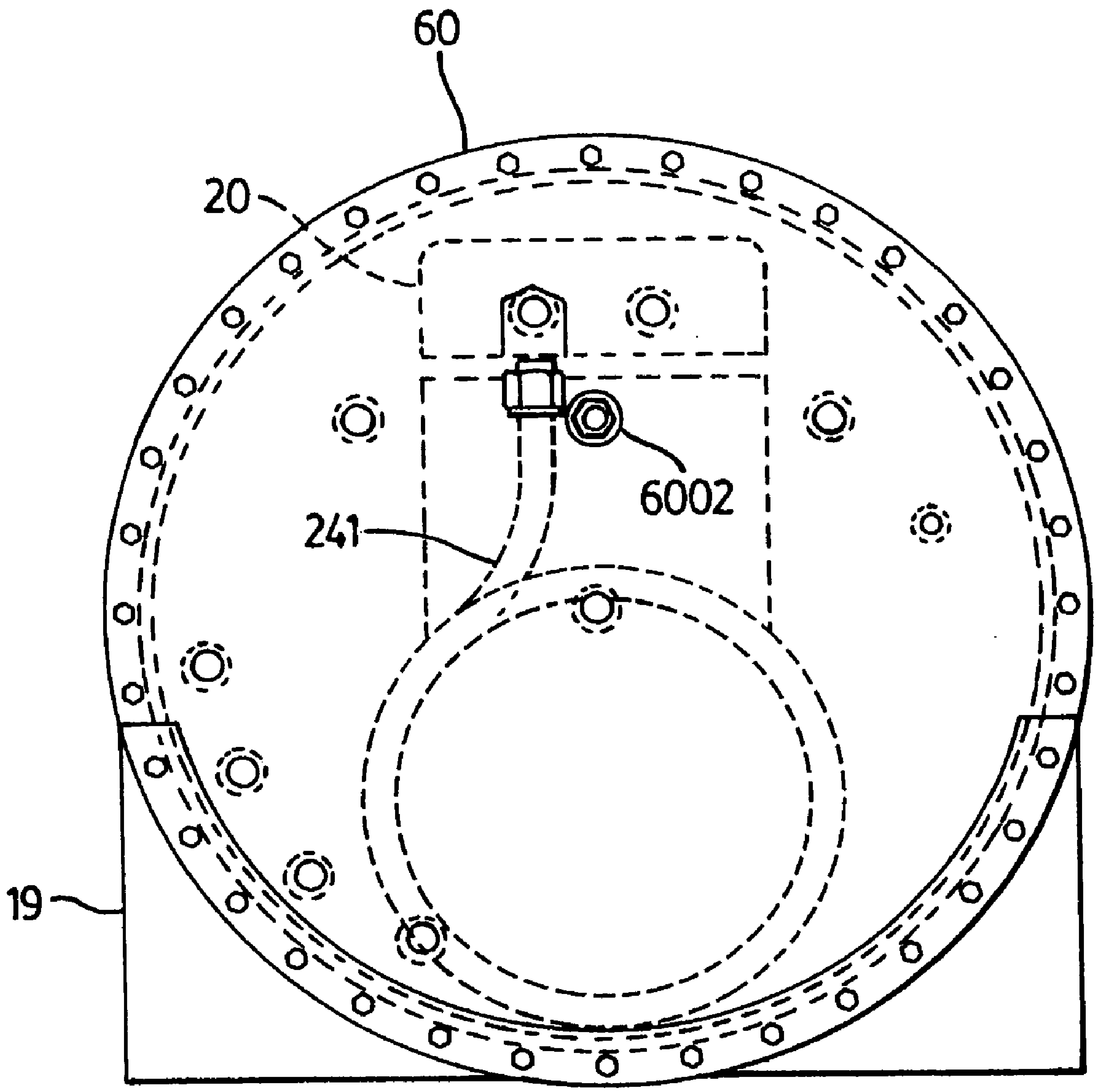


FIG. 3B

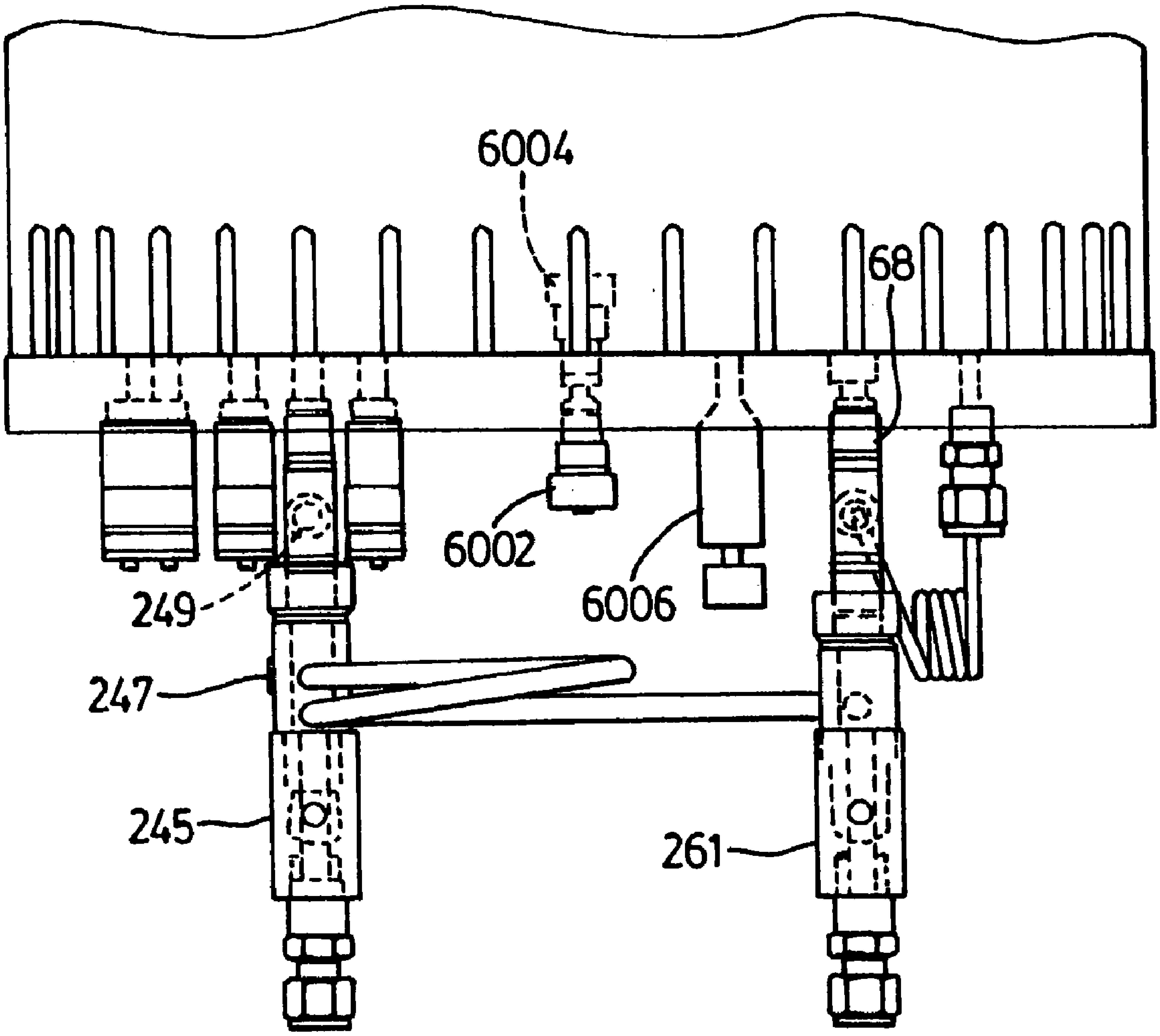


FIG. 3C

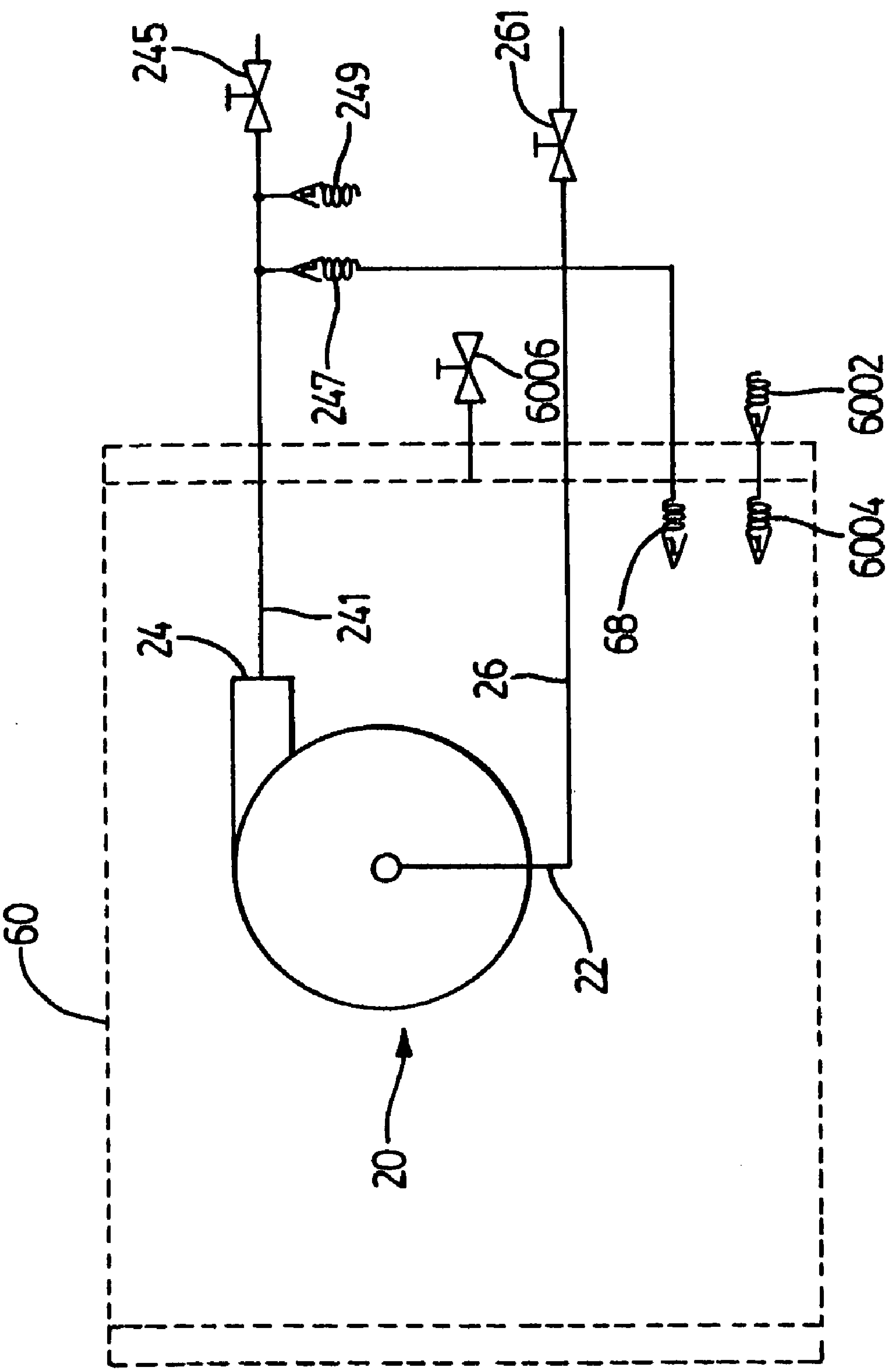


FIG. 4

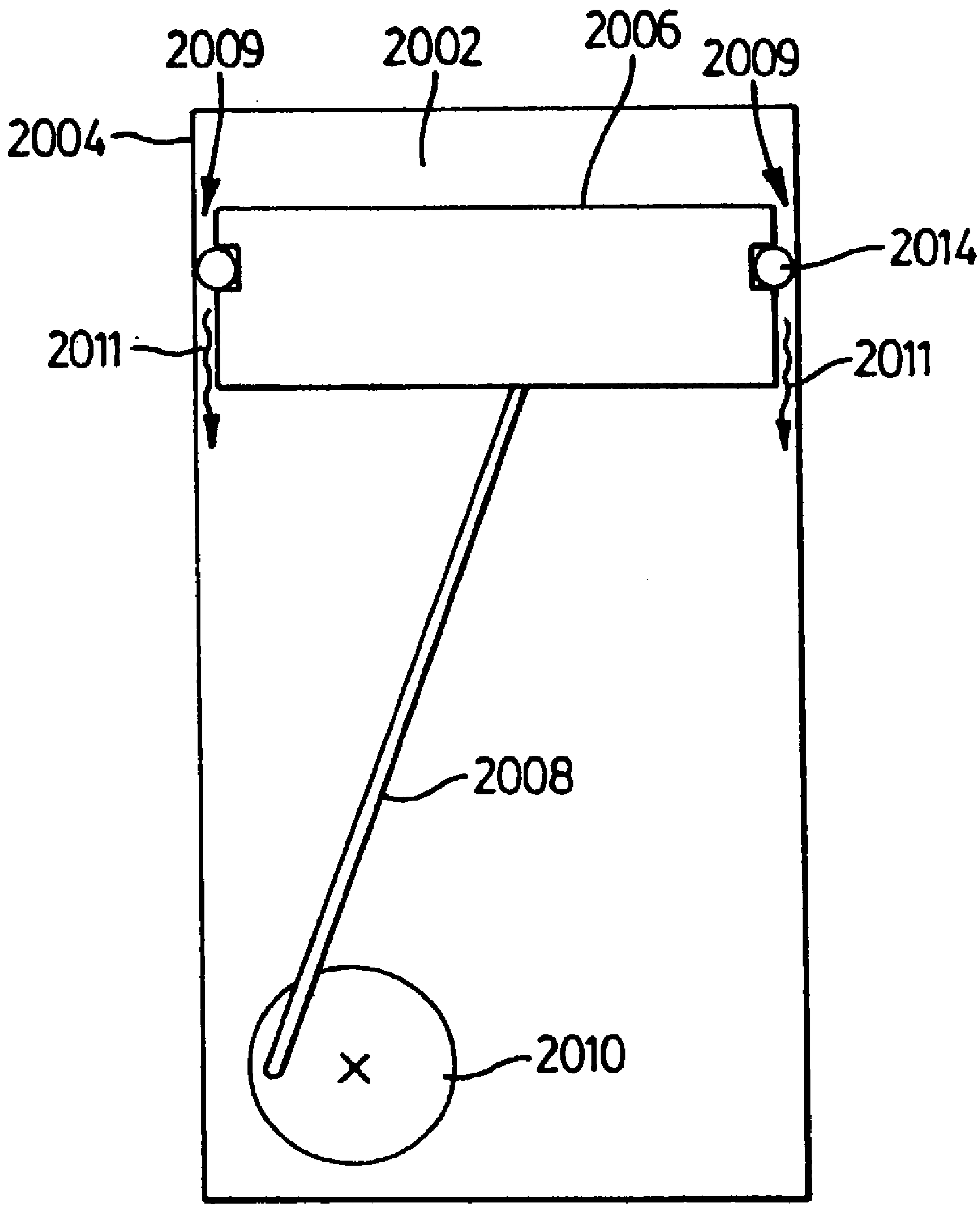


FIG. 5A

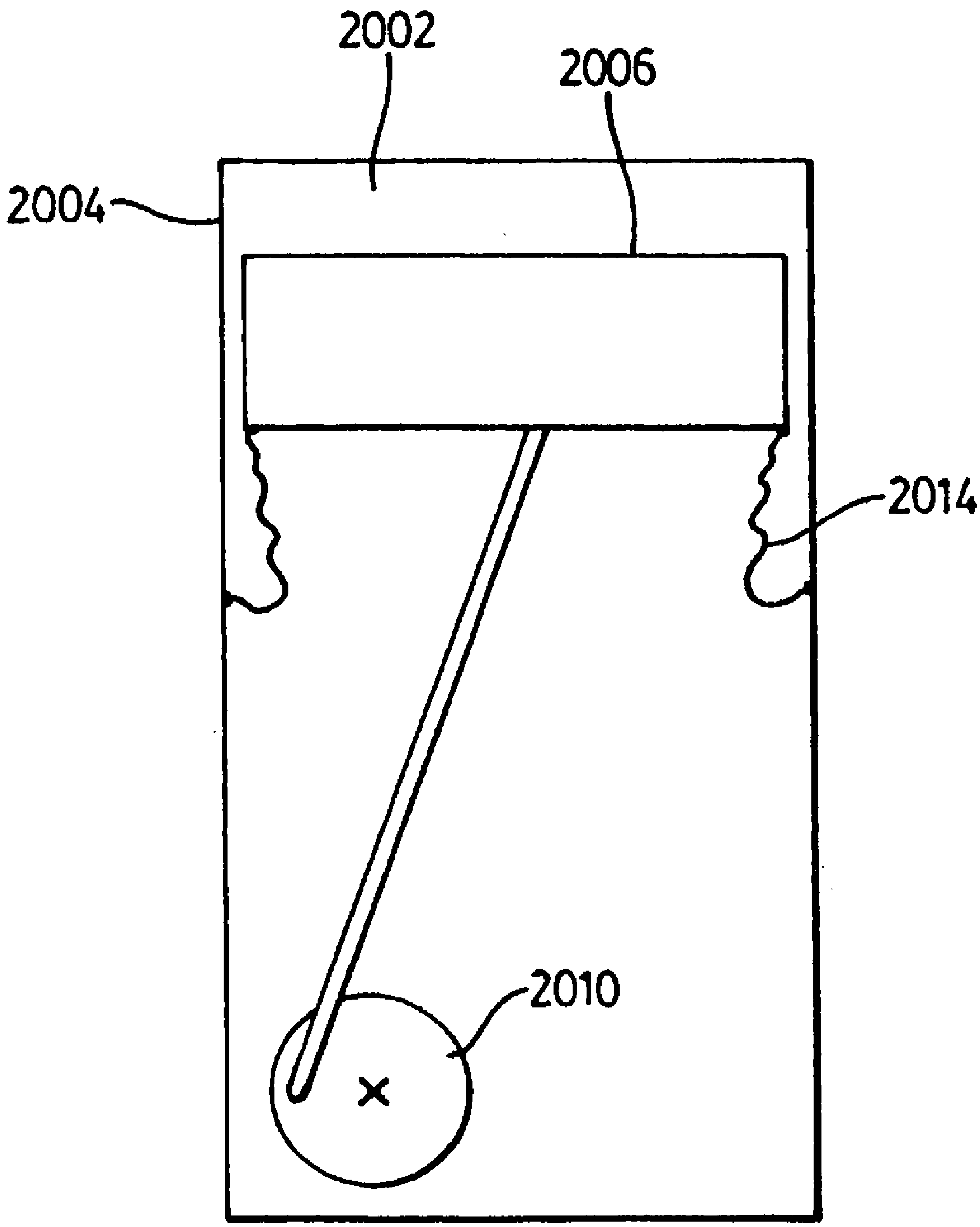
