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CA 2807416 C 2019/02/19

(11)(21) 2 807 416

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(86) Date de dépôt PCT/PCT Filing Date: 2011/08/16
(87) Date publication PCT/PCT Publication Date: 2012/02/23
(45) Date de délivrance/Issue Date: 2019/02/19
(85) Entrée phase nationale/National Entry: 2013/02/01
(86) N° demande PCT/PCT Application No.: US 2011/047994
(87) N° publication PCT/PCT Publication No.: 2012/024342
(30) Priorité/Priority: 2010/08/16 (US61/374,126)

(51) Cl.Int./Int.Cl. *A62B 7/02* (2006.01)

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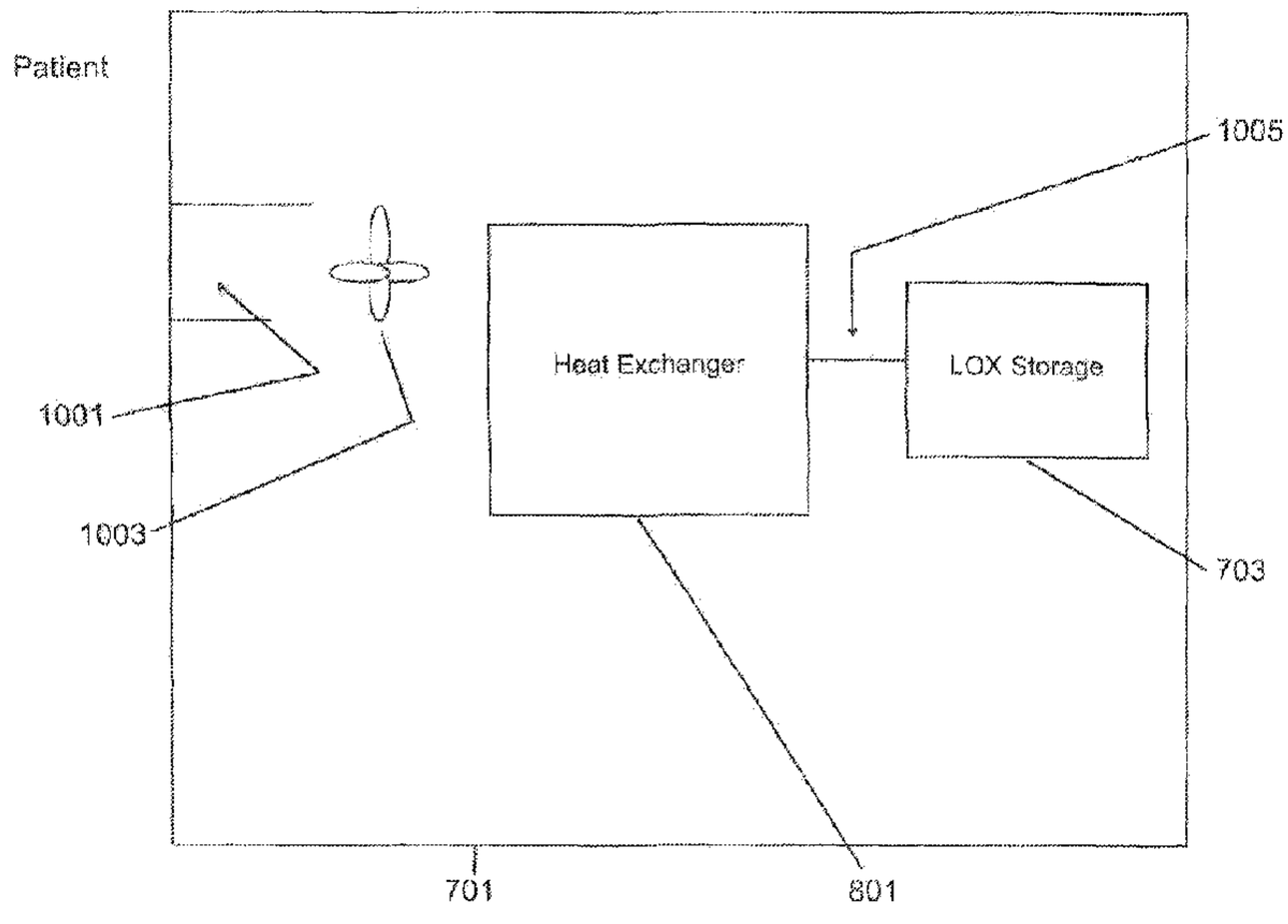
(54) Titre : PROCEDES, SYSTEMES ET DISPOSITIFS UTILISANT DE L'OXYGENE LIQUIDE POUR FOURNIR UNE ASSISTANCE VENTILATOIRE

(54) Title: METHODS, SYSTEMS AND DEVICES USING LOX TO PROVIDE VENTILATORY SUPPORT



(57) Abrégé/Abstract:
A portable liquid oxygen system may provide an average flow rate of oxygen gas at approximately 6 - approximately 20 lpm using a rapid gas conversion mode. The liquid oxygen system may weigh less than 10 pounds. A heat exchanger may be provided, and wherein the rapid gas conversion mode may utilize a heater on the heat exchanger. The rapid gas conversion mode may utilize a Stirling engine passing air from a hot sink across the heat exchanger to a cold sink. The system may have multiple modes of operation. The modes of operation may be a continuum of settings and not discrete modes of operation. Flow capacity may be changed when switching between modes of operation. Oxygen gas pressure may be changed when switching between modes of operation. The system may automatically switch modes of operation based on a patient's condition.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 February 2012 (23.02.2012)

PCT

(10) International Publication Number
WO 2012/024342 A1

(51) International Patent Classification:
A62B 7/02 (2006.01)

(21) International Application Number:
PCT/US2011/047994

(22) International Filing Date:
16 August 2011 (16.08.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/374,126 16 August 2010 (16.08.2010) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH,

[Continued on next page]

(54) Title: METHODS, SYSTEMS AND DEVICES USING LOX TO PROVIDE VENTILATORY SUPPORT

(57) Abstract: A portable liquid oxygen system may provide an average flow rate of oxygen gas at approximately 6 - approximately 20 lpm using a rapid gas conversion mode. The liquid oxygen system may weigh less than 10 pounds. A heat exchanger may be provided, and wherein the rapid gas conversion mode may utilize a heater on the heat exchanger. The rapid gas conversion mode may utilize a Stirling engine passing air from a hot sink across the heat exchanger to a cold sink. The system may have multiple modes of operation. The modes of operation may be a continuum of settings and not discrete modes of operation. Flow capacity may be changed when switching between modes of operation. Oxygen gas pressure may be changed when switching between modes of operation. The system may automatically switch modes of operation based on a patient's condition.

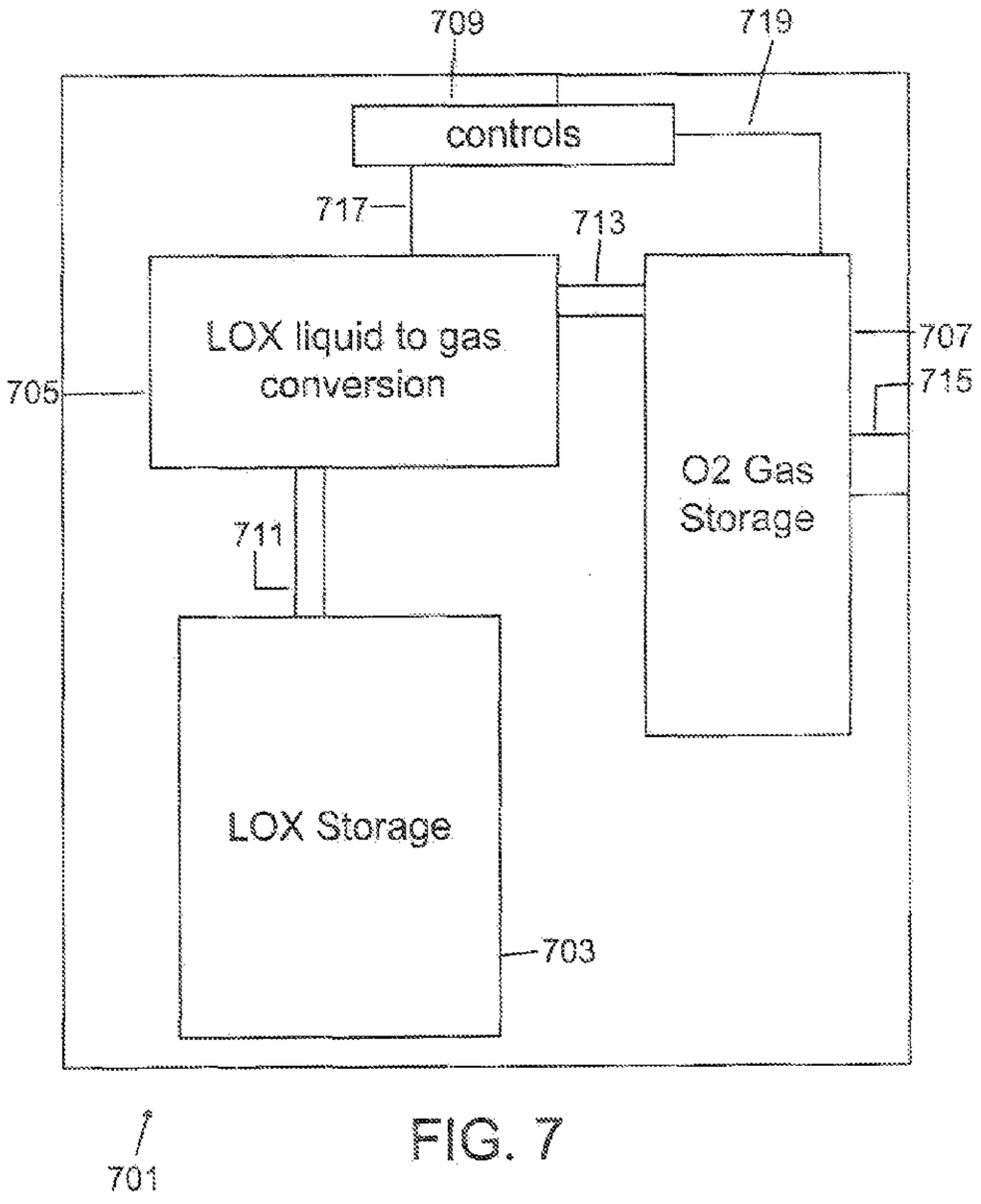

FIG. 7

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GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

METHODS, SYSTEMS AND DEVICES USING LOX TO PROVIDE VENTILATORY SUPPORT

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Patent Application No. 61/374,777, filed August 16, 2010.

FIELD OF THE INVENTION

The present invention relates to ventilation therapy for persons suffering from respiratory and breathing disorders, such as respiratory insufficiency and sleep apnea. More specifically, the present invention relates to methods and apparatus for assisting in the work of breathing, and restoring, augmenting, or providing ventilation to the lungs using a liquid oxygen (LOX) supply as a gas source.

BACKGROUND OF THE INVENTION

There are a range of clinical syndromes that require some form of mechanical ventilation therapy with elevated concentrations of inspired oxygen. These syndromes include hypoxemia, various forms of respiratory insufficiency, and congestive heart failure. Ventilators that treat these conditions provide ventilatory support for the lung, and typically deliver elevated concentrations of oxygen to help oxygenate the organs. The oxygen supplies used as inputs to

these ventilators are typically compressed oxygen gas in cylinders or a hospital's compressed oxygen supply piped into the treatment room. More recently, attempts have been made to tee oxygen into a ventilator from an oxygen concentrator, which makes 92% oxygen from room air. In general, even the most portable ventilation therapy systems have limited portability due to the size and weight of the ventilator. Additionally, if the patient requires elevated concentrations of oxygen, also because of the size and weight of the oxygen cylinder that is required as input to the ventilator. Because of this, a large number of patients that need ventilatory support choose not to have it because they do not want to be immobilized by being connected to a conventional ventilator. To solve this dire unmet need, recently, a unique new ventilation system has been devised (U.S. Patent Nos. 7,487,778, 7,533,670 and 7,588,033) that works using non-conventional gas delivery and patient interface principles, which render the ventilation and oxygen supply equipment highly portable, and in fact wearable. Thus, for the first time, patients that require mechanical ventilatory support can have that support while conveniently and easily ambulating.

Separate from mechanical ventilation therapy, there are also clinical syndromes that require oxygen therapy, but not necessarily ventilatory support. These oxygen therapy systems include compressed oxygen gas in cylinders, oxygen concentrators, and liquid oxygen (LOX) systems. These liquid oxygen systems store oxygen in liquid form, and over time the liquid oxygen converts to gaseous oxygen before being delivered to the patient as gaseous oxygen. LOX can be very advantageous in that it has a more efficient gas volume to storage volume ratio. A liter of LOX typically creates about 800 liters of gaseous oxygen at atmospheric pressure, whereas one liter of compressed oxygen gas in a cylinder typically creates about 100 liters of gaseous oxygen at atmospheric pressure.

In the ambulatory mechanical ventilatory support system described in U.S. Publication Nos. 2008/0135044, 2010/0252042, 2010/0252041, 2010/0252040, 2010/0252039, 2010/0252037, use of LOX has been described for (A) an oxygen supply for a mechanical ventilator, and (B) to use the gas pressure created by a LOX system to power a pneumatically powered ventilator. The advantage of using LOX as an input to a mechanical ventilator is that it can help make the ventilation system highly portable, which is very useful in many clinical applications such as chronic obstructive pulmonary disease (COPD), interstitial lung disease (ILD), some neuromuscular diseases, as well as field and pandemic uses. However, to be technically feasible to use a LOX system for the input into such a ventilator, the LOX system, the ventilator, or both, requires special unique features.

In summary, existing mechanical ventilation therapies have the following disadvantages: they do not offer respiratory support in an ambulatory form factor that can be easily borne or worn by the patient.

SUMMARY OF THE INVENTION

The present invention solves the limitations of prior systems with unique features that allow use of a ventilator in conjunction with LOX. Embodiments of the present invention include a portable liquid oxygen system providing an average flow rate of oxygen gas at approximately 6 - approximately 20 lpm using a rapid gas conversion mode. The liquid oxygen system may weigh less than 10 pounds. A heat exchanger may be provided, and wherein the rapid gas conversion mode may utilize a heater on the heat exchanger. The rapid gas conversion mode may utilize a Stirling engine passing air from a hot sink across the heat exchanger to a cold

sink, wherein the hot sink is ambient air, and wherein the cold sink is proximal to a liquid oxygen store. A liquid oxygen store may be provided, and wherein the rapid gas conversion mode may utilize a reduction in insulation at least partially surrounding the liquid oxygen store. An oxygen gas store may be provided, and wherein higher peak flow rates than the average flow rate may be achieved utilizing oxygen stored in the oxygen gas store. The system may have multiple modes of operation. The modes of operation may be a continuum of settings and not discrete modes of operation. Flow capacity may be changed when switching between modes of operation. Oxygen gas pressure may be changed when switching between modes of operation. The system may automatically switch modes of operation based on a patient's condition.

Embodiments of the present invention may also include a ventilation system that includes a portable ventilator; and a portable liquid oxygen system providing a flow rate of oxygen gas at approximately 6 - approximately 20 lpm using a rapid gas conversion mode. The portable ventilator and the portable liquid oxygen system may be integrated into a single portable or wearable unit. The liquid oxygen system may weigh less than 10 pounds. A heat exchanger may be provided, and wherein the rapid gas conversion mode may utilize a heater on the heat exchanger. The rapid gas conversion mode may utilize a Stirling engine passing air from a hot sink across the heat exchanger to a cold sink, wherein the hot sink is ambient air, and wherein the cold sink is proximal to a liquid oxygen storage device. A liquid oxygen storage device may be provided, and wherein the rapid gas conversion mode may utilize a reduction in insulation at least partially surrounding the liquid oxygen storage device. An oxygen gas store may be provided, and wherein peak flow requirements of the portable ventilator may be achieved by utilizing oxygen stored in the oxygen gas store. A patient interface may be provided, wherein the patient interface is a nasal interface, a mask, an endotracheal tube, a tracheostomy tube, or a

trans-oral tube. The ventilator may be wearable. A blender may be provided for titrating the amount of oxygen needed.

Embodiments of the present invention may include a liquid oxygen system including a liquid oxygen store; a heat exchanger; a fan; a hot sink; and a cold sink, wherein the fan passes ambient air across the heat exchanger from the hot sink to the cold sink to produce a rapid gas conversion mode. The liquid oxygen system may be portable. The hot sink may be an opening to ambient. The cold sink may be a region near the liquid oxygen store or evaporative coils.

Embodiments of the present invention may include a portable liquid oxygen system including a liquid oxygen store; an oxygen gas store; a liquid oxygen to gas conversion unit, wherein the liquid oxygen to gas conversion unit further comprises a heat exchanger between the liquid oxygen store and the oxygen gas store; and one or more controls for determining a mode of operation for the heat exchanger. The mode of operation may be switched automatically. A mode of the heat exchanger may be a rapid gas conversion mode for ventilation therapy providing an average gas flow at approximately 6 - approximately 20 lpm. A mode of the heat exchanger may be a low gas conversion mode for oxygen therapy providing an average gas flow at approximately 1 - approximately 6 lpm. The one or more controls may receive a signal from one or more respiration sensors, and wherein the one or more controls may cause the heat exchanger to switch between modes. The one or more controls may receive a signal from one or more pulse oximeters, and wherein the one or more controls may cause the heat exchanger to switch between modes.

Embodiments of the present invention may include a method of treating respiratory and breathing disorders, the method including providing a portable liquid oxygen system, wherein the liquid oxygen system comprises a liquid oxygen store, an oxygen gas store, a liquid oxygen

to gas conversion unit, a heat exchanger between the liquid oxygen store and the oxygen gas store; and providing an average flow rate of oxygen gas at approximately 6 - approximately 20 lpm using a rapid gas conversion mode. The method may also include receiving an input from one or more respiration sensors regarding ventilation needs of the patient at one or more controls; automatically determining a mode of operation for the heat exchanger based on signals from one or more respiration sensors; and sending a control signal to one or more of the liquid oxygen store, the oxygen gas store, the liquid oxygen to gas conversion unit, and the heat exchanger to initiate the determined mode of operation. The liquid oxygen system may weigh less than 10 pounds. The rapid gas conversion mode may utilize a heater on a heat exchanger. The rapid gas conversion mode may utilize a Stirling engine passing air from a hot sink across a heat exchanger to a cold sink, wherein the hot sink is ambient air, and wherein the cold sink is proximal to the liquid oxygen storage device. The rapid gas conversion mode may utilize a reduction in insulation at least partially surrounding the liquid oxygen store. Higher peak flow rates than the average flow rate may be achieved utilizing oxygen stored in the oxygen gas store.

Additional features, advantages, and embodiments of the invention are set forth or apparent from consideration of the following detailed description, drawings and claims. Moreover, it is to be understood that both the foregoing summary of the invention and the following detailed description are exemplary and intended to provide further explanation without limiting the scope of the invention as claimed.

BRIEF DESCRIPTIONS OF THE FIGURES

The accompanying drawings, which are included to provide a further understanding of the invention and are incorporated in and constitute a part of this specification, illustrate preferred embodiments of the invention and together with the detailed description serve to explain the principles of the invention. In the drawings:

Fig. 1 is a system schematic of the invention, according to an exemplary embodiment.

Fig. 2 illustrates a patient using an exemplary embodiment of the present invention for treating respiratory insufficiency.

Fig. 3 illustrates prior art controlled mechanical ventilation.