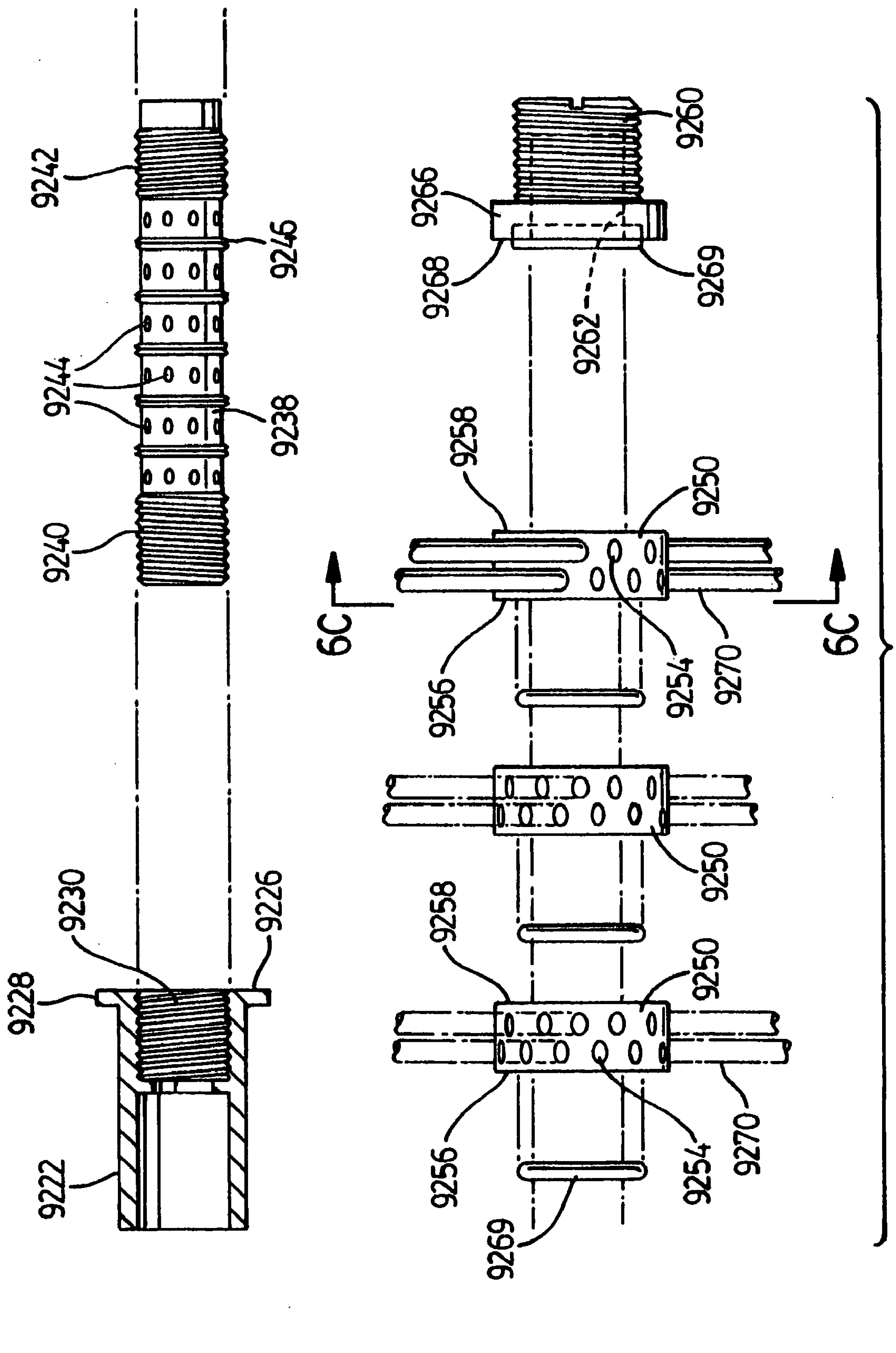


FIG. 5B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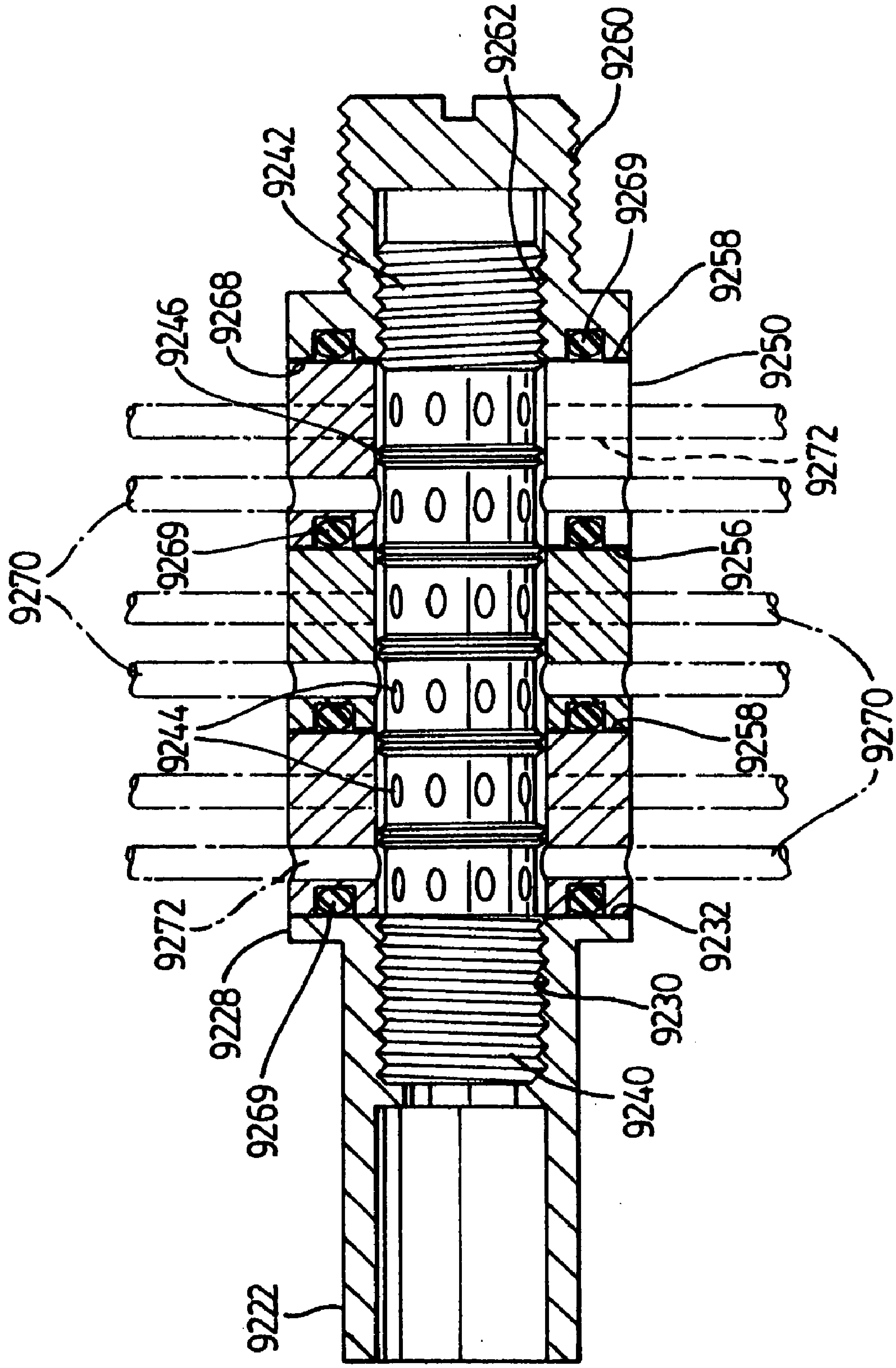
9246
9244
9238
9240
9228
9230
9226
9222
9260
9266
9268
9269
9262
9258
9250
6C
6C
9256
9254
9270
9250
9258
9250
9256
9254
9270
9269