Fig. 4 illustrates prior art continuous positive airway pressure (CPAP) ventilation.

Fig. 5 illustrates prior art nasal cannula oxygen therapy.

Fig. 6A is a schematic of a LOX system, according to an exemplary embodiment.

Fig. 6B is a schematic of a two pressure setting LOX system, according to an exemplary embodiment.

Fig. 7 is a schematic of a LOX module, according to an exemplary embodiment.

Fig. 8 is a schematic of a LOX gas conversion module, according to an exemplary embodiment.

Fig. 9 is a schematic of an oxygen gas storage module, according to an exemplary embodiment.

Fig. 10 is a schematic of a Stirling engine, according to an exemplary embodiment.

DETAILED DESRIPTION OF THE EMBODIMENTS

The present invention may include LOX systems that are used for (A) input to a ventilator for the ventilator to deliver elevated concentrations of oxygen to the patient, and (B) for providing pressurized gas input to a ventilator to drive the ventilator with pneumatic power. The latter may allow the ventilator to consume relatively small amounts of electrical power, thus enabling the ventilator to be portable using battery power for extended periods.

The present invention may provide ventilation to a patient using a ventilation system that typically employs a non-invasive nasal interface or a transtracheal interface. The present invention can be used to treat respiratory insufficiency by providing mechanical ventilation to support the work of breathing of a patient. The patient interface may include a jet pump having a geometric configuration that optimizes the fluid dynamics of the system to improve the efficiency of the system and efficacy of the therapy. A pressurized gas, such as a therapeutic gas, and more specifically oxygen-rich gas, may be delivered through a catheter. For purposes of this disclosure, the terms tube, catheter, hose, gas delivery circuit, etc. are used interchangeably. Further, the term catheter does not necessarily require insertion into a patient airway, and does not require the device to be long and flexible. Various configurations are possible depending on specific uses. When the pressurized gas exits a catheter distal tip, the gas may entrain approximately 25-250% of ambient air due to the design of the catheter, so that a combination of ventilator-delivered gas and entrained gas is delivered to the patient. Embodiments of the present invention may, for example, create an increase of approximately 2-40 cmH_2O in the upper airway, and approximately 1-30 cmH_2O in the lung. A ventilator-delivered gas volume of approximately 50ml can entrain for example approximately 50ml, so that approximately 100ml is delivered to the patient, with a sufficient driving pressure so that a significant amount of the

approximately 100ml volume reaches the airway or lung to increase pressure in those areas, thus mechanically supporting respiration. For purposes of this disclosure, nasal cannula, nasal catheter, jet nozzle, and ventilation interface are often used interchangeably when pertaining to the present invention. Other ventilation interfaces can also be used, such as conventional non-invasive ventilation masks or airway tubes, etc.

Embodiments of the present invention may provide ventilation to a patient using a ventilator described as follows. The ventilator can be wearable, and weight less than approximately 3 lbs, preferably approximately 1 lb. The ventilator typically includes a valve that regulates the output of the ventilator to a desired volume, pressure or flow. The ventilator typically includes other features related to patient activity, such as actigraphy or pedometry sensing, biofeedback control of the therapy level based on patient's activity level, dyspnea questionnaires, and bi-directional communication capability with a remote clinician. The ventilator can also include a piston or reservoir system for amplifying the output pressure or storing oxygen gas volume in-between volume deliveries to the patient.

Figure 1 is a schematic diagram showing an exemplary overall system of the invention. A patient may be ventilated using a ventilation gas delivery circuit 113 and non-invasive open nasal ventilation interface 129, or other interfaces, such as endotracheal tubes, trans-oral tubes, etc. The nasal interface 129 preferably does not seal against the patient's nose, and instead leaves the nose open for the user to breathe normally and freely from the ambient surroundings. Ventilation gas may be delivered at a speed that entrains ambient air, such that the combination of ventilation gas and entrained air are delivered to the user's airways and lung under power. The nasal interface 129 may optimize the physics and fluid dynamics to maximize its performance.

The ventilation system may include several primary components: (1) a LOX storage portion, (2) a LOX gas conversion and storage portion, (3) an oxygen gas storage portion, (4) a ventilator portion, (5) a gas delivery circuit, and (6) a patient interface or mask. The LOX storage, LOX gas conversion and storage, the oxygen gas storage portion, and the ventilator can be separate units or can be integrated into one unit or more units. A spontaneous breathing respiration sensor may also be used to detect, determine and measure the spontaneous breathing pattern/phases of the user. This information may be used to synchronize and/or titrate the therapy to the needs of the patient and to match the gas delivery comfortably with the patient's breathing.

Embodiments of the present invention may be used to support the respiration of the patient, including supporting the work of breathing by increasing pressure and volume in the lung. When using the invention, the patient breathes normally through their upper airway and through their nose, while receiving mechanical support through the interface. The patient can keep their mouth closed during use, to help direct the mechanical support to the lower airways, or can use a bite block or mouth guard or chin band, if necessary. The patient can use the therapy while stationary, while being transported, while mobile and active, or while resting or sleeping. The therapy has homecare, hospital, subacute care, emergency, military, pandemic and transport applications. It should be noted that the LOX storage and LOX gas conversion aspects of the invention can be used to supply ventilation gas to conventional ventilators or for conventional oxygen therapy delivery systems, and other medical and non-medical applications, in addition to delivering oxygen to the ambulatory non-invasive open airway ventilation system.

Figure 2 shows an exemplary embodiment as used to treat respiratory insufficiency. A ventilator 201 can be borne or worn by the patient 203, such as being placed discretely on the

user's body, head or face. Because the ventilation system may contribute to some of the mechanical work required for a person to breathe, the user can be active without suffering from dyspnea, hypoxemia, hypercapnia or fatigue. The user can benefit from ambulation, activity, and participate in the routine activities of daily living, such as preparing meals, bathing, chores around the house, and leaving the house for outside activities. Further, the user can communicate, eat, drink and swallow, while receiving mechanical ventilation, as opposed to other ventilation interfaces in which the patient's airway is closed with an external mask, or sealed internally with a cuffed airway tube. The ventilation parameters, ventilation timing algorithms, and the effect on the lung are described in subsequent descriptions. The patient 203 may breathe through an interface 205, such as a nasal interface. The ventilator 201 may be coupled to an external oxygen supply 207 via conduits 209.

Figure 3 shows a prior art therapy for mechanical ventilation. A patient 301 is intubated with an endotracheal (ET) tube 303 and a cuff 305 is inflated in the trachea 307, thus closing the airway off from ambient air. The patient 301 is sedated and their lungs are ventilated with gas being delivered and removed through the ET tube 303. Gas may be delivered through a gas delivery tube 309. A sensor 311 may measure airflow. This therapy is highly effective in providing mechanical support for respiration; however, in some situations such as field emergencies, providing elevated concentrations of oxygen gas may be required.

Figure 4 shows a prior art respiratory support therapy, non-invasive ventilation, using a nose mask 401 and typically using a BiPAP ventilation mode. Non-invasive ventilation (NIV) is used to breathe for the patient, or can be used to help the breathing of a patient, in which case the patient's spontaneous breathing effort triggers the ventilator to deliver the pressure or volume based mechanical ventilation. All of the volume delivered to and from the lungs is delivered and

removed from a ventilation circuit 403 and the nose mask 401. A similar system can be used for obstructive sleep apnea, in which case exhaust vents 405 are included in the nose mask so that a portion of the exhaled gas is exhaled through the vent ports. NIV, CPAP and bilevel positive airway pressure (BiPAP) are clinically very effective for spontaneously breathing patients; however, these modes and therapies do not facilitate activities of daily living, the ventilator can not be borne by the patient, the patient cannot breathe room air naturally and freely, and the patient's upper airway cannot function normally and naturally because it is sealed off with the external mask seal.

Figure 5 shows the conventional prior art oxygen delivery cannula 501, for administering oxygen therapy. Distal ends of the cannula 505 are configured to enter the nares 503. The proximal end is connected to an oxygen delivery device that can deliver continuous flow oxygen at 1-6 lpm to the user's nose, or which delivers a bolus of oxygen upon detection of an inspiratory effort. This prior art does not mechanically support the work of breathing of the patient.

In Figure 6A, a LOX system is described to provide pressure and flow required for a ventilator. Exemplary embodiments may include a ventilator 100, LOX unit 110, LOX 112, LOX unit vacuum chamber 114, LOX outlet tube 116, heat exchanger 124, heater 120, check valve 122, oxygen gas reservoir 128, reservoir pressure regulator 126, gas outlet on/off valve 130, outlet to patient Pt and incoming breath signal S.

Typical LOX systems include a liquid phase oxygen compartment and an oxygen gas phase compartment that is continually filled by the boiling of the liquid oxygen. The phase change is catalyzed by a heat exchanger unit. These systems maintain the gas phase compartment at about 23 psi by bleeding gas to atmosphere to avoid pressurization beyond 23

psi. Typical medical LOX systems have been designed specifically to conserve oxygen and as such their output is relatively weak compared to the requirements of a ventilator. The compact LOX systems that are designed for portability are engineered to deliver gas at very low flow rates (< 3 lpm) and low pressures (below 5 psi). The larger, less portable LOX units are engineered for greater flow output; however, these units are not realistically suited for active ambulatory patients because of their larger size. The typical systems are capable of delivering oxygen gas at a continuous flow rate of below 4 lpm at a pressure well below 23 psi since the pressure in the gas phase compartment drops within fractions of a second when the system is opened to the patient. The gas phase compartment typically contains less than 50 ml of gas and the rate of gas creation by boiling is limited to below 4 lpm due to the design and construction of the heat exchanger, which is typically less than 20 square inches surface area. Gas flow output to the patient is also limited by the size of the orifice in the outlet valve, typically less than 0.10" diameter, thus restricting airflow.

In the present invention the heat exchanger unit 124 is designed with greater surface area, typically greater than 30 square inches, to produce gas at the rate of 6-10 lpm and the outlet orifice allows that flow rate output as well, typically greater than 0.15" diameter. The heater 120 may be added to increase the rate of production of gaseous oxygen. The gas volume of the gas phase compartment is typically above approximately 80 ml and can be approximately 250 ml, which typically includes a pressure regulator 126, a reservoir 128, check valve 122, on/off valve 130 and incoming breath signal S. This configuration may provide an oxygen gas output flowrate of above approximately 6 lpm at above approximately 20 psi continuously, thus meeting the parameters required by some ventilators. The LOX system may include a catheter and all the

requisite sensing components and timing functions described herein to deliver the required volume of gas at the correct pressure and at the correct time of the breathing curve.

An additional embodiment is shown in Figure 6B, where a LOX system includes two pressure settings. A low pressure regulator 126 with a setting of approximately 23 psi may be used when a patient requires less powerful therapy or needs to conserve the LOX. A higher pressure regulator 132 with a setting of approximately 30-50 psi may be used for increasing the output of the unit when needed or when conserving the LOX is not a concern. For example, when traveling on an airplane, the LOX system can be set at the low 23 psi setting, and reset to the high setting after the flight or when arriving to the destination where there is a refill station. The two pressure regulators may be configured in a manifold 136 that can be operated by a switch 134 to switch between settings. During flight, the patient can still receive the ventilation therapy but at a lower level of augmentation corresponding the to 23 psi setting. After the flight and when the patient becomes more active again, the augmentation level can be increased because the pressure is set to the higher output setting. Two pressure settings are exemplary and it can be any number of pressure settings or even a continuous adjustment of the pressure setting between a minimum and maximum value. The modes of operation of the LOX system may be a continuum of settings and not discrete modes of operation in certain embodiments.

Figure 7 shows an exemplary overall LOX device 701 according to an embodiment of the present invention. Generally, the LOX device 701 may have components including, but not limited to, a LOX storage 703, a LOX liquid to gas conversion device 705, an oxygen gas storage device 707, and one or more controls 707. The LOX storage 703 may be in fluid communication 711 with the LOX liquid to gas conversion device 705. The LOX liquid to gas conversion device 705 may be in fluid communication 713 with the oxygen gas storage device

707. The oxygen gas storage device 707 may be in fluid communication 715 with the exterior of the overall LOX device 701, and other devices such as an oxygen delivery system, a gas delivery circuit, ventilator, etc. The one or more controls 707 may provide control signals 717, 719 to various components internal or external to the LOX device 701. The oxygen gas storage device 707 may be sized appropriately to support the spontaneous oxygen needs of a ventilation system, whereas the LOX liquid to gas conversion device 705 may only be able to support the average oxygen needs of a ventilation system.

The LOX system 701 may be portable and/or wearable. In preferred embodiments, the LOX system may weigh less than 20 lbs, more preferably less than 15 lbs, more preferably less than 10 lbs, and more preferably less than 5 lbs. Weights of the LOX system less than 10 lbs may allow for a patient to comfortable carry and/or wear the device while moving.

Figure 8 shows the LOX liquid to gas conversion device 705 according to one embodiment. The LOX liquid to gas conversion device 705 may typically include a heat exchanger 801 that receives liquid oxygen via the LOX storage 703 via its input 711 and outputs gaseous oxygen to the oxygen gas storage device 707 via its output 713. The heat exchanger 801 may have multiple modes that are controlled via a control signal 717, for instance to switch between low average oxygen gas output flowrates, such as approximately 1 lpm to approximately 6 lpm, preferably approximately 3 lpm, and high average flowrates, such as above approximately 6 lpm, preferably between approximately 6 lpm and approximately 20 lpm. Alternative higher average flowrates may include greater than approximately 7 lpm, greater than approximately 8 lpm, greater than approximately 9 lpm, greater than approximately 10 lpm, greater than approximately 11 lpm, greater than approximately 12 lpm, greater than approximately 13 lpm, greater than approximately 14 lpm, greater than approximately 15 lpm,

greater than approximately 16 lpm, greater than approximately 17 lpm, greater than approximately 18 lpm, greater than approximately 19 lpm, and ranges therein, such as approximately 7 lpm - approximately 19 lpm, approximately 8 lpm - approximately 18 lpm, etc. Higher or lower flowrates may also be used. Note that these are average flowrates that are either continuous at a set level or average out to these ranges. Peak flowrates may be higher than the average flowrates. One such mode may be a rapid gas conversion mode, which may be achieved by adding heat to the heat exchanger 801 via a heater 120. Another such mode may bypass the insulation surrounding LOX storage device 703 to preheat the oxygen gas temperature entering the LOX liquid to gas conversion device 705 and effectively increase the surface area of the heat exchanger 801 by including additional surface area of the LOX storage device 703 in the heat exchange. Another such mode may utilize a Stirling engine to utilize the heat across the heat exchanger to power a fan to blow ambient air across the heat exchanger to increase its capacity. Additional details of the Stirling engine are described below.

Ventilator flowrates may demand change during the patients' breathing cycles. Higher flow rates may typically be required during inspiration, and lower or no flowrates may typically be required during exhalation. When interfacing the LOX system to a ventilator, peak flowrates greater than the approximately 6-20 lpm range may be achieved during inspiration by using oxygen gas stored in the oxygen gas storage device 707. The oxygen gas storage device 707 may be recharged during exhalation by the LOX liquid to gas conversion module 705.

The multi-modality of the LOX system 701 may provide for switching based on flow capacity and/or output gas pressure. The mode of operation may be switched manually, automatically, and/or based on input from one or more sensors, such as respiration sensors.

Figure 9 shows the oxygen gas storage device 707 according to one embodiment. The oxygen gas storage device 707 may include a multi-modal pressure regulator module 901, for instance to change output pressure between approximately 23 psi when in conserving/airplane mode and approximately 50 psi when in the mode of maximizing patient ventilation.. The multi-modal pressure regulator module 901 may typically receive oxygen gas from the LOX liquid to gas conversion device 705 and be in fluid communication with the oxygen gas storage 903, thereby regulating the gas pressure of the oxygen gas storage 903. The multi-modal pressure regulator module 901 may contain multiple pressure regulators that are switched on and off to control the pressure settings. Alternately, the multi-modal pressure regulator module 901 may also contain a singular pressure regulator that is switched between multiple pressure settings, such as by changing a spring force on a regulating diaphragm within the regulator.

The LOX device 701 may have a dual mode operation controlled by the one or more controls 709. The one or more controls 709 may be in communication with the LOX liquid to gas conversion device 705, the oxygen gas storage device 707, and/or other components of the LOX device 701, ventilator, etc. As possible examples, the controls may be affect a heater 120 on the heat exchanger 801, may affect the insulation level surrounding the LOX storage device 703, may switch between multiple pressure regulators within the multi-modal pressure regulator module 901, or may affect the pressure regulator setting within the multi-modal pressure regulator module 901. The one or more controls 709 may include one or more processors and one or more memories.

A first mode of operation for the LOX device 701 may be used for oxygen therapy, while a second mode of operation for the LOX device 701 may be used for powering a ventilator. When in oxygen therapy mode, the conversion rate of liquid to gas may be an average gas flow

rate of approximately 1-6 lpm. When in ventilator mode, the conversion rate of liquid to gas may be an average gas flow rate of approximately 4-10 lpm. Having both modes in one device may allow a patient to own only one LOX system, rather than requiring two, one for oxygen therapy and a separate one for mechanical ventilation. When the patient only requires oxygen therapy, the LOX device may only produce an average gas flow rate of approximately 1-6 lpm, and the device does not waste any excess oxygen. When the patient requires mechanical ventilation, the LOX device may produce an average gas flow rate of approximately 4-10 lpm, which may be necessary to obtain sufficient mechanical support. The LOX device may have the ability to automatically determine whether it is being used for oxygen therapy or ventilation therapy and can automatically switch between these modes. For example, the type of patient circuit attached to the LOX device may signal the LOX device whether it is an oxygen therapy tube or a ventilation therapy tube, and the LOX device may switch operating modes accordingly. Alternatively, the ventilator can send a signal to the LOX device that the ventilator is being used for ventilation therapy and the LOX device change accordingly. Alternatively, the LOX device may receive input directly from patient sensors regarding whether the patient requires oxygen therapy or mechanical ventilation. Other signaling systems may be also be used depending on particular situations.

To change from the low conversion rate mode to the high conversion rate mode, the LOX device heat exchanger 801 may be switched from a first state to a second state. For example, liquid oxygen may be channeled through an additional heat exchanger 803 by opening a valve 805, or the heat exchanger 801 may be modified for example by applying heat to the outside of the heat exchanger 801, such as application of a heater 120. The heater may be controlled electrically or by other means.

While the foregoing describes changing the LOX device 701 from one output to a second output, or the heat exchanger 801 having a first and second state, the outputs and states can be more than two, or can be a continuum. For example, the LOX device 701 may adjust the conversion rate automatically within a range based on the needs of the therapy. As such, if the patient is walking briskly while using the ventilation therapy, the LOX device 701 may be signaled by a sensor and/or control system to increase the gas conversion rate to handle the demand of the patient. Conversely, if the LOX device 701 is being used for oxygen therapy and the patient is resting or asleep, the LOX device 701 may be signaled by a sensor and/or control system to reduce the conversion rate to conserve the liquid oxygen supply and prevent wasting converted gas as it is vented to atmosphere.

In an alternative embodiment, a LOX device 701 may have gas produced by the liquid oxygen not vented to atmosphere, but instead collected in another reservoir or cylinder. In this manner, there may be no or minimal waste of the liquid oxygen.