FIG. 6A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9260
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9250
9272
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9272
9232
9228
9230
9269
9240
9222

FIG. 6B

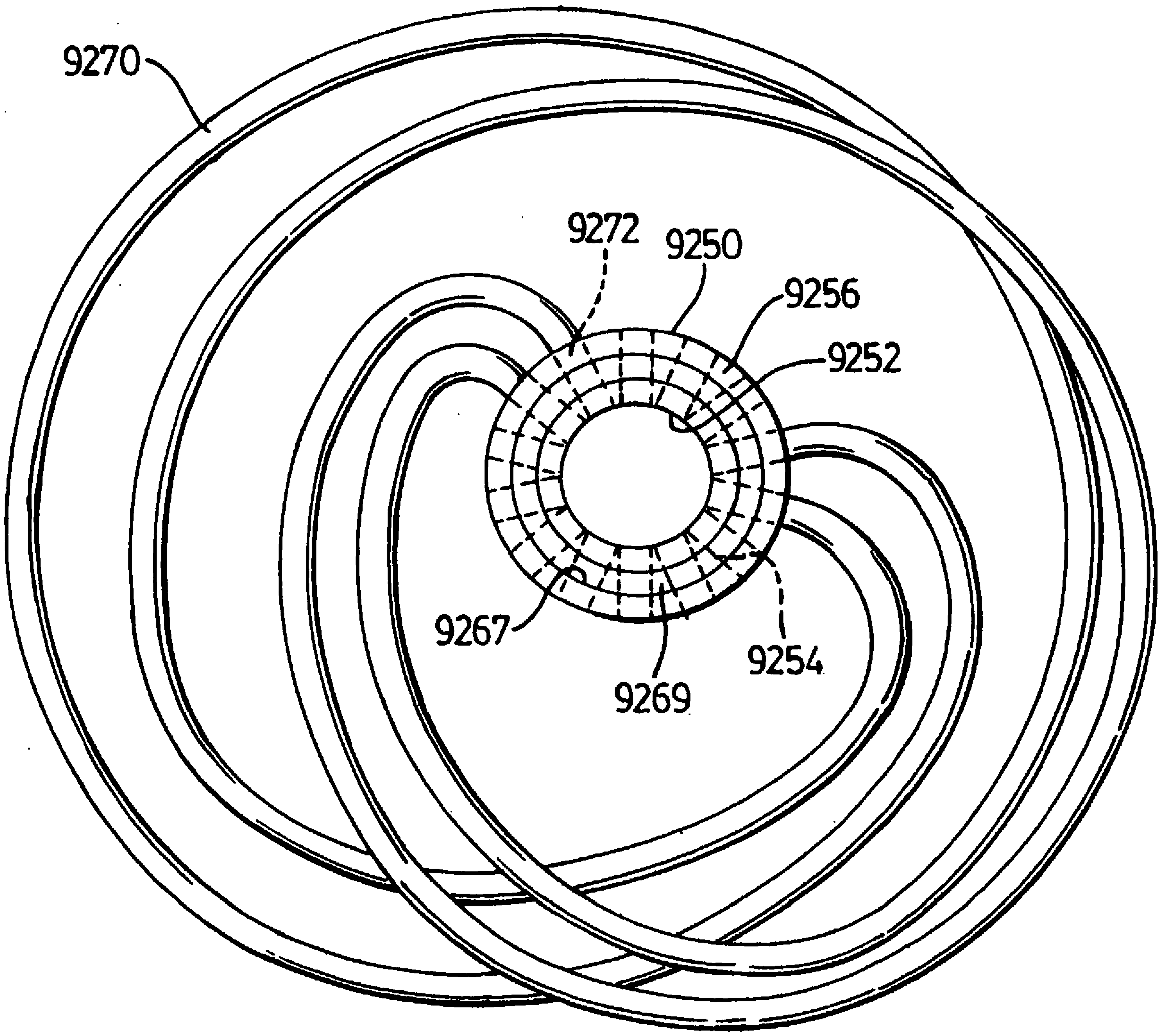

FIG. 6C

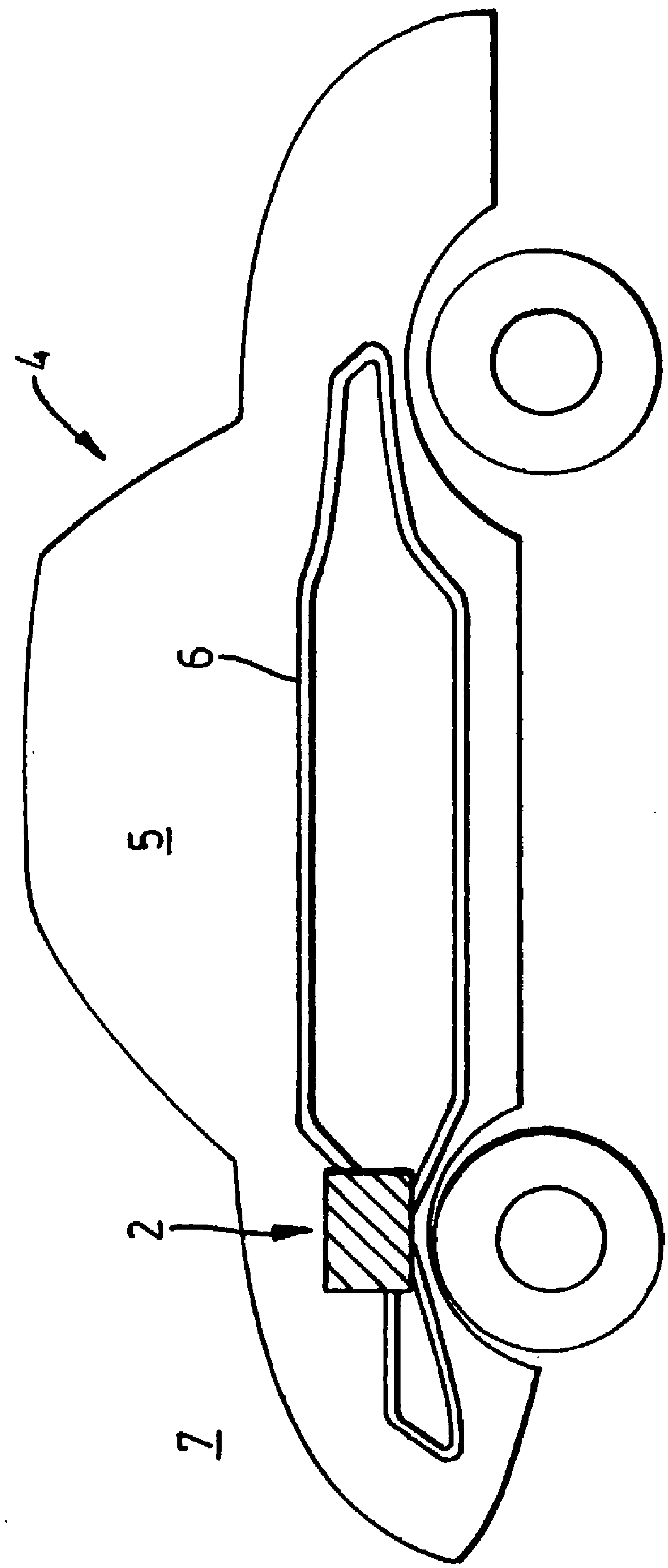

FIG. 7

METAL HYDRIDE AIR CONDITIONER

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of International Application No. PCT/US2004/039147 filed Nov. 22, 2004, which is a non-provisional of U.S. patent application Ser. No. 60/571,867 filed May 17, 2004, the entire disclosures of which are hereby incorporated by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to air conditioners and, in particular, metal hydride air conditioners.

BACKGROUND OF THE INVENTION

[0003] Metal hydride heat exchangers have been considered for use in providing cool passenger air to vehicles, such as automobiles. Such application is described in U.S. Pat. No. 5,571,251. To effect the described heat exchanger operation, adequate heat must be available on-board the vehicle to facilitate compression of gaseous hydrogen. Unfortunately, due to a lack of high quality heat available in hybrid vehicles, other means must be considered to effect the necessary compression of hydrogen during the operation of metal hydride heat exchangers.

SUMMARY OF THE INVENTION

[0004] According to one aspect of the present invention there is provided a system for flowing gaseous hydrogen comprising: a collection container; compression machinery disposed within the collection container, and including an inlet, a fluid compression space, and an outlet, wherein the inlet is fluidly coupled to the outlet through the fluid compression space, and wherein the inlet is coupled to an inlet fluid conduit and the outlet is coupled to an outlet fluid conduit and each of the inlet and outlet fluid conduits extends through and externally of the container; and a hydrogen storage container containing hydrogen storage material and fluidly coupled to the outlet of the compression machinery; wherein the collection container is configured for receiving gaseous hydrogen leakage flow from the compression space, and wherein the collection container is fluidly coupled to the inlet of the compression machinery to facilitate flow of the leaked gaseous fluid to the inlet of the compression machinery.

[0005] According to another aspect of the present invention, there is provided a system for flowing gaseous fluid comprising: a collection container; compression machinery comprising: an inlet; a fluid compression space fluidly coupled to the inlet; a moveable member disposed in force application communication relative to the fluid compression space and configured for effecting an application of a force to the fluid compression space upon a movement of the moveable member; and an outlet fluidly coupled to the fluid compression space; and a hydrogen storage container containing hydrogen storage material and fluidly coupled to the outlet of the compression machinery; wherein the collection container is configured for receiving gaseous fluid which leaks across the moveable member from the compression space, and is fluidly coupled to the inlet of the compression machinery to facilitate flow of the leaked gaseous fluid to the inlet of the compression machinery.

[0006] According to a further aspect of the present invention, there is provided a vehicle including a passenger compartment and a cooling system, the cooling system comprising: a first hydrogen storage container containing a first hydrogen storage material; a first process fluid conduit disposed in thermal communication disposition with the hydrogen storage container, and fluidly coupled to the passenger compartment for flowing hot ambient air flow received from within the passenger compartment and effecting heat transfer from the hot ambient air flow to the first hydrogen storage container to provide a cooled ambient air flow to the passenger compartment; compression machinery fluidly coupled to the first hydrogen storage container for receiving a low pressure gaseous fluid from the hydrogen storage container, and configured for pressurizing the received low pressure gaseous fluid to provide a high pressure gaseous fluid, and discharging a flow of the high pressure gaseous fluid; a second hydrogen storage container fluidly coupled to the compression machinery for receiving the discharged flow of the high pressure gaseous fluid, the second hydrogen storage container containing a second hydrogen storage material; and a second process fluid conduit disposed in thermal communication disposition with the hydrogen storage container, and fluidly coupled to an environment exterior to the vehicle.

[0007] According to a further aspect of the present invention, there is provided a method of effecting cooling of a first process fluid and heating of a second process fluid comprising: transferring heat from a hot first process fluid to a first hydrogen storage material to effect desorption of gaseous hydrogen and provide a cooled first process fluid; mechanically compressing the desorbed gaseous hydrogen to provide pressurized gaseous hydrogen; effecting absorption of the pressurized gaseous hydrogen by a second hydrogen storage material to produce heat energy; transferring the produced heat energy to a second process fluid.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The invention will be better understood by reference to the following detailed description of the invention in conjunction with the following drawings, in which:

[0009] **FIG. 1** is a schematic sectional illustration, illustrating the circulation of ambient air from the interior or a vehicle and across heat exchanges, and also the circulation of ambient air external to the vehicle and across an embodiment of the system of the present invention, where a single fan is used to effect flow of external air across either heat exchanger, and where separate fans are provided to effect flow of interior vehicle air across each heat exchanger;

[0010] **FIG. 2** is a process flow diagram of an embodiment of a system of the present invention;

[0011] **FIG. 3A, 3B**, and 3C are, respectively, side elevation (**3A**), front elevation (**3B**), and top plan, (**3C**) detailed views of the collection container of the present invention, with associated piping components, and internal components (eg., compressor and piping) in dotted outline;

[0012] **FIG. 4** is a schematic illustration of the suction and discharge piping of the compressor of the present invention, as well as the return conduit effecting fluid coupling between the collection container and the suction conduit of the compressor;

[0013] **FIG. 5A** is a schematic sectional illustration of a compressor used in an embodiment of a system of the present invention;

[0014] **FIG. 5B** is a schematic sectional illustration of another compressor used in another embodiment of a system of the present invention;

[0015] **FIG. 6A** illustrates in an exploded view a modular heat exchanger assembly useful in practice of the invention;

[0016] **FIG. 6B** illustrates the assembled modular heat exchanger of **FIG. 6A**;

[0017] **FIG. 6C** illustrates a detail view of the assembly of **FIG. 6A** and the connection to tubular elements which contain the hydrogen storage material; and

[0018] **FIG. 7** is a schematic illustration of a vehicle employing an embodiment of a system of the present invention.