The LOX device 701 may include additional features. The LOX device 701 may include one or more fittings for a high pressure quick connect to attach a ventilator input hose. The output gas may be warmed so as to be more comfortable to the patient when the ventilation gas enters the patient's body. Additionally, moisture or water can be fed into the gas phase of the LOX device 701. Condensation created by the LOX device 701 can be collected, recycled and/or used to moisten the oxygen gas being delivered to the patient. The LOX storage 703 can be a high pressure bladder so that the form factor can be flatter and more convenient for wearing by the patient. The LOX device 701 and ventilator can be integrated or can be modularly attached. The heat exchanger 801 can be black or other colors to modify heat transfer characteristics. The heat exchanger 801 can include fins and/or be made of multiple small tubes

to increase surface area. The heat exchanger 801 can also be a tube inside a tube, with a heated annular space and liquid within the inside tube.

As shown in Figure 10, the LOX device 701 can also produce an effect similar to a Stirling engine. The LOX Stirling engine may be powered by the use of two temperature sinks, one relatively hot 1001 and the other relatively cold 1005. The LOX Stirling engine may drive a fan 1003 to blow air across the evaporative coils of the LOX system to increase the rate of evaporation. The hot sink of the Stirling engine may be ambient temperature, and the cold sink may be provided by evaporative tubing nearest the LOX storage 703 and/or the area proximal to the LOX storage 703. Once the evaporation process begins, i.e., oxygen begins flowing, the coil may reduce in temperature starting a Stirling engine fan. Once the fan starts, evaporation may become more efficient, i.e., greater convection across tubing may lead to more heat for evaporation. No electrical power may be needed to run this system.

The LOX device output may be of higher pressure and higher flow rate than standard LOX devices to meet the needs of a critical care jet ventilator. The output pressure may typically be approximately 15-80 psi during ventilation mode, and preferably approximately 25-40 psi. A flow rate may typically be approximately 4-20 lpm during ventilation mode, and preferably approximately 8-10 lpm.

While the foregoing descriptions describe the LOX device being used for an ambulatory ventilation therapy, the same principles of the invention can be employed for stationary ventilation. For example, a stationary LOX system can be modified with the embodiments of the invention to be used to power a mechanical ventilator.

Optionally, high frequency low volume ventilation can be delivered by the ventilator and patient interface where very low volumes of gas are delivered at very fast frequencies, such as approximately 5-50 ml at approximately 12-120 cycles per minute, or preferably approximately 10-20 ml at approximately 30-60 cycles per minute. In this manner, substantial minute volumes can be delivered to the lung while controlling the pressures achieved in the airway and lung more closely to a desired level, albeit in an open airway system. This delivery waveform can be continuous or can be synchronized with an inspiratory phase of breathing. Again, different waveforms described can be combined in whole or in part, for example, volumes can be synchronized and delivered in one shot during inspiration, and then high frequency low volume ventilation can be delivered during exhalation. It should also be noted that ventilation gas delivery, when activated, can gradually ramp up so that it is not a sudden increase in amplitude, which could arouse the patient.

While the foregoing has described the therapy of this invention using a nasal interface, other interfaces may also be included in the invention such as a trans-oral interface. The tip of a catheter can be proximal to the mouth entrance, coplanar with the mouth entrance, or recessed inside the mouth between the lips and the jaw line. The catheter can be shaped to be routed along the teeth, either on the buccal side or lingual side of the teeth, or through the center of the mouth. The catheter can be positioned so that a portion of the catheter rests on the superior surface of the tongue, or can be positioned so that a portion of the catheter rests against the inferior surface of the hard palate, in which case the distal tip of the catheter may be angled or curved inferiorly away from the palate and towards the oropharyngeal airway. The catheter can be bifurcated so that there is a left and right catheter positioned on both the right and left side of the mouth. The catheter can be integral to a bite block or mouth guard. The catheter preferably

is easily inserted and removed from the patient's mouth. All of the appropriate details described previously in conjunction with the nasal interface may apply to the oral catheter used in embodiments of the invention.

The present invention can also be used with an endotracheal tube (ET) interface. This version of the interface can be helpful to institutions that walk their patients during the weaning stages off of invasive mechanical ventilation. Walking patients that are on ICU ventilators is typically very onerous because the patient must have the assistance of a number of medical staff to move the large and complex ICU ventilator alongside the patient. The present invention may be used to help a patient walk, while receiving adequate ventilatory support from the ventilation system and interface described in this invention. In this embodiment, the ET tube connector may include an attachment for the ventilation interface of this invention. The patient can breathe ambient air spontaneously through the proximal end of the ET tube proximal connector, which is left open, while the patient's spontaneous breaths are efficaciously augmented by the ventilation system and catheter interface of the invention. Optionally, if it is desired to apply positive end-expiratory pressure (PEEP), a special PEEP valve may be included for attachment to the end of the ET tube. The special PEEP valve may include a one way valve so that ambient air may be easily entrained into the ET tube toward the patient's lung by a jet nozzle of the invention, but also allows exhalation through the PEEP valve, while maintaining the desired PEEP level. Preferably, the patient can still also breathe room air spontaneously through the PEEP valve through an inspiratory valve integral to or in parallel with the PEEP valve. The ventilator used in the present invention can provide PEEP as previously described by delivering gas with the appropriate waveform during the patient's expiratory phase. The catheter tip can be slightly proximal to the proximal end opening of the ET tube proximal connector, or can be coplanar

with the proximal end opening, or can be inserted into the ET tube to the appropriate depth, typically at around the mid-point, but the appropriate depth may depend on other variables of the system. The depth can be adjustable to optimize the entrainment and performance or function for individual situations, as required clinically or for patient tolerance. The ET tube connector used in this embodiment of the invention may provide the necessary jet pump geometry as previously described in conjunction with the nasal cannula outer concentric tube. The ET tube connector can include a jet inlet, jet throat and diffuser section. Or, alternatively, the ET tube can be of a special configuration, which incorporates dimensions and geometries advantageous to the jet pump performance. All of the appropriate details described previously with the nasal interface, apply to the ET tube catheter interface used in this version of the invention. In addition, PEEP can be included in the other patient interfaces described in the invention by including a similar special PEEP valve for each of the different patient interfaces.

As previously indicated, Figure 1 is a block diagram describing an embodiment of the invention with expanded features and capabilities. A ventilator module includes or is in communication with several other accessories or functional modules.

A transmitter and/or receiver 103 may be included to transmit and/or receive information regarding the patient, the patient's therapy, and the ventilator performance to a remote location for review, analysis and archival. For example, the patient's compliance to the therapy or utilization of the therapy can be monitored and assessed. Important information can be trended, for example the patient's breath rate, I:E ratio or depth of breathing. Also, information can be sent to the ventilator, for example programming of settings to titrate the ventilator output to meet the needs of the patient.

An internal or external humidifier 105 can be included for extended uses of the therapy, or if using in dry climates. The humidity can be delivered using a humidification generator that is integral or coupled with the ventilator, or using a stand alone humidifier. The humidified air or oxygen can be delivered through the gas delivery channel of the gas delivery circuit, or through another lumen in the gas delivery circuit as previously described, or through a separate cannula or tubing. For extended use, when the patient is likely to be stationary, the humidification system can be a stationary system and capable of delivering a relative high amount of humidity, and for periods of mobility, the patient can either not receive humidification, or use a portable humidification system that is capable of delivering relatively a small amount of humidity, due to size and energy consumption constraints.

In addition to a LOX system 107, a compressed air source 109 can be included, typically external attached to the ventilator, however optionally internal to the ventilator if the therapy is being used for stationary use, for example in the home. Examples of a compressed air source 109 may include a pressurized air source and/or a generator. A blender 111 can be included to control the fractional delivered oxygen in a gas delivery circuit 113. The blender 111 may receive input from the compressed air source 109 and/or the LOX system 107 and output to a ventilator 115. The blender 111 may be used to titrate the amount of oxygen needed, either based on a clinical determination, or by pulse oximetry or other biofeedback signals. For oxygen concentrations needed that are less than 100%, the system can use compressed air from a compressor, tank or wall source, or the air can be entrained into the system from the pressurized oxygen gas, for example at the patient interface, or elsewhere in the system, such as the gas delivery circuit or ventilator. If air is entrained in, it can be entrained in from room air. For treating other diseases and applications, other therapeutic gases can also be delivered by blending

into the delivered gas, such as helium-oxygen mixtures, nitric oxide, or combinations of air, oxygen, helium and nitric oxide. A pulse oximeter 117 can be used to determine correct blender settings to achieve proper oxygen saturation. The pulse oximeter 117 can also be used to titrate other settings of the ventilator system to meet the physiological needs of the patient, or to control the rapid gas conversion mode of a LOX system used with a nasal cannula instead of a ventilator. A controller may use a signal from one or more pulse oximeters to switch modes of the LOX system. In addition to compressed supplies of oxygen and air gas, the ventilator can include internal or external air and oxygen generating means, such as a pump or blower to create pressurized air, and an oxygen generator and/or pump to create pressurized oxygen gas. The oxygen source can also be liquid oxygen, or a liquid oxygen generating system.

Because the therapy is frequently used to help activities of daily living, and to promote activity, a pedometer 119 and/or actigraphy sensor 121 can be included internal to or external to the ventilator system. A carbon dioxide monitor 131 may also be included.

An external respiration sensor 123 can be included, such as a respiratory muscle effort sensor, a chest impedance sensor, or other types of respiration, such as a tracheal microphone or vibration sensor. The external sensor 123 may be used either as a redundant sensor to a nasal airflow or nasal pressure sensor 125, or to complement the information obtained from the nasal airflow sensor, or in place of the nasal airflow sensor. The nasal airflow or nasal pressure sensor 125 may measure spontaneous respiration. The nasal airflow or nasal pressure sensor may be located at a non-invasive open nasal ventilation interface 129 or at other appropriate locations.

A drug delivery module 127 can be incorporated internally or externally to the ventilator system. Due to challenges with current aerosolized drug delivery inhalers, the current invention can be used to propel and deposit medication particles deep in the respiratory system, without a

carrier propellant. Because a patient's using the therapy often also requires prescription medication, this may be a convenient and efficient way to administer the medication.

When the therapy is being used for respiratory support, the user may have two options; (1) wearing or toting the ventilator so that the user can be ambulatory or enjoy the activities of daily living, or (2) stationary use, in the event the patient plans on being stationary or does not have the ability to ambulate. The delivery circuit can optionally be provided in a 25-100 foot length, such that the gas source and ventilator can be stationary in the patient's home, while the patient can move around their home while wearing the interface and receiving the therapy. Or, the gas source can be stationary, and connected to the ventilator with a 25-100 foot hose, so that the patient can wear or tote the ventilator and be mobile within the range of the hose. In certain embodiments, the gas delivery circuit may be connected to a blender, which receives pressurized oxygen and pressurized air from, for example, the hospital pressurized gas supply. In these applications, in which mobility may be less important, the system can be attached to the house gas supply, and higher levels of therapy can be delivered, as well as PEEP therapy during exhalation. All of these different options of stationary use and mobile use apply to the various different interface techniques described in the foregoing.

The ventilator can be self-contained with a battery and gas supply to enable it to be borne by the patient, so that the patient can ambulate and participate in activities of daily living, which is made possible by the respiratory support they are receiving from the ventilator, but in a package that can easily be borne.

For the therapy described in this invention to be more effectively titrated to the needs of the patient, the ventilator system can perform a determination to determine the level of respiratory support needed. To accomplish this, the ventilator can titrate the output to the needs

of the patient, for example, during ambulation or activity the output can increase. Alternatively, during higher respiratory rates as measured by the spontaneous breath sensor, the output can increase. Or during higher breath effort as measured by the breath sensor, the output can increase. Other biofeedback signals can be used. In addition to the output increasing or changing to meet the respiratory needs of the patient, the timing of the ventilator output relative to the patient's spontaneous inspiratory phase, and the output waveform can change to meet the comfort and physiological needs of the patient. For example, during exercise, the output can change from an early delivery at 75 ml with an ascending waveform, to being triggered with a delay to start for example 100 msec after the start of inspiration, and with a decelerating waveform.

To facilitate integration of this new therapy into the existing therapeutic paradigms, a convertible system may be provided. Specifically, the patient interface can be modular, such that a patient can be administered conventional oxygen therapy with a typical or slightly modified oxygen nasal cannula. Then, when it is desired to switch the patient to this new therapy, an additional component, such as an outer concentric tube, may be added to the nasal cannula to create the jet pump design and to position the distal tips of the cannula properly to achieve the function of this invention. Alternatively, for example, a switch on the gas delivery equipment can be switched to change the output of the equipment from oxygen therapy, to this therapy, by for example, enabling additional breath sensing functions, timing functions, waveform functions, and switching to the output amplitude necessary. The LOX portions of the system can be modular as well, for example, they can be replaced with oxygen gas cylinders, wall oxygen, compressed gas, and an oxygen-air blender.

It should be noted that the different embodiments described above can be combined in a variety of ways to deliver a unique therapy to a patient and while the invention has been described in detail with reference to the preferred embodiments thereof, it will be apparent to one skilled in the art that various changes and combinations can be made without departing for the present invention. Also, while the invention has been described as a means for mobile respiratory support for a patient, it can be appreciated that still within the scope of this invention, the embodiments can be appropriately scaled such that the therapy can provide higher levels of support for more seriously impaired and perhaps non-ambulatory patients or can provide complete or almost complete ventilatory support for non-breathing or critically compromised patients, or can provide support in an emergency, field or transport situation. Also, while the invention has mostly been described as being administered via a nasal interface it should be noted that the ventilation parameters can be administered with a variety of other airway interface devices such as ET tubes, tracheostomy tubes, laryngectomy tubes, cricothyrotomy tubes, endobronchial catheters, laryngeal mask airways, oropharyngeal airways, nasal masks, trans-oral cannula, nasal-gastric tubes, full face masks, etc. And while the ventilation parameters disclosed in the embodiments have been mostly specified to be compatible with adult respiratory augmentation, it should be noted that with the proper scaling the therapy can be applied to pediatric and neonatal patients. Further, while the target disease states have mostly been described as respiratory insufficiency and sleep apnea, other breathing, lung and airway disorders can be treated by the therapy with the requisite adjustment in ventilation parameters, for example, ALS, neuromuscular disease, spinal cord injury, influenza, CF, ARDS, lung transplant bridging, and other diseases can be addressed with this therapy, as well as mass casualty, pandemic, military, bridge and transport applications. Lastly, while the invention has been

described as a stand alone therapy, the therapy can be modular, for example a ventilation system can be adapted which can switch between invasive or non-invasive or other closed system ventilation modes and the non-invasive open ventilation mode described herein. Or, the therapy can be used simultaneously in conjunction with other modes of ventilation, such as during a conscious sedation medical procedure in which the patient is ventilated with a conventional ventilator as a back up means of respiration while the patient receives ventilation from the mode described herein.

Although the foregoing description is directed to the preferred embodiments of the invention, it is noted that other variations and modifications will be apparent to those skilled in the art, and may be made departing from the spirit or scope of the invention. Moreover, features described in connection with one embodiment of the invention may be used in conjunction with other embodiments, even if not explicitly stated above. The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive.

Claims:

1. A portable liquid oxygen system providing oxygen gas using a rapid gas conversion mode, the portable liquid oxygen system comprising:

a liquid oxygen store;

a heat exchanger for evaporating liquid oxygen from the liquid oxygen store into oxygen gas;

a Stirling engine having a heat source and a heat sink, wherein the heat source is an opening to ambient air and wherein the heat sink is proximal to the liquid oxygen store; and

a fan, wherein during the rapid gas conversion mode, the Stirling engine drives the fan to blow ambient air from the heat source across the heat exchanger to more rapidly evaporate liquid oxygen from the liquid oxygen store into oxygen gas.

2. The portable liquid oxygen system of claim 1, wherein the portable liquid oxygen system provides an average flow rate of oxygen gas at 6-20 lpm using the rapid gas conversion mode.

3. The portable liquid oxygen system of claim 1, wherein the portable liquid oxygen system weighs less than 10 pounds.

4. The portable liquid oxygen system of claim 1, wherein the rapid gas conversion mode utilizes a heater on the heat exchanger.

5. The portable liquid oxygen system of claim 1, wherein the rapid gas conversion mode utilizes a reduction in insulation at least partially surrounding the liquid oxygen store.

6. The portable liquid oxygen system of claim 1, further comprising an oxygen gas store, and wherein higher peak flow rates than the average flow rate are achieved utilizing oxygen stored in the oxygen gas store.

7. The portable liquid oxygen system of claim 1, wherein the portable liquid oxygen system has multiple modes of operation.

8. The portable liquid oxygen system of claim 7, wherein the modes of operation are a continuum of settings and not discrete modes of operation.

9. The portable liquid oxygen system of claim 7, wherein flow capacity is changed

when switching between modes of operation.

10. The portable liquid oxygen system of claim 7, wherein oxygen gas pressure is changed when switching between modes of operation.

11. The portable liquid oxygen system of claim 7, wherein the portable liquid oxygen system automatically switches modes of operation based on a patient's condition.

12. The portable liquid oxygen system of claim 1, further comprising:

one or more controls for determining a mode of operation for the heat exchanger.

13. The portable liquid oxygen system of claim 12, wherein the mode of operation is switched automatically.

14. The portable liquid oxygen system of claim 12, wherein the rapid gas conversion mode is a mode of the heat exchanger for ventilation therapy.

15. The portable liquid oxygen system of claim 14, wherein another mode of the heat exchanger is a low gas conversion mode for oxygen therapy.

16. The portable liquid oxygen system of claim 15, wherein the low gas conversion mode for oxygen therapy provides an average gas flow at 1-6 lpm.

17. The portable liquid oxygen system of claim 12, wherein the one or more controls receive a signal from one or more respiration sensors, and wherein the one or more controls cause the heat exchanger to switch between modes.

18. The portable liquid oxygen system of claim 12, wherein the one or more controls receive a signal from one or more pulse oximeters, and wherein the one or more controls causes the heat exchanger to switch between modes.

19. A ventilation system comprising:

a portable ventilator; and

a portable liquid oxygen system providing oxygen gas evaporated from a liquid oxygen store to the portable ventilator using a rapid gas conversion mode, the portable liquid oxygen system comprising:

a heat exchanger for evaporating the liquid oxygen from the liquid oxygen store into oxygen gas;

a Stirling engine having a heat source and a heat sink, wherein the heat source is an

opening to ambient air and wherein the heat sink is proximal to the liquid oxygen store; and

a fan, wherein during the rapid gas conversion mode, the Stirling engine drives the fan to blow ambient air from the heat source across the heat exchanger to more rapidly evaporate liquid oxygen from the liquid oxygen store into oxygen gas.

20. The ventilation system of claim 19, wherein the portable liquid oxygen system provides an average flow rate of oxygen gas evaporated from the liquid oxygen store to the portable ventilator at 6-20 lpm.

21. The ventilation system of claim 19, wherein the portable ventilator and the portable liquid oxygen system are integrated into a single portable or wearable unit.