DETAILED DESCRIPTION

[0019] The present invention provides a system **2** for cooling air.

[0020] The preferred embodiment of the cooling system includes two heat exchangers **802**, **804**. Each of these heat exchangers comprises a container containing at least one hydrogen storage material.

[0021] References to hydrogen are intended to refer to protium and deuterium (isotopes of hydrogen), alone or in combination.

[0022] Each of the hydrogen storage materials within each of the containers consists essentially of a hydrogen storage composition and/or a hydridable form of the hydrogen storage composition.

[0023] In the context of the hydrogen storage material, "consisting essentially of" means that matter other than the hydrogen storage composition and/or the hydridable form of the hydrogen storage composition may or may not be present in the hydrogen storage material. In other words, the hydrogen storage material can consist entirely of the hydrogen storage composition and/or the hydridable form of the hydrogen storage composition. However, if present, this other matter may be present as impurities introduced into the hydrogen storage material as by-products arising during processing or from the raw materials, or introduced by contamination when assembling the system or during operation of the system. This other matter may also be intentionally present to function as a catalyst for hydrogen transfer (eg., hydrogenation or dehydrogenation) reactions, or may also be intentionally present to function as a dessicant. This other matter is present in amounts which are not significant so as to effect the desired properties of the hydrogen storage material, as discussed herein, or to noticeably interfere with any of the processes occurring during the operation of the system of the present invention.

[0024] Various gaseous fluids are described below as "consisting essentially of gaseous hydrogen". In the context of the gaseous fluids, the term "consisting essentially of" means that matter (eg., other gases) other than gaseous hydrogen may or may not be present in the gaseous fluid. In other words, the gaseous fluid can consist entirely of the gaseous hydrogen, without any further matter present. However, if present, this other matter may be present as impurities introduced into the gaseous fluid as by-products arising during processing or from the raw materials, or as impurities introduced into the system of the present invention when assembling the system or during operation of the system. This other matter is present in amounts which are not significant so as to effect the desired properties of the gaseous hydrogen, or to noticeably interfere with any of the processes occurring during the operation of the system.

[0025] It is understood that the hydrogen storage composition of each of the at least one first hydrogen storage material is different for each of the at least one first hydrogen storage material.

[0026] The hydridable form of a hydrogen storage composition can be any of: a metal, a metalloid, an alloy of a metal, an alloy of a metalloid, a compound of a metal, or a compound of a metalloid. The metal or the metalloid of the hydridable form must be available to become associated with hydrogen so as to form the hydrogen storage composition. Conversely, decomposition of the hydrogen storage composition (dissociation of hydrogen from the first hydrogen storage composition) results in the formation of the hydridable form.

[0027] Absorption of hydrogen by hydrogen storage material refers to the association of hydrogen with the hydrogen storage material. Possible mechanisms for association in a "simple metal hydride" include: dissolution, covalent bonding, or ionic bonding. Dissolution describes the process where a hydrogen atom is incorporated in the voids of a lattice structure of a metal or intermetallic alloy. Examples of such materials include vanadium hydrides, titanium hydrides, and hydrides of vanadium-titanium alloys. An example of hydrogen association with a hydrogen storage material by way of a covalent bonding mechanism is magnesium hydride. An examples of hydrogen association with a hydrogen storage material by way of an ionic bonding mechanism is sodium hydride and potassium hydride. Complex hydrides are metal hydrides which exhibit partially covalent/partially ionic bonding between any of (i) a trivalent group IIIB metal, or (ii) a metalloid atom (such as aluminium), (iii) or a transition metal (such as iron) of the hydrogen storage material and a hydrogen atom. It is understood that the present understanding of the metal-hydrogen or metalloid-hydrogen bonding coordination in a complex metal hydride is explained in Hauback et al., "Accurate Structure of $LiAlD_4$ studied by combined powder and x-ray diffraction", Journal of Alloys and Compounds 346 (2002) 184-189, Elsevier Science B. C. Examples of complex hydrides are sodium alanate and lithium alanate.

[0028] The term "a hydrogen storage composition and/or a hydridable form of the hydrogen storage composition" means any of: (i) the hydrogen storage composition, (ii) the hydridable form of the hydrogen storage composition, and (iii) a homogeneous or an inhomogeneous combination of the hydrogen storage composition and the hydridable form of the hydrogen storage composition.

[0029] In one embodiment, each of the hydrogen storage materials is in the form of a powder. Preferably, the powder has an average diameter of less than 0.01 inches before it has been hydrided the first time, and less than 0.000039 inches after it has undergone several hydriding and dehydriding cycles.

[0030] Suitable hydrogen storage compositions include simple metal hydrides and complex metal hydrides. In a preferred embodiment, the hydridable form of the hydrogen storage composition is lanthanium pentanickel ($LaNi_5$). In another preferred embodiment, the hydrogen storage composition (in a hydridable form) is $Ti_x Zr_x Mn_y V_x Fe_x Cr_x Ni_x$ where x is 0.001 to 1, and y is 0.01 to 2.0. A preferred species of this hydrogen storage material is $Ti_{0.89} Zr_{0.122} Mn_{1.487} V_{0.407} Fe_{0.048} Cr_{0.045} Ni_{0.006}$.

[0031] The system **2** cools air by using the heat energy of ambient air to effect desorption of hydrogen from a first hydrogen storage material disposed in a first container **30**. The combination of the first container **30** and the first hydrogen storage material functions as a first heat exchanger **802**. The first container contains the first hydrogen material and a gaseous liquid consisting essentially of gaseous hydrogen, wherein the gaseous fluid is in contact with the first hydrogen storage material. Hydrogen desorption from the first hydrogen storage material and into the gaseous fluid occurs at a predetermined temperature, and upon input of a predetermined amount of heat energy, when the first hydrogen storage material comprises a hydrogen storage composition having, at the predetermined temperature, a desorption plateau pressure which is greater than the partial pressure of gaseous hydrogen in the gaseous fluid contacting the hydrogen storage composition of the first hydrogen storage material.

[0032] Desorption of hydrogen from the first hydrogen storage material is an endothermic reaction, requiring an input of heat energy to the first hydrogen storage material. Such heat energy is supplied by a fluid, preferably air for which cooling is desired. In the preferred embodiment, the first container **30** is contacted with air for which cooling is desired. The air is characterized by a higher temperature than the temperature of the first hydrogen storage material disposed in the first container **30**. Preferably, the air is drawn from the interior passenger compartment of a vehicle **4** (see **FIG. 7**), such as an automobile, and forced by a first fan **10*a*** through conduit **302** to flow across and contact the first container **30**. The air flows across the container **30**, and heat is transferred from the air to the first hydrogen storage material, effecting desorption of hydrogen from the hydrogen storage material, and also a reduction in the temperature of the air. The cooled air is then returned to the interior of the vehicle through conduit **304**.

[0033] Once the hydrogen of the first hydrogen storage material available for desorption becomes desorbed or substantially desorbed from the first hydrogen storage material, regeneration of the first hydrogen storage material with hydrogen must be effected so that the first hydrogen storage material can continue to function as an effective heat sink to effect desired cooling of the air (this is referred to as "regeneration"). In the present invention, mechanical compression machinery such as a mechanical compressor **20** is provided and fluidly coupled to the first container **30**. The mechanical compressor **20** receives a low pressure gaseous fluid consisting essentially of hydrogen through an inlet or suction **22**, imparts mechanical energy to the low pressure gaseous fluid to effect pressurization thereof to form a high pressure gaseous fluid consisting essentially of gaseous hydrogen, and delivers the high pressure gaseous fluid to the first container through an outlet or a discharge **24**. Absorption of hydrogen, from the high pressure gaseous fluid consisting of essentially hydrogen, by the first hydrogen storage material occurs at a predetermined temperature when the first hydrogen storage material comprises a hydridable form of a hydrogen storage composition having, at the predetermined temperature, an absorption plateau pressure which is less than the partial pressure of the gaseous hydrogen in the high pressure gaseous fluid contacting the hydridable form of the hydrogen storage composition of the first hydrogen storage material.

[0034] Hydrogen absorption by the first hydrogen storage material is an exothermic reaction, resulting in the generation of heat energy. Such heat energy is removed by a cooling system. In one embodiment, the necessary cooling is effected by the first container **30** being contacted with a fluid, wherein the fluid is characterized by a lower temperature than the temperature of the first hydrogen storage material disposed in the first container **30**. Preferably, the fluid is ambient air which is drawn from the environment **7** external to the vehicle (see **FIG. 7**) and is forced by a second fan **50** through conduit **402** to flow across and contact the first container **30**. The ambient air flows across the first container **30**, and heat is transferred from first hydrogen storage material to the ambient air to facilitate hydrogen absorption by the first hydrogen storage material. The ambient air is heated and is returned through conduit **404** to the environment **7** external to the vehicle.

[0035] Referring to **FIGS. 1 and 2**, in one embodiment, so as to continue to provide the necessary desired cooling of the air from within the vehicle during regeneration of the first hydrogen storage material of the first container **30**, the present invention provides a second container **40** containing a second hydrogen storage material. The combination of the second container **40** and the second hydrogen storage material functions as a second heat exchanger **804**. While the first hydrogen storage material is being regenerated by the compressor **20**, the second container **40** is contacted with a fluid, preferably air, at a higher temperature than the second hydrogen storage material. Heat energy is transferred from the air to the second hydrogen storage material to effect desorption of hydrogen from the second hydrogen storage material. Desorption of hydrogen from the second hydrogen storage material occurs at a predetermined temperature, and upon input of a predetermined amount of heat energy, when the second hydrogen storage material comprises a hydrogen storage composition having, at the predetermined temperature, a desorption plateau pressure which is greater than the partial pressure of gaseous hydrogen in the gaseous fluid contacting the hydrogen storage composition of the second hydrogen storage material.

[0036] Preferably, the air is drawn from the interior passenger compartment of a vehicle **4**, such as an automobile, and forced by a fan to flow through conduit **602** and across the second container **40**. The air contacts and flows across the container **40**, and heat is transferred from the air to the second hydrogen storage material, and the cooled air is then returned through conduit **604** to the interior of the automobile.

[0037] Referring to **FIG. 1**, in one embodiment, a third fan **10*b*** is used to effect flow of ambient air from an interior of a vehicle and across the second container **40**. In another embodiment, the system can be configured such that the first fan **10*a*** could be used to perform the function of third fan **10*b*** if the conduits **304** and **604** are joined together.

[0038] Upon the first hydrogen storage material being fully or partially regenerated and becoming available to participate in the cooling of the desired air mass, the second hydrogen storage material can then be regenerated in a manner similar to that described as for the first hydrogen storage material, with the use of the compressor **20**. The compressor is fluidly coupled to the second container **40**. The compressor **20** receives a low pressure gaseous fluid consisting essentially of hydrogen through the suction **22**, imparts mechanical energy to the gaseous fluid to effect pressurization of the gaseous fluid (and, therefore, the gaseous hydrogen) to form a high pressure gaseous fluid consisting essentially of hydrogen, and delivers the high pressure gaseous fluid to the second container **40** through the discharge **24**. The second hydrogen storage material becomes regenerated when hydrogen is absorbed by the second hydrogen storage material. Such absorption occurs, at a predetermined temperature, when the second hydrogen storage material comprises a hydridable form of a hydrogen storage composition having, at the predetermined temperature, an absorption plateau pressure which is lower than the partial pressure of gaseous hydrogen in the high pressure gaseous fluid contacting the hydridable form of the hydrogen storage composition of the second hydrogen storage material.

[0039] During regeneration of the second hydrogen storage material, heat energy is generated. Preferably, the second fan **50** is used to cool the second container **40** during the regeneration cycle by drawing ambient air from the environment external to the vehicle and forcing such drawn ambient air to flow through conduit **502** and across the second container **40**. The ambient air becomes heated as it flows across the second container **40**, and this heated air is then returned through conduit **504** to the environment external to the vehicle.