22. The ventilation system of claim 19, wherein the portable liquid oxygen system weighs less than 10 pounds.

23. The ventilation system of claim 19, wherein the rapid gas conversion mode utilizes a heater on the heat exchanger.

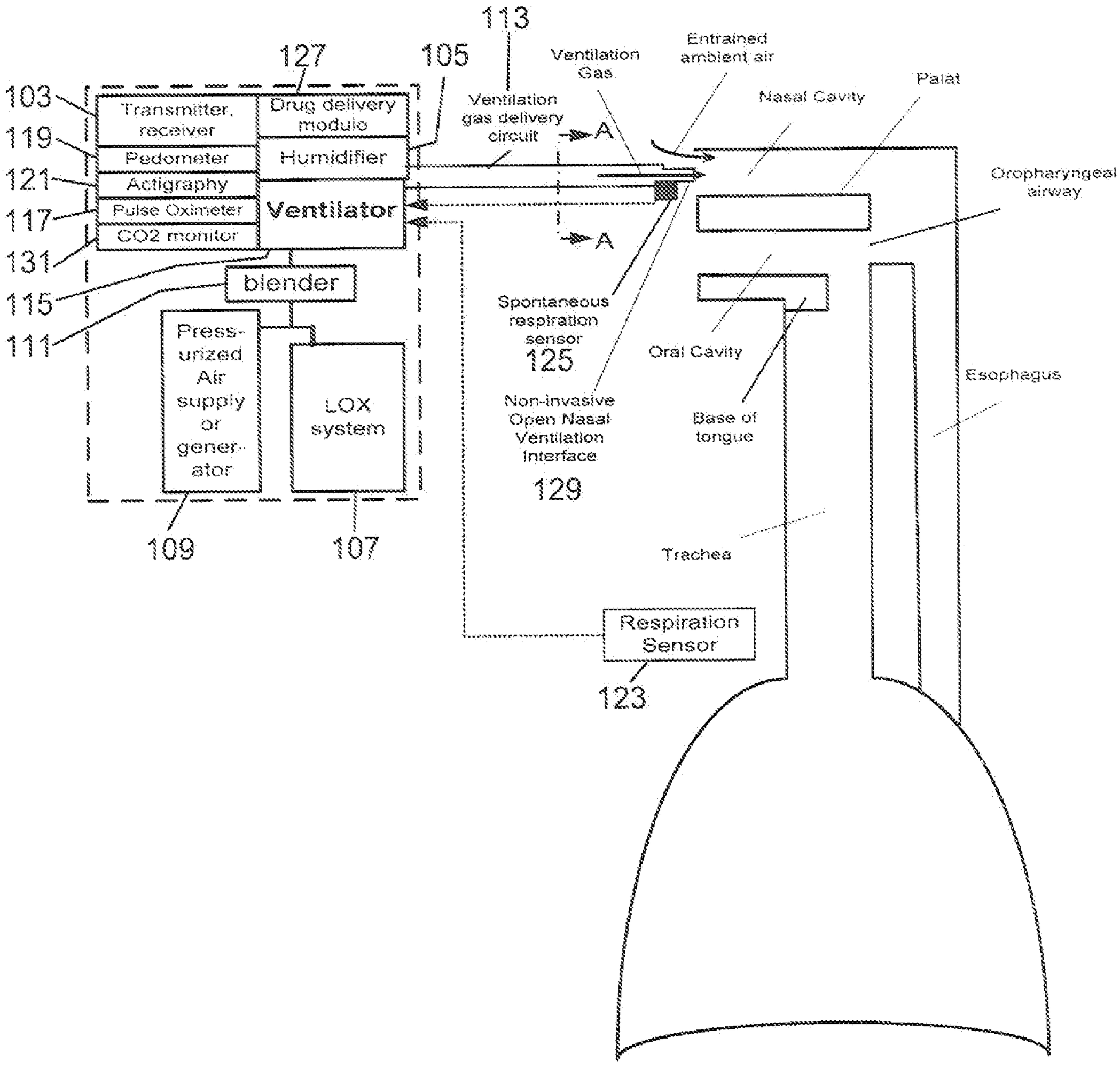
24. The ventilation system of claim 19, wherein the rapid gas conversion mode utilizes a reduction in insulation at least partially surrounding the liquid oxygen store.

25. The ventilation system of claim 19, further comprising an oxygen gas store, and wherein peak flow requirements of the portable ventilator are achieved utilizing oxygen stored in the oxygen gas store.

26. The ventilation system of claim 19, further comprising a patient interface, wherein the patient interface is a nasal interface, a mask, an endotracheal tube, a tracheostomy tube, or a trans-oral tube.

27. The ventilation system of claim 19, wherein the portable ventilator is wearable.

28. The ventilation system of claim 19, further comprising a blender for titrating the amount of oxygen needed.


113
127
105
Ventilation Gas
Entrained ambient air
Palat
Nasal Cavity
103
Transmitter, receiver
Drug delivery module
Ventilation gas delivery circuit
A
119
Pedometer
Humidifier
121
Actigraphy
Oropharyngeal airway
117
Pulse Oximeter
Ventilator
CO2 monitor
A
131
blender
115
Spontaneous respiration sensor
125
Oral Cavity
111
Press-urized Air supply or gener-ator
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Esophagus
Non-invasive Open Nasal Ventilation Interface
129
Base of tongue
Trachea
Respiration Sensor
123
109
107