[0040] Preferably, the second hydrogen storage material is the same as, or substantially the same as the first hydrogen storage material. However, it is understood that it is not necessary that the first and second hydrogen storage materials are the same or substantially the same. Like the first hydrogen storage material, suitable second hydrogen storage materials include simple metal hydrides, complex metal hydrides, and hydridable forms thereof. Like the first hydrogen storage material, in one embodiment, the second hydrogen storage material is in the form of a powder, and, preferably, the powder has an average particle size diameter of less than

[0041] Preferably, each of the first and second containers **30**, **40** containing the respective hydrogen storage materials, includes a plurality of modules of the modular heat exchanger configuration described and illustrated in U.S. Pat. No. 5,623,987.

[0042] Referring now to **FIG. 6A**, an exploded view of a preferred modular heat exchanger assembly useful in heat exchangers **802** and **804** is illustrated.

[0043] For each modular assembly, an inlet conduit **9222** is provided and with expanded flat end **9228**. The inner surface adjacent end **9228** includes threads **9230**, shown in phantom, for connection to other elements of the assembly. An annular, radially extending, flat end surface **9232** of the end **9228** extends through a plane which lies substantially perpendicular to the centerline of **9222**.

[0044] A cylindrical ring manifold **9238** is provided comprising a tubular element with two threaded ends **9240**, **9242** and a number of apertures **9244** which extend through the tube wall and are disposed circumferentially around the ring manifold **9238**. Each of the apertures **9244** provides gas communication to the inside of the manifold **9238**. The threaded end **9240** is adapted for connection to the threads **9230** on the inner surface of the end **9228** of conduit **9222** and provides a framework for further connection with additional elements of the assembly, as is discussed below.

[0045] The ring manifold **9238** advantageously includes upstanding ribs **9246** which separate groups of apertures **9244**. The other threaded end **9242** provides a connection for other elements of the assembly. Plural modular ring elements **9250** are each adapted for sliding onto and over the ring manifold **9238**. Each ring element **9250** comprises an annular ring having a central opening which has an inner diameter slightly larger than the outer diameter of the ring manifold **9238**. The ring element **9250** has a plurality of apertures **9254** which extend radially through the circumferential wall of the element **9250** from the outer to the inner diameter surfaces.

[0046] Each ring element **9250** can be fitted over the ring manifold **9238** until it reaches a position overlying the apertures **9244** of the ring manifold. Optimally, each aperture **9254** of the ring element **9250** is disposed over a portion of ring manifold **9238** which includes an aperture **9244**. This arrangement should essentially provide more or less direct communication from the inner diameter of the manifold **9238** through the apertures **9244**, **9254** to the outside diameter of the ring element **9250**.

[0047] Each ring element **9250** further provides two radially extending faces **9256**, **9258** which, when assembled, are each disposed substantially perpendicularly to the centerline of the device. Preferably, each of the ring elements **9250** are identical and interchangeable. Placing the plural ring elements **9250** end-to-end, that is, each face **9256** of one ring is placed adjacent face **9258** of the next adjacent ring, provides a cylindrical tube having stacked annular ring elements **9250**. When assembled, the cylindrical tube formed by the ring elements **9250** overlies the ring manifold **9238**.

[0048] The axial widths of the ring elements **9250** between the faces **9256**, **9258** are of a predetermined dimension. When the ring manifold **9238** is screwably attached to valve threads **9230** and the ring elements **9250** are assembled over the ring manifold **9238**, there is a substantial portion of the threads **9242** which protrude through the central opening of the last ring element **9250** in the stack of plural ring elements. An end piece **9260**, having a chamber **9262** with a threaded, circumferential, internal surface, is securably attached to the ring manifold **9238**. Threads **9242** of the ring manifold **9238** conform to the internal threads of the surface, thus enabling the end piece to be screwably attached onto the ring manifold **9238**. Each piece **9260** has an outer thread in order to accommodate a bracket or fixture that will allow the entire heat exchanger to be mounted from the manifold **9238** and not the component tubes **9270** (see below).

[0049] End piece **9260** also has a radially extending, circumferential flanged member **9266** having a face **9268** at the axial terminus which is coextensive with the face **9258** of the last of the plural, stacked ring members **9250**. Accordingly, after assembly of the ring elements **9250** over the ring manifold **9238**, the face **9256** of the first ring element **9250** is adjacent and opposite the flat end surface **9232** and also, each of the walls **9256**, **9258** of the other ring elements **9250** are adjacent and opposite each other. Rotation and engagement of the end piece **9260** onto the threads **9242** of the ring manifold **9238** brings the end face **9268** of the end piece **9260** opposite and adjacent the face **9258** of the last ring element **9250** in the stack.

[**0050**] As the end piece **9260** is screwed onto the ring manifold **9238**, the face **9268** exerts an axial pressure on the face **9258** of the ring element **9250** and, in turn, on each face **9256**, **9258** of the stack of ring elements. In order to provide an airtight enclosure for the space inside the cylindrical tube comprised of the ring elements **9250**, a sealing element **9269**, such as a washer or **0**-ring, is disposed between each pair of faces **9256**, **9258**, **9232**, **9256** and **9258**, **9268**. The sealing element **9269** may be inserted into a circumferential groove **9267** in each face **9256** and in face **9268**, best shown in **FIG. 6C**. In one embodiment, the sealing element **9269** comprises a soft crushable metal, such as **321** stainless steel (silver-plated) which will hermetically seal the faces against each other to eliminate passage of all gases, including hydrogen, through the seal. In the preferred embodiment, the sealing element **9269** is a VITON™-ring.

[**0051**] **FIG. 6C** shows a front view of one of the ring elements **9250**, together with certain of the elements which are connected thereto. Referring now to **FIGS. 6A**, **6B** and 6C, tubes **9270** are shown connected into the ring elements **9250**. Each of the apertures **9254** are adapted to receive a tube end **9272** therethrough. **FIG. 7** shows two tubes **9270**, the ends **9272** of which tubes **9270** have been inserted into adjacent apertures **9254** which are disposed on the same modular ring element **9250**. **FIG. 6C** shows the ring element **9250** having a radial face **9256** and central opening **9252**, and being connected to only two of the plurality of tubes **9270** for purposes of illustration.

[**0052**] **FIG. 6B** shows an assembled modular exchanger assembly with the same numbering as **FIG. 6A**.

[**0053**] An end **9272** of each tube **9270** is shown inserted into an aperture **9254** in fluid-tight relationship and extending in a spiral around the ring element **9250**. When the outwardly directed spiral of tube **9270** reaches a point spaced farthest from the ring element **9250**, the spiral then becomes inwardly directed and returns toward the ring element **9250** at another aperture **9254** on the same ring element **9250**. For greater ease in manufacture and assembly, the tube **9270** is not contained in a single plane but the path of the tube is shifted in a lateral direction, i.e. along the axial direction as defined by the centerline of **FIG. 6A**, and the other end **9272** of each tube is inserted through an aperture **9254** that is in a different circumferential and axial position on the ring element **9250**.

[**0054**] For convenience during assembly, the apertures **9254** can comprise twelve equally spaced apertures disposed along a circumferential path on the ring element **9250** in two rows. One row is connected to all of the outwardly directed spirals of tubes **9270**, and the other row of apertures **9254** is connected to all of the inwardly directed tube ends **9272**. The second row of apertures **9254** are not visible in **FIG. 6C** because they are behind the outwardly directed tube ends **9272**.

[**0055**] The shift in lateral position of the tube **9270** is necessary because as each tube **9270** reaches its outer periphery as measured from the ring element **9250**, the tubes **9270** would intersect if they were in the same plane. Because each tube **9270** has an identical path, but a different circumferential starting and end point (at successive apertures **9254** in different planes) each of the twelve tubes **9270** are offset by 30 degrees in the circumferential direction. Thus intersection of the tubes at the outer periphery is avoided, and the final configuration appears to comprise a single assembly of plurality of intertwined tubes **9270** with layers of tubes **9270** being disposed one on top of another.

[**0056**] Preferably, the tubes **9270** are copper tubing, having an outer diameter of about ⅛ of an inch and having a radial wall thickness of 0.010 inches. These parameters have been found capable of containing gas under pressures of up to 1000 p.s.i.g. without failure of the tube **9270**. The length of tubes **9270** can be any desirable length, depending on the desired final dimensions of the assembled modular heat exchange unit. A length of about two feet is appropriate for a smaller size heat exchange unit, and results in the outer periphery of all of the tubes **9270** having an essentially circular configuration with a diameter of about 68 inches. In the preferred embodiment, the length is 22 inches.

[**0057**] The tubes **9270** are not in the same plane, but are shifted slight distances, as is explained above. The distance which tubes **9270** are shifted, however, is small compared to the outer diameter of the periphery of the assembly. In fact, all of the tubes **270** are within a space which is bounded by the planes defined by the radial walls **9256**, **9258** of modular ring element **9250**.

[**0058**] This configuration provides for assembly of the modular ring elements **9250** in stacks after the tubes **9270** have been connected to the apertures **9254** of the ring elements **9250**. Other configurations are possible in which the tubes **270** may be out of the plane boundaries, as long as each modular ring element **9250** is consistently identical and the tubes **9270** do not interfere with the tubes **9270** of the adjacent modular ring elements **9250**.

[**0059**] It is also possible that the tube **9270** can have a shape other than a spiral, or indeed, that only one end **9272** of each tube **9270** is connected to the ring element **9250**. The configuration shown in **FIGS. 6A**, **6B** and 6C, however, is preferable from the consideration of compactness, and also to provide better circulation and transfer of gas through the tubes **9270** and through the system during operation.

[**0060**] In accordance with generally known practices, positioned within tubes **9270** are the metal hydride alloys. Preferably, as described in U.S. Pat. No. 4,396,114, flexible tubular means porous to the passage of hydrogen gas therethrough, e.g., a stainless steel garter spring, coaxial with tube **9270**, is provided. The annular space between the outer surface of the spring and the inner surface of tube **9270** is packed with the appropriate metal hydride alloy. The center portion within the flexible spring provides a passage for hydrogen during use.

[**0061**] In practice of the invention, for each heat exchanger **802**, **804**, one or more modular assemblies containing the hydrogen storage material is mounted by conventional means in the housing **806** such that the modular assembly is configured for heat exchange relationship with air flowing through the housing **806** such that the air passes in direct contact with tubes **270** of the modular assembly. Each modular assembly is suitably fluidly coupled to respective conduits **8022, 8042**, for facilitating hydrogen supply and return. In the preferred embodiment, each heat exchanger **802, 804** includes fifteen (15) modular assemblies (ie. separate ring manifolds **9238**) disposed in parallel relative to each other. The ring manifold **9238** for each of the modular assemblies is separately fluidly coupled to respective conduits **8022, 8042**. Each modular assembly includes twelve (12) tubes **9270**.

[**0062**] In one embodiment, heat exchangers **802** and **804** are mounted to a bracket fastened within a metal duct housing **806**. The metal duct housing **806** defines air flow conduits **302, 304, 402, 404, 502, 504, 602** and **604**.

[**0063**] Preferably, the gaseous hydrogen of the low pressure gaseous fluid received by the compressor **20** is hydrogen which has been desorbed from the hydrogen storage material of one of the first and second containers **30, 40**. Accordingly, in one embodiment, a low pressure gaseous fluid is provided consisting essentially of hydrogen desorbed from one of the first and second hydrogen storage materials (during the "cooling cycle"). The low pressure gaseous fluid consisting essentially of hydrogen desorbed from one of the first and second hydrogen storage materials is received by the compressor **20**. The compressor **20** then compresses the delivered low pressure gaseous fluid to form a high pressure gaseous fluid consisting essentially of gaseous hydrogen desorbed from one of the first and second hydrogen storage materials and effects the delivery of this high pressure gaseous fluid to the hydrogen storage material of the other one of the first and second containers **30, 40**. In this respect, while the hydrogen storage material of one of the first and second containers **30, 40** is undergoing a cooling cycle, the hydrogen storage material of the other one of the first and second containers **30, 40** is undergoing a regeneration cycle, and the desorbed hydrogen from one of the containers **30, 40** is used to charge (become absorbed by) the hydrogen storage material of the other one of the containers **30, 40**.

[**0064**] Air flow across the heat exchangers **802, 804** is controlled by dampers **3021, 3045, 4022, 4046, 5023, 5047, 6024** and **6048** disposed in the conduits **302, 304, 402, 404, 502, 504, 602**, and **604**. The damper **3021** is disposed in the conduit **302** for opening and closing fluid communication between ambient air being drawn from the interior of the vehicle and the heat exchanger **802**. The damper **3045** is disposed in the conduit **304** for opening and closing fluid communication between fluid flowing across the heat exchanger **802** and the interior of the vehicle. Both dampers **3021** and **3045** must be open to allow fan **10*a*** to effect flow through conduits **302** and **304** and across heat exchanger **802**. The damper **4022** is disposed in the conduit **402** for opening and closing fluid communication between outside ambient air being drawn from the external environment and the heat exchanger **802**. The damper **4046** is disposed in conduit **404** for opening and closing fluid communication between fluid flowing across heat exchanger **802** and the external environment (outside ambient air). Both dampers **4022** and **4046** must be open to allow fan **50** to effect flow through conduits **402** and **404** and across heat exchanger **802**. The damper **5023** is disposed in the conduit **502** for opening and closing fluid communication between the outside ambient air being drawn from the external environment and the heat exchanger **804**. The damper **5047** is disposed in the conduit **504** for opening and closing fluid communication between fluid flowing across the heat exchanger **804** and the external environment (outside ambient air). Both dampers **5023** and **5047** must be open to allow fan **50** to effect flow through conduits **502** and **504** and heat exchanger **804**. The damper **6024** is disposed in the conduit **602** for opening and closing fluid communication between ambient air being drawn from the interior of the vehicle and the heat exchanger **804**. The damper **6048** is disposed in the conduit **604** for opening and closing fluid communication between fluid flowing across the heat exchanger **804** and the interior of the vehicle. Both dampers **6024** and **6048** must be open to allow fan 1Ob (in the **FIG. 1** embodiment) or fan **10*a*** (in the embodiment where a single fan **10*a*** is used to also perform the function of fan **10*b***, where conduits **304** and **604** are joined together) to effect flow through conduits **602** and **604** and across heat exchanger **804**.

[**0065**] The dampers can be in the form of any of any mechanical closing device such as a flat piece of metal that slides, or is brought to lay over, the duct opening. Modes of actuation of this damper can vary, with electromechanical actuators such as solenoids, servos, or pistons performing the conversion of electrical or compressed gas energy into mechanical motion.

[**0066**] Air flow across the heat exchangers **802, 804** is generated by fans **10*a*** and **50** (and, in the **FIG. 1** embodiment, also fan lob). In the preferred embodiment, each of the fans is EBM Model No. W2G130-AA33-01, 14 Watts. Each of the fans is mounted with simple metal brackets and sheet metal screws to the metal duct work housing **806**. **FIG. 1** shows the presence of separate fans **10*a*, 10*b*** for each of exchangers **802**, and **804**. The function of these two fans could also be accomplished with only one fan if the conduits (ducts) **304** and **604** are joined together.

[**0067**] Referring to **FIGS. 3A, 3B**, 3C, and 4, the compressor **20** is disposed within a collection container **60** which defines a collection space **62** to effect collection and containment of any gaseous fluid (consisting essentially of gaseous hydrogen) which may escape or leak from the compressor **20** as gaseous fluid leakage flow. Preferably, the collection container **60** is made from **6061** aluminum. The outer diameter of this compressor container **60** or "can" is 11 inches, with a wall thickness of 0.5 inches, and a length of 17 inches. Flat, circular, aluminum end plates **61, 63**, that are 0.75 inches thick, are attached to the ends of a tubular portion **65** to seal the "can". The end plates **61, 63** are attached to the tubular portion **65** via the use of 36 equally spaced high strength machine screws. An O-ring is disposed between each of the ends of the tubular portion **65** and the respective end plates **61, 63** to provide a leak tight seal of the endplates **61, 63** to the tubular portion **65**. The container is mounted on a stand **19** which, in turn, is mountable to the frame **6** of the vehicle **4**.

[**0068**] Preferably, the interior of the container **60** includes a precious metal based catalytic material that has been treated to operate in a moist environment and is provided to convert free oxygen within the space **62**, with hydrogen that is present, into water vapor, thus keeping the presence of oxygen in the system at very low concentrations at all times. Preferably, the catalytic material is a fuel cell type catalytic electrode material that has been applied to an 8 inch porous substrate, and then suitably mounted within the container **60**.

[0069] The collection space **62** is fluidly coupled to the suction **22** of the compressor through a return conduit **64**. The return conduit **64** is coupled, at a tee junction **66**, to a suction conduit **26** extending from the suction **22** of the compressor. A one-way valve **68** (eg. a check valve) is disposed in the return conduit **64**. The one-way valve **68** is configured to prevent flow from the suction conduit **26**, through the return conduit **64**, and to the collection container **60**. The one-way valve is normally biased closed (ie., preventing fluid flow through conduit **64**). Once sufficient gaseous fluid (consisting essentially of hydrogen) becomes collected within the collection container **60** so that the pressure of the collected gaseous fluid exceeds the combination of the mechanical bias of the one-way valve **68** and the fluid pressure on the downstream side (when fluid flow is understood to be from the collection container **60**, through the conduit **64**, and to the compressor suction **22**) of the one-way valve **68**, the one-way valve **68** is forced open so as to facilitate flow of the collected gaseous fluid from the collection container **60** and to the compressor suction **22** so as to thereby effect usage of at least a portion, and preferably a significant portion, of the gaseous fluid which leaks from the compressor **20**. In this respect, the valve **68** opens in response to the condition where the pressure in the container **60** exceeds the fluid pressure in the suction conduit **26** (or suction **22**) by a minimum predetermined amount. The valve **68** is rated to open at 1 psig. In the preferred embodiment, the valve **68** is a Circle Seal Model No. 2232B-2MM.

[0070] The collection container **60** is also provided with a relief valve **6002** mounted to the exterior of the container **60**. The relief valve **6002** is rated to open at 50 psig and is fluidly coupled to the collection space **62** and is provided to provide overpressure protection for the container **60** in the event that pressure in the container **60** were to rise above 50 psig, thus preventing the possibility of excessive pressure occurring within the container **60**. The relief valve **6002** is configured to discharge to the immediate environment. Preferably, the relief valve **6002** is Circle Seal, Model No. HP532B-2M-50.

[0071] Upstream of the relief valve **6002**, and disposed within the collection space **62**, a check valve **6004** is provided. The check valve is rated to open at 1 psig. The check valve **6004** prevents air and/or contamination from entering the compressor container **60** if the relief valve **6002** were to be inadvertently opened, or if one desired to replace the relief valve **6002** with a relief valve of a different setting. Preferably, the check valve **6004** is Circle Seal, Model No. 2232B-2MM.

[0072] The collection container is further provided with an access valve **6006** mounted to the exterior of the container **60**. The access valve **6006** is fluidly coupled to the collection space **60** for removing air and/or contamination from the collection space, and for the addition of hydrogen and/or other gases into the collection space. In the preferred embodiment, the access valve **6006** is Swagelock Model No. B-4HK4.

[0073] Referring to **FIG. 5**, the compressor **20** includes a variable volume space **2002** disposed within a housing **2004** of the compressor **20**. The variable volume space **2002** communicates with the suction **22** and discharge **24** of the compressor **20**. The compressor **20** receives a low pressure gaseous fluid consisting essentially of gaseous hydrogen (and, in a preferred embodiment, gaseous hydrogen desorbed from a hydrogen storage material) through the suction **22**, and the received gaseous fluid is then flowed to the variable volume space **2002**. The gaseous fluid in the variable volume space is then compressed by a moveable piston **2006** of the compressor **20**, resulting in the pressurization of the gaseous fluid. In this respect, the space **2002** is an example of a fluid compression space. The piston **2006** is connected by a connecting rod **2008** to a crank **2010** on a shaft of an electric motor. The shaft turns the crank **2010**, which in turn drives or otherwise actuates the piston **2006** via the connecting rod **2008** to effect compression of the gaseous fluid and to form a high pressure gaseous fluid consisting essentially of gaseous hydrogen. The high pressure gaseous fluid then becomes discharged from the compressor through the discharge **24**, and is flowed to the container **30** or **40** containing the hydrogen storage material undergoing a regeneration cycle.

[0074] The piston **2006** is substantially sealed against the housing **2004** of the compressor **20** with a sealing member **2014** so as to substantially prevent leakage of the gaseous fluid from the variable volume space **2002**. Referring to **FIG. 5***a*, in one embodiment, the sealing member is a u-cup seal, an o-ring seal, or a piston ring seal. Alternatively, and referring to **FIG. 5***b*, the sealing member **2014** is a rolling diaphragm seal which extends between, and is coupled to each of the piston **2006** and the housing **2004**. Preferably, the rolling diaphragm seal is an aluminized Mylar™ sheet, bonded on both sides with a rubber diaphragm material (preferably VITON™) (ie., the aluminized Mylar™ sheet is sandwiched between two diaphragms of VITON™). However, when leakage of the gaseous fluid does occur from the variable volume space **2002** and past or across the sealing member **2014** of the piston **2006** by virtue of a bypass conduit **2009**, such leaked gaseous fluid flow **2011** is intended to be collected within the collection container **60**, and then re-introduced to the suction **22** of the compressor **20** in the manner described above. Leakage from the compressor **20** is understood to include leakage from the variable volume space **2002** and includes flow past or across the sealing member **2014** of the piston **2006** which effects substantial sealing of the piston **2006** against the housing **2004**. For the u-cup seal, or o-ring seal, or piston ring seal, the major leakage is between the sealing member and the housing. In the case of the rolling diaphragm seal, the leakage results from diffusion of the gaseous fluid across the diaphragm. The rate of leaked gaseous fluid flow can be expected to be anywhere from less than 5% to less than 50% of the total flow of gaseous fluid through the compressor **20**. Preferably, the compressor **20** is a Thomas Model No. 2650CE44. This compressor **20** has a suction pressure of 15 psia and a discharge pressure of 75 psia at a flow of 125 SLPM.

[0075] Referring to **FIGS. 3A, 3B**, and **3C**, the compressor **20** fluidly communicates with the first and second hydrogen storage materials via fluid passages defined by fluid flow conduits extending through (or penetrating) the collection container **60**. The fluid flow conduits are sealed or substantially sealed to the collection container **60** (eg., by means of welding, or by means of conventional tapered national standard pipe threads) for preventing, or substantially preventing, any leakage of collected gaseous hydrogen from the collection container **60** and externally of the collection container **60**. Additionally, the compressor **20** is electrically coupled to a power supply via suitable wiring which extends through (or penetrates) the collection container **60**. The wire connections are sealed or substantially sealed to the collection container **60** via "Pete's Plug" fittings. These effect sealing of the wire against the collection container **60** by compressing rubber seals evenly around the protruding wire.

[**0076**] The suction conduit **26** extends from the compressor suction **22** and is fluidly coupled to a hydrogen return conduit **806** coupling to a tee junction **808**. The hydrogen return conduit **806** is fluidly coupled to each of the hydrogen supply/return conduits **8022, 8042** for the respective containers **30, 40**, by a respective tee junction, **8024, 8044**. Each of the hydrogen supply/return conduits **8022, 8042** is fluidly coupled to a respective container **30, 40**. This described manner of fluid coupling facilitates fluid communication between each of the containers **30, 40** and the compressor suction **22**, and thereby facilitate flow of low pressure gaseous fluid consisting essentially of gaseous hydrogen from containers **30, 40** during the respective cooling cycle.

[**0077**] The tee junction **808** includes a pressure gauge port. This port allows either an analog pressure gauge or pressure transducer to be attached, which enables the pressure of the gaseous fluid at this point to be known during the operation of the system.

[**0078**] Each of pressure relief devices **8028, 8048** are mounted to the respective tee junction **8024, 8044**. These pressure relief devices are set to release gaseous fluid from the system at any time if the pressure of this gaseous fluid were to rise to a value greater than 150 psig, thus keeping the system pressure at less than or equal to 150 psig. In the preferred embodiment, each of the relief devices **8028, 8048** is a Circle Seal, Model No. HP532B-2M-150.

[**0079**] Each of manual isolation valves **8029, 8049** is disposed in a respective hydrogen supply/return conduit **8022, 8042** between a respective tee junction **8024, 8044** and a respective container **30, 40**. These isolation valves help to isolate the heat exchangers **802, 804** from the system piping so that air and contamination cannot enter the heat exchangers **802, 804** during system assembly. In the preferred embodiment, each of the isolation valves is a Nupro Model No. B-4P6T4.

[**0080**] Each of particle filters **8030, 8050** is also disposed between a respective isolation valve **8022, 8024** and a respective container **30, 40**. These particle filters capture and thus prevent particle contamination from entering the solenoid valves, and thus prevents disruption of successful and leak tight operation. In one embodiment, the particle filters are Parker/Balston's model number 97S6.

[**0081**] Solenoid valve **8026** is disposed in conduit **806** between tee junctions **808** and **8024** to open and close fluid communication between the container **30** and the compressor suction **22**. Solenoid valve **8026** is open when the heat exchanger **802** is in the cooling cycling mode, and is closed when the heat exchanger **802** is in the regeneration cycle mode. Solenoid valve **8046** is disposed in conduit **806** between tee junctions **808** and **8044** to open and close fluid communication between the container **40** and the compressor suction **22**. Solenoid valve **8046** is open when the heat exchanger **804** is in the cooling cycle mode, and is closed when the heat exchanger **804** is in the regeneration cycle mode.

[**0082**] The isolation valve **261** is used (the valve is closed) only during system assembly, to keep air and contamination from entering the container **60**. In the preferred embodiment, the isolation valve **261** is McMaster-Carr Model No. 4912K48.

[**0083**] A discharge conduit **241** extends from the compressor discharge **24**, and is fluidly coupled to a hydrogen supply conduit **810** by coupling to a tee junction **812**. Isolation valve **245** is disposed in conduit **241**, between the discharge **24** and the tee junction **812**. Isolation valve **245** is used (ie. the valve is closed) only during system assembly, to keep air and contamination from entering the discharge outlet connection of the compressor **20**. The hydrogen supply conduit **810** is fluidly coupled to each of the hydrogen supply/return conduits **8022, 8042** by a respective tee junction **8024, 8044**. This described manner of fluid coupling facilitates fluid communication between each of the containers **30, 40** and the compressor discharge **24**, and thereby facilitates flow of high pressure gaseous fluid consisting essentially of hydrogen from the compressor discharge **24** to the containers **30, 40** during the respective regeneration cycle.

[**0084**] A relief valve **247** is fluidly coupled to discharge conduit **241** between the discharge **24** and the isolation valve **245**. The relief valve **247** is a 130 psig relief valve. Preferably, the relief valve **247** is Circle Seal, Model No. HP532B-2M-130. The relief valve **247** discharge is fluidly coupled to the suction conduit **26** between the isolation valve **261** and the suction **22**. The relief valve **247** is provided for allowing high pressure gas to flow back to the suction of the compressor **20** should valve **245** (or any other solenoid or access valve) be inappropriately closed, thus prolonging the operational life of the compressor **50**.

[**0085**] A further relief valve **249** is fluidly coupled to discharge conduit **241** downstream of the relief valve **247** and upstream of the isolation valve **245**. The relief valve **249** is a 150 psig relief valve. Preferably, the relief valve **249** is Circle Seal, Model No. HP532B-2M-150. The relief valve **249** discharges to the immediate environment, and is provided for allowing high pressure gas to escape the discharge of the compressor should relief valve **247** not function properly and/or the pressure at the discharge exceed 150 psig.

[**0086**] Preferably, the isolation valve **245** is McMaster-Carr Model No. 4912K86.

[**0087**] Solenoid valve **8032** is disposed in the conduit **810** between the tee junctions **812** and **8024** to open and close fluid communication between the container **30** and the compressor discharge **24**. Solenoid valve **8032** is open when the heat exchanger **802** is in the regeneration cycle mode, and is closed when the heat exchanger **802** is in the cooling cycle mode. Solenoid valve **8052** is disposed in the conduit **810** between the tee junctions **812** and **8044** to open and close fluid communication between the container **40** and the compressor discharge **24**. Solenoid valve **8052** is open when heat exchanger **804** is in the regeneration cycle mode, and is closed when the heat exchanger **804** is in the cooling cycle mode.

[**0088**] In the preferred embodiment, each of the solenoid valves **8026, 8046, 8032** and **8052** is a Kip Model No. 241116.

[0089] A H_2/Fill/Purge Evacuation valve **243** is disposed in the discharge conduit **241**, between the compressor discharge **24** and the tee junction **812**. This valve **243** is used to provide an access port during system assembly so that air and contamination can be removed from the system, via the use of a vacuum. Once the system has been evacuated, then gaseous hydrogen can be introduced through the valve **243** and the system can then be "charged" with the necessary amount of hydrogen gas. An example of the valve **243** is Whitey valve, model number B-1KF4.

[0090] A programmable logic controller **900** is provided to control the operation of the compressor **20**, the fans **10***a*, **10***b* and **50**, and the solenoid valves **8026**, **8046**, **8032**, **8052**, including effecting parallel operation of cooling and regeneration cycles. This controller will open the solenoid valves at the appropriate time so as to provide the most optimal operation of the heat exchangers **802**, **804** given the ambient conditions and the desired cooling output temperature. The controller **900** may also be used to operate the above-mentioned dampers.

[0091] In general, components of the system will be connected using soldered, silver soldered, and welded connections. The fluid conduits and other components which contain gaseous hydrogen are copper tubing with an outer diameter of 0.375 inches, and a tube wall thickness of 0.035 inches.

[0092] Electrical power can be supplied to the various components by coupling of electrical motors to an electrical system of the vehicle. Alternatively, power can be supplied by an independent electrical generator.

[0093] Referring to **FIG. 7**, the system **2** can be mounted to the frame **6** of a vehicle **4**, and suitable fluid connections of the conduits of the system can be made to existing air flow ducts of the vehicle for fluid communication with vehicle interior air **5**. Also, for those conduits requiring fluid communication with the ambient air **7** external to the vehicle, conduits (ducts) can be configured to extend outside of the engine compartment to receive such ambient air without substantial thermal influences from the engine compartment.

[0094] The operation of the preferred embodiment of the system of the present invention will now be described with reference to **FIGS. 1 and 2**, where each of the first and second hydrogen storage materials consists essentially of La Ni_5 and also includes about 0.25 wt % platinum and 0.25 wt % palladium (each based on total weight of the hydrogen storage material) for catalytic function, and also includes about 0.5 wt % (based on total weight of the hydrogen storage material) of Syloid-63 (a dessicant).

[0095] 1. Start: All components off.

[0096] 2. Action:Turn on main power switch from either "Off" to "Manual Control", or "Off" to "Automatic Cooling".

[0097] 3. If switched to "Manual Control", power would now be supplied to several on/off "power" switches. Each solenoid, fan and compressor (and dampers) will have its own switch that can be manually energized as desired, so as to effect operation of the system in a manner similar to that described below for the "Automatic Cooling" mode.

[0098] 4. If switched to "Automatic Cooling", system would proceed through four separate, consecutive time intervals, namely Time Interval Nos. 1 through 4.

[0099] The system then repeats itself, for so long as desired.

[0100] During Time Interval Nos. 1 and 2, heat exchanger **802** is in the cooling mode, and heat exchanger **804** is in the heat rejection mode (regeneration). Flow of gaseous fluid consisting essentially of gaseous hydrogen during this time will average about 125 SLPM (Standard Litres Per Minute). The temperature of heat exchanger **802** during this time will be about 7° C., and the heat exchanger **802** operates at a pressure of about 15 psia (ie. the pressure of the gaseous fluid consisting essentially of gaseous hydrogen within the heat exchanger is about 15 psia). The temperature of the air leaving the heat exchanger **802** should be about 18° C. The temperature of heat exchanger **804** during this time will be about 40° C., and the heat exchanger **804** operates at a pressure of about 75 psia (ie. the pressure of the gaseous fluid consisting essentially of gaseous hydrogen within the heat exchanger is about 75 psia). The temperature of the air leaving heat exchanger **804** should be about 40° C.

[0101] Initially, the system operates in Time Interval No. 1. The duration of Time Interval No. 1 is variable, and lasts from 0 to at least 30 seconds. Three (3) seconds is a preferred duration for Time Interval No. 1. At the beginning of Time Interval No. 1, compressors are turned on (compressors remain on after this and continuously through Time Interval Nos., 1, 2, 3, and 4). Heat exchanger **802** is in the cooling mode, and the dampers **3021** and **3045** are open. Heat exchanger **804** is in the heat rejection mode (regeneration), and the dampers **5023** and **5047** are open. All other dampers are closed. Fans **10***a* and **50** are on. Air flow rate generated by fan **10***a* (during cooling mode) is maintained relatively less than the air flow rate generated by fan **50** (during regeneration). Preferably, the air flow rate during cooling mode is 50% less than the air flow rate during regeneration mode. In this respect, air velocity during the regeneration mode is 5 m/s, and air velocity during the cooling mode is 2.5 m/s. However, the program controller may determine that a higher air flow rate for either fan **10***a* and/or fan **50** is desired in order to provide optimal heat exchanger performance.

[0102] Solenoid valves **8026**, **8046**, **8032**, and **8052** are all open during Time Interval No. 1. This is done to allow the hydrogen pressure in the system to equilibrate quickly, thus equalizing the temperature of each heat exchanger and ensuring that the pressure differential (between the compressor inlet and the compressor discharge) are minimal during system bed switchover, thus providing a gentle and gradual pressure gradient for the compressor, as well as improve the efficiency of the heat exchangers.

[0103] After Time Interval No. 1 is completed, Time Interval No. 2 begins and lasts from 0 to at least 500 seconds. One hundred and twenty (120) seconds is a preferred duration for Time Interval No. 2. Upon commencement of Time Interval No. 2, solenoid valves **8046** and **8032** close. This leaves solenoid valves **8026** and **8052** open, and heat exchanger **802** is in the cooling mode, and heat exchanger **804** is in the regeneration mode.

[0104] After Time Interval No. 2 is completed, Time Interval Nos. 3 and 4 proceed sequentially. During Time

Interval Nos. 3 and 4, heat exchanger **802** is in the heat rejection mode (regeneration), and heat exchanger **804** is in the cooling mode. Flow of gaseous fluid consisting essentially of gaseous hydrogen through the compressor during this time will average about 125 SLPM. The temperature of heat exchanger **804** during this time will be about 7° C., and the heat exchanger **802** operates at a pressure of about 15 psia (ie. the pressure of the gaseous fluid consisting essentially of gaseous hydrogen within the heat exchanger is about 15 psia). The temperature of the air leaving heat exchanger **804** should be about 18° C. The temperature of heat exchanger **802** during this time will be about 40° C., and the heat exchanger **802** operates at a pressure of about 75 psia (ie. the pressure of the gaseous fluid consisting essentially of hydrogen within the heat exchanger is about 75 psia). The temperature of the air leaving heat exchanger **802** should be about 40° C.

[0105] The duration of Time Interval No. 3 is variable, and lasts from 0 to at least 30 seconds. Three (3) seconds is a preferred duration for Time Interval No. 3. During Time Interval No. 3, heat exchanger **802** is in the heat rejection mode (regeneration), and dampers **4022** and **4046** are open. Also, heat exchanger **804** is in the cooling mode and dampers **6024** and **6048** are open. All other dampers are closed. Fans **10***b* (or **10***a*, in the case of the above-described embodiment where conduits **304** and **604** are joined together) and **50** are on. Air flow generated by fan **50** during cooling is maintained relatively less than the air flow rate generated by fan **10***b* (or **10***a*) during regeneration. Preferably, air velocity during the regeneration mode is 5 m/s, and air velocity during the cooling mode is 2.5 m/s (ie. preferably, the air flow rate during the cooling mode is 50% less than the air flow rate during regeneration mode). However, the program controller may determine that a higher air flow rate for either fan **10***b* (or **10***a*) and/or fan **50** is desired in order to provide optimal heat exchanger performance.

[0106] Solenoid valves **8026**, **8046**, **8032** and **8052** are all open during Time Interval No. 3. This is done to allow the gaseous fluid pressure in the system to equilibrate quickly, thus equalizing the temperature of each heat exchanger and ensuring that the pressure differential (between the compressor suction and the compressor discharge) are minimal during system bed switchover, thus providing a gentle and gradual pressure gradient for the compressor, as well as improve the efficiency of the heat exchangers.

[0107] After Time Interval No. 3 is completed, Time Interval No. 4 begins and lasts from 0 to at least 500 seconds. One hundred and twenty (120) seconds is a preferred duration for Time Interval No. 4. Upon commencement of Time Interval No. 4, solenoid valves **8026** and **8052** close. This leaves each of solenoid valves **8032** and **8046** in an open condition, and heat exchanger **802** in the regeneration mode, and heat exchanger **804** in the cooling mode.

[0108] After completion of Time Interval No. 4, the system can repeat itself, beginning at Time Interval No. 1, and moving through Time Interval Nos. 2, 3, and 4.

[0109] Although the disclosure describes and illustrates preferred embodiments of the invention, it is to be understood that the invention is not limited to these particular embodiments. Many variations and modifications may occur to those skilled in the art within the scope of the invention.

1. A system for flowing gaseous fluid comprising:

a collection container;

compression machinery disposed within the collection container, and including an inlet, a fluid compression space, and an outlet, wherein the inlet is fluidly coupled to the outlet through the fluid compression space, and wherein the inlet is fluidly coupled to an inlet fluid conduit and the outlet is fluidly coupled to an outlet fluid conduit and each of the inlet and outlet fluid conduits extends through and externally of the container;

wherein the collection container is configured for receiving gaseous fluid leakage flow from the compression space, and is fluidly coupled to the inlet of the compression machinery to facilitate flow of the received leaked gaseous fluid to the inlet of the compression machinery.

2. The system as claimed in claim 1, wherein the collection container is fluidly coupled to the inlet fluid conduit by a return fluid conduit, and wherein a one-way valve is disposed in the return fluid conduit and is configured to prevent fluid flow through the return conduit from the inlet fluid conduit and to the container.

3. The system as claimed in claim 2, wherein the one-way valve is biased to a normally closed position preventing flow through the return conduit.

4. The system as claimed in claim 3, wherein the one-way valve is configured to open in response to a condition wherein a fluid pressure within the container exceeds a fluid pressure within the inlet fluid conduit by a predetermined minimum amount.

5. The system as claimed in claim 1, wherein the compression machinery includes a housing and the housing defines the inlet and the outlet, and wherein the compression space is disposed within the housing, and wherein the housing is disposed within the collection container.

6. The system as claimed in claim 5, wherein the compression machinery includes a bypass conduit for effecting the leakage flow from the fluid compression space and to the collection container.

7. The system as claimed in claim 6, wherein the bypass conduit is disposed in fluid communication with the fluid compression space upstream of the outlet and downstream of the inlet.

8. A system for flowing gaseous hydrogen comprising:

a collection container;

compression machinery disposed within the collection container, and including an inlet, a fluid compression space, and an outlet, wherein the inlet is fluidly coupled to the outlet through the fluid compression space, and wherein the inlet is coupled to an inlet fluid conduit and the outlet is coupled to an outlet fluid conduit and each of the inlet and outlet fluid conduits extends through and externally of the container; and

a hydrogen storage container containing at least one hydrogen storage material and fluidly coupled to the outlet of the compression machinery;

wherein the collection container is configured for receiving gaseous hydrogen leakage flow from the compression space, and wherein the collection container is fluidly coupled to the inlet of the compression machinery to facilitate flow of the leaked gaseous fluid to the inlet of the compression machinery.

9. The system as claimed in claim 8, wherein the collection container is fluidly coupled to the inlet fluid conduit by a return fluid conduit, and wherein a one-way valve is disposed in the return fluid conduit and is configured to prevent fluid flow through the return conduit from the inlet fluid conduit and to the container.

10. The system as claimed in claim 9, wherein the one-way valve is biased to a normally closed position preventing flow through the return conduit.

11. The system as claimed in claim 10, wherein the one-way valve is configured to open in response to a condition wherein a fluid pressure within the container exceeds a fluid pressure within the inlet fluid conduit by a predetermined minimum amount.

12. The system as claimed in claim 8, wherein the compression machinery includes a housing and the housing defines the inlet and the outlet, and wherein the compression space is disposed within the housing, and wherein the housing is disposed within the collection container.

13. The system as claimed in claim 12, wherein the compression machinery includes a bypass conduit for effecting the leakage flow from the fluid compression space and to the collection container.

14. The system as claimed in claim 12, wherein the bypass conduit is disposed upstream of the outlet and downstream of the inlet.

15. A system for flowing gaseous fluid comprising:

a collection container;

compression machinery comprising:

an inlet;

a fluid compression space fluidly coupled to the inlet;

a moveable member disposed in force application communication relative to the fluid compression space and configured for effecting an application of a force to the fluid compression space upon a movement of the moveable member; and

an outlet fluidly coupled to the fluid compression space;

wherein the collection container is configured for receiving gaseous fluid leakage flow across the moveable member from the fluid compression space, and is fluidly coupled to the inlet of the compression machinery to facilitate flow of the received leaked gaseous fluid to the inlet of the compression machinery.

16. The system as claimed in claim 15, wherein the collection container is fluidly coupled to the inlet by a return fluid conduit, and wherein a one-way valve is disposed in the return fluid conduit and is configured to prevent fluid flow through the return conduit from the inlet and to the container.

17. The system as claimed in claim 16, wherein the one-way valve is biased to a normally closed position preventing flow through the return conduit.

18. The system as claimed in claim 16, wherein the one-way valve is configured to open in response to a condition wherein a fluid pressure within the container exceeds a fluid pressure at the inlet by a predetermined minimum amount.

19. The system as claimed in claim 15, wherein the application of the force is configured to effect pressurization of any gaseous fluid in the fluid compression space and effect flow of the pressurized gaseous fluid through the outlet.

20. The system as claimed in claim 19, wherein the compression machinery includes a housing defining the inlet and the outlet and the fluid compression space is disposed within the housing, and wherein the compressor machinery further comprises a bypass conduit for effecting the gaseous fluid leakage flow from the fluid compression space and across the moveable member.

21. The system as claimed in claim 20, wherein the compression machinery includes a housing, the housing defining the inlet and the outlet, wherein the fluid compression space is disposed within the housing, and wherein the moveable member is configured for movement relative to the housing, and wherein the collection container is configured to receive any gaseous fluid leakage flow through a bypass conduit defined between the moveable member and the housing.

22. The system as claimed in claim 21, wherein the bypass conduit is disposed upstream of the outlet and downstream of the inlet.

23. The system as claimed in claim 19, wherein the compression machinery includes a housing, wherein the fluid compression space is disposed within the housing, and wherein the moveable member comprises a piston and a rolling diaphragm member, and wherein the piston is coupled to the housing by the rolling diaphragm member, and wherein a bypass conduit is provided in the rolling diaphragm to facilitate the gaseous fluid leakage flow.

24. The system as claimed in claim 23, wherein the bypass conduit is disposed upstream of the outlet and downstream of the inlet.

25. A system for flowing gaseous fluid comprising:

a collection container;

compression machinery comprising:

an inlet;

a fluid compression space fluidly coupled to the inlet;

a moveable member disposed in force application communication relative to the fluid compression space and configured for effecting an application of a force to the fluid compression space upon a movement of the moveable member; and

an outlet fluidly coupled to the fluid compression space; and

a hydrogen storage container containing at least one hydrogen storage material and fluidly coupled to the outlet of the compression machinery;

wherein the collection container is configured for receiving gaseous fluid which leaks across the moveable member from the compression space, and is fluidly coupled to the inlet of the compression machinery to facilitate flow of the leaked gaseous fluid to the inlet of the compression machinery.

26. The system as claimed in claim 25, wherein the collection container is fluidly coupled to the inlet by a return fluid conduit, and wherein a one-way valve is disposed in the return fluid conduit and is configured to prevent fluid flow through the return conduit from the inlet and to the container.

27. The system as claimed in claim 26, wherein the one-way valve is biased to a normally closed position preventing flow through the return conduit.

28. The system as claimed in claim 27, wherein the one-way valve is configured to open in response to a condition wherein a fluid pressure within the container exceeds a fluid pressure at the inlet by a predetermined minimum amount.

29. The system as claimed in claim 26, wherein the application of the force is configured to effect pressurization of any gaseous fluid in the fluid compression space and effect flow of the pressurized gaseous fluid through the outlet.

30. The system as claimed in claim 29, wherein the compression machinery includes a housing defining the inlet and the outlet and the fluid compression space is disposed within the housing, and wherein the compressor machinery further comprises a bypass conduit for effecting the gaseous fluid leakage flow from the fluid compression space and across the moveable member.

31. The system as claimed in claim 30, wherein the compression machinery includes a housing, the housing defining the inlet and the outlet, wherein the fluid compression space is disposed within the housing, and wherein the moveable member is configured for movement relative to the housing, and wherein the collection container is configured to receive any gaseous fluid leakage flow through a bypass conduit defined between the moveable member and the housing.

32. The system as claimed in claim 31, wherein the bypass conduit is disposed upstream of the outlet and downstream of the inlet.

33. The system as claimed in claim 29, wherein the compression machinery includes a housing, wherein the fluid compression space is disposed within the housing, and wherein the moveable member comprises a piston and a rolling diaphragm member, and wherein the piston is coupled to the housing by the rolling diaphragm member, and wherein a bypass conduit is provided in the rolling diaphragm to facilitate the gaseous fluid leakage flow.

34. The system as claimed in claim 33, wherein the bypass conduit is disposed upstream of the outlet and downstream of the inlet.

35. A system for effecting cooling of a first process fluid and heating of a second process fluid comprising:

a first hydrogen storage container containing at least one first hydrogen storage material;

a first process fluid conduit disposed in thermal communication disposition with the hydrogen storage container;

compression machinery fluidly coupled to the first hydrogen storage container for receiving a low pressure gaseous fluid from the hydrogen storage container, and configured for pressurizing the received low pressure gaseous fluid to provide a high pressure gaseous fluid, and discharging a flow of the high pressure gaseous fluid;

a second hydrogen storage container fluidly coupled to the compression machinery for receiving the discharged flow of the high pressure gaseous fluid,

the second hydrogen storage container containing at least one second hydrogen storage material; and

a second process fluid conduit disposed in thermal communication disposition with the hydrogen storage container.

36. The system as claimed in claim 35, wherein at least a portion of the first hydrogen storage container is disposed within the first process fluid conduit, and wherein at least a portion of the second hydrogen storage container is disposed within the second process fluid conduit.

37. The system as claimed in claim 36, wherein compression machinery includes:

an inlet fluidly coupled to the first hydrogen storage container for receiving the low pressure gaseous fluid from the first hydrogen storage container;

a fluid compression space fluidly coupled to the inlet;

a moveable member disposed in force application communication relative to the fluid compression space and configured for effecting an application of a force to the fluid compression space upon a movement of the moveable member to effect the pressurizing of the received low pressure gaseous fluid to provide a flow of high pressure gaseous fluid; and

an outlet fluidly coupled to the fluid compression space and configured for discharging the flow of the high pressure gaseous fluid;

wherein the second hydrogen storage container is fluidly coupled to the outlet for receiving the discharged flow of the high pressure gaseous fluid.

38. The system as claimed in claim 37, wherein each of the first and second hydrogen storage materials comprises a metal hydride material.

39. A vehicle including a passenger compartment and a cooling system, the cooling system comprising:

a first hydrogen storage container containing at least one first hydrogen storage material;

a first process fluid conduit disposed in thermal communication disposition with the hydrogen storage container, and fluidly coupled to the passenger compartment for flowing hot ambient air flow received from within the passenger compartment and effecting heat transfer from the hot ambient air flow to the first hydrogen storage container to provide a cooled ambient air flow to the passenger compartment;

compression machinery fluidly coupled to the first hydrogen storage container for receiving a low pressure gaseous fluid from the hydrogen storage container, and configured for pressurizing the received low pressure gaseous fluid to provide a high pressure gaseous fluid, and discharging a flow of the high pressure gaseous fluid;

a second hydrogen storage container fluidly coupled to the compression machinery for receiving the discharged flow of the high pressure gaseous fluid,

the second hydrogen storage container containing at least one second hydrogen storage material; and

a second process fluid conduit disposed in thermal communication disposition with the hydrogen storage container, and fluidly coupled to an environment exterior to the vehicle.

40. The vehicle as claimed in claim 39, wherein at least a portion of the first hydrogen storage container is disposed within the first process fluid conduit, and wherein at least a portion of the second hydrogen storage container is disposed within the second process fluid conduit.

41. The vehicle as claimed in claim 40, wherein compression machinery includes:

an inlet fluidly coupled to the first hydrogen storage container for receiving the low pressure gaseous fluid from the first hydrogen storage container;

a fluid compression space fluidly coupled to the inlet;

a moveable member disposed in force application communication relative to the fluid compression space and configured for effecting an application of a force to the fluid compression space upon a movement of the moveable member to effect the pressurizing of the received low pressure gaseous fluid to provide a flow of high pressure gaseous fluid; and

an outlet fluidly coupled to the fluid compression space and configured for discharging the flow of the high pressure gaseous fluid;

wherein the second hydrogen storage container is fluidly coupled to the outlet for receiving the discharged flow of the high pressure gaseous fluid.

42. The vehicle as claimed in claim 41, wherein each of the first and second hydrogen storage material comprises a metal hydride material.

43. A method of flowing gaseous fluid comprising:

pressurizing the gaseous fluid with compression machinery;

collecting gaseous fluid which leaks from within the compression machinery in a collection container; and

flowing the collected leaked gaseous fluid to the compression machinery.

44. The method as claimed in claim 43, wherein the compression machinery includes an inlet, a fluid compression space, and an outlet, wherein the inlet is fluidly coupled to the outlet through the fluid compression space, and wherein the leaking gaseous fluid leaks from the fluid compression space.

45. The method as claimed in claim 44, wherein the collected leaked gaseous fluid is flowed to the compression machinery in response to a condition wherein a fluid pressure in the container exceeds a fluid pressure at the inlet by a minimum predetermined amount.

46. The system as claimed in claim 45, wherein the compression machinery includes a housing, the housing defining the inlet and the outlet, wherein the fluid compression space is disposed within the housing, and the gaseous fluid leaks from the fluid compression space.

47. The system as claimed in claim 46, wherein the gaseous fluid leaks from upstream of the outlet and downstream of the inlet.

48. The method as claimed in claim 47 wherein the gaseous fluid consists essentially of gaseous hydrogen.

49. The method as claimed in claim 48 wherein the gaseous fluid is gaseous hydrogen.

50. A method of effecting cooling of a first process fluid and heating of a second process fluid comprising:

transferring heat from a hot first process fluid to a first hydrogen storage material to effect desorption of gaseous hydrogen and provide a cooled first process fluid;

mechanically compressing the desorbed gaseous hydrogen to provide pressurized gaseous hydrogen;

effecting absorption of the pressurized gaseous hydrogen by a second hydrogen storage material to produce heat energy;

transferring the produced heat energy to a second process fluid.

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