FIG. 1

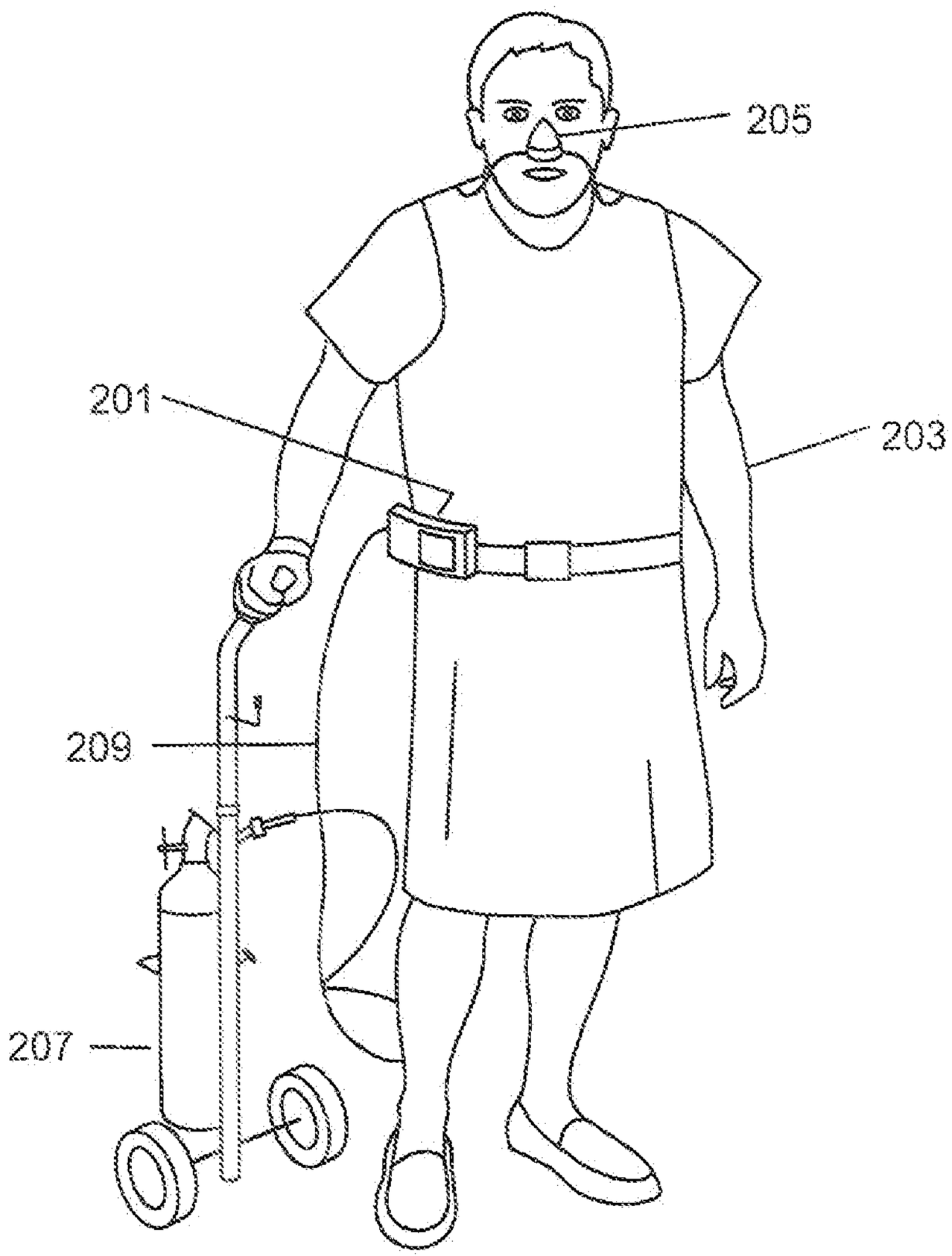


FIG. 2

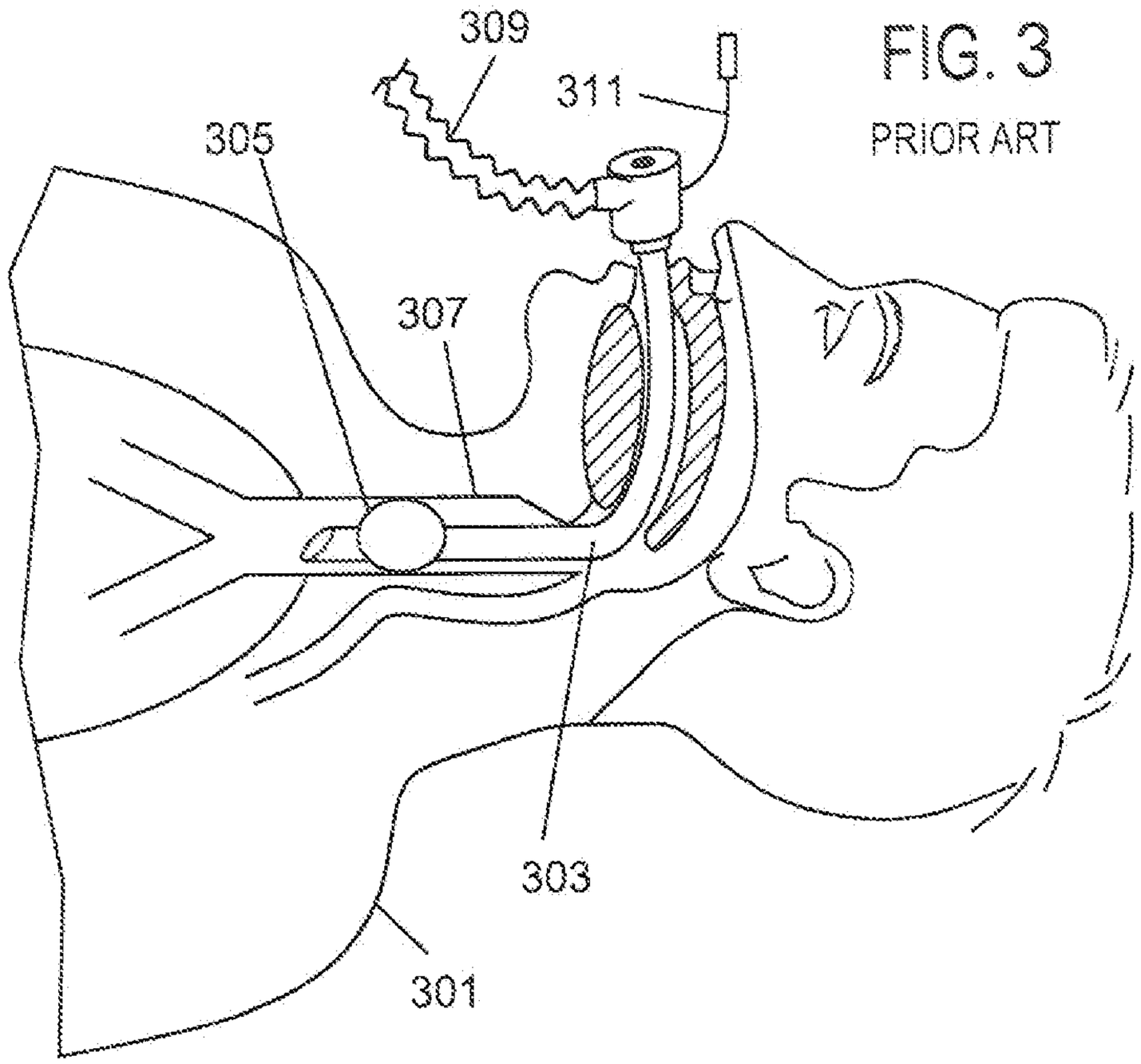


FIG. 3
PRIOR ART

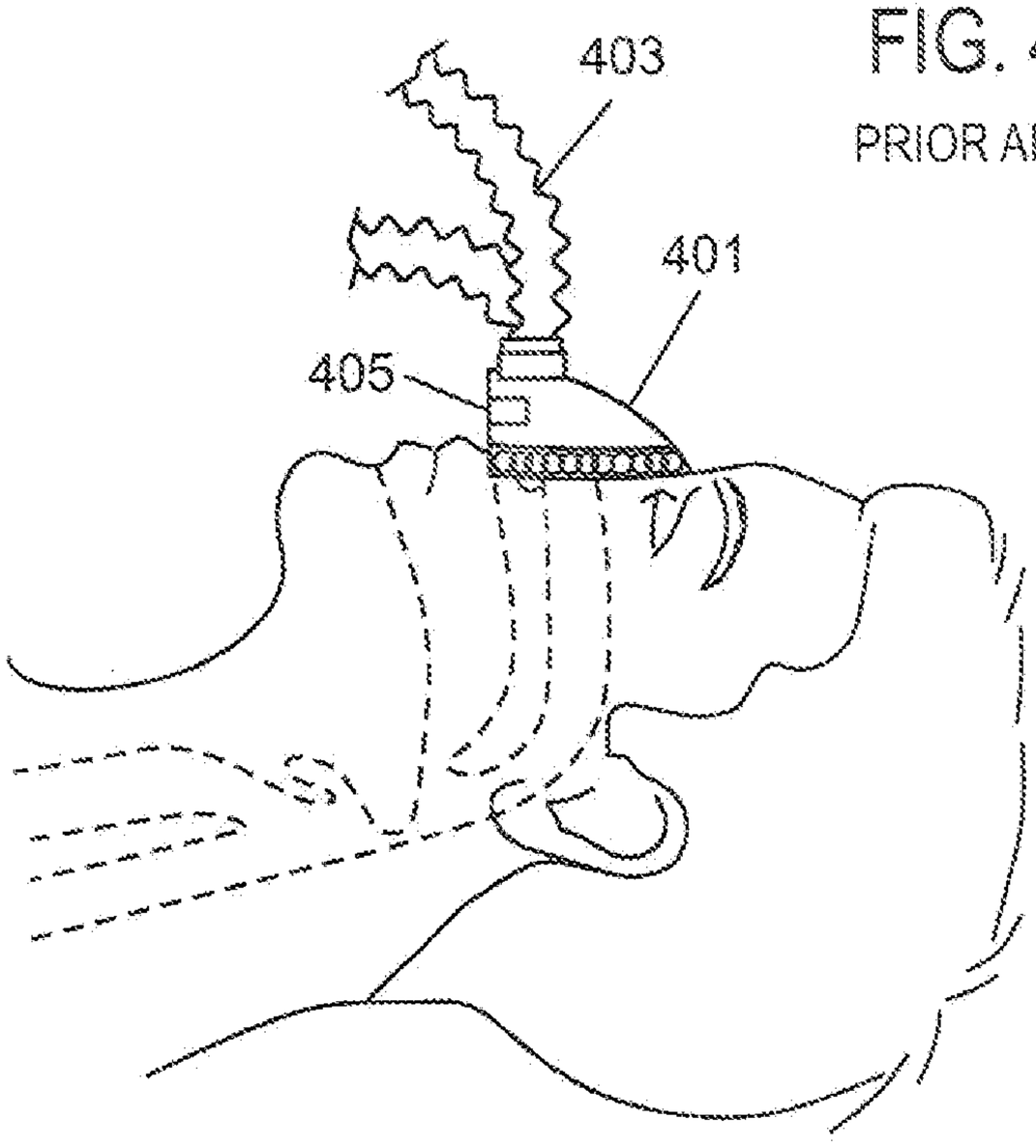
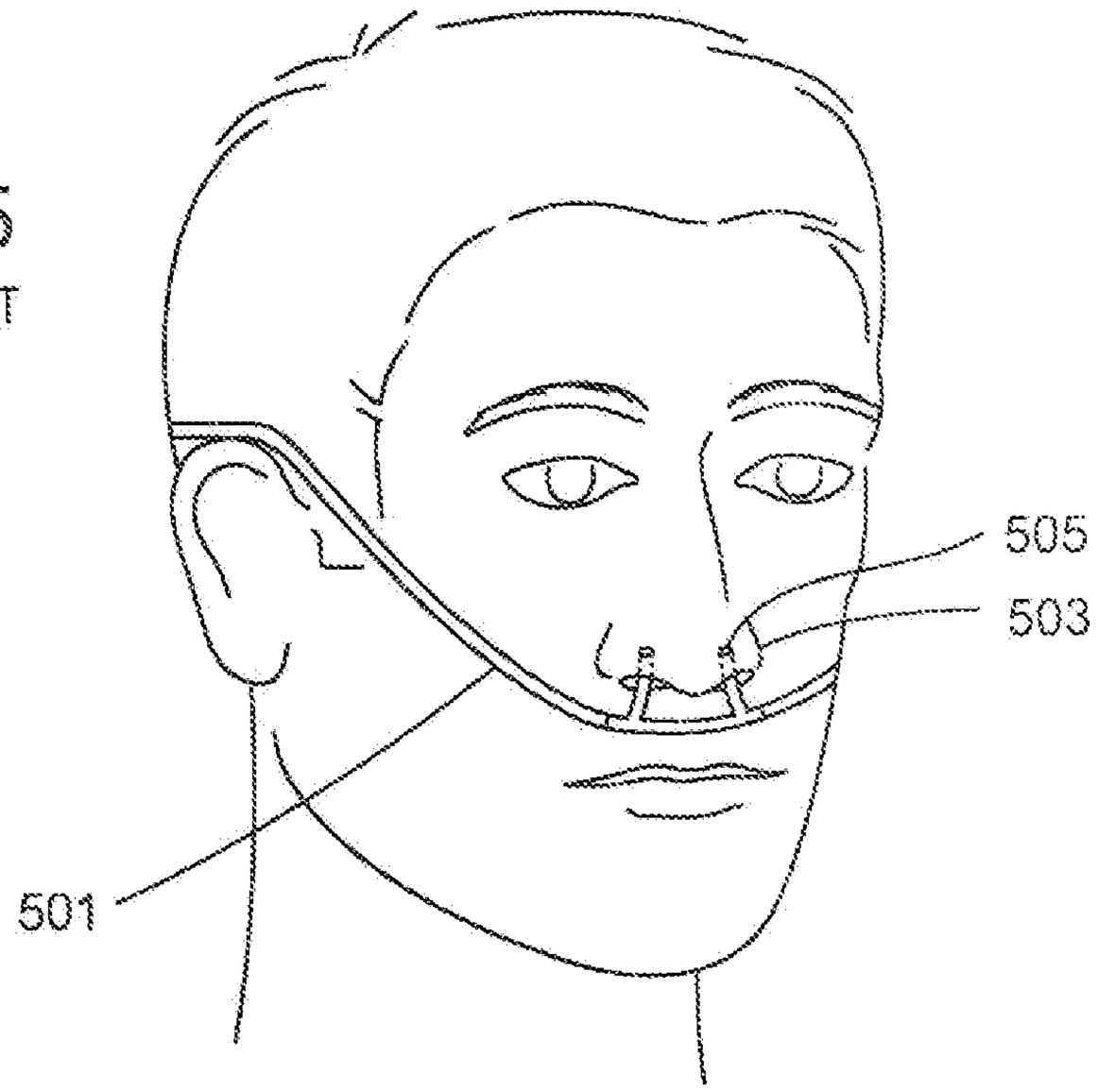


FIG. 4
PRIOR ART

FIG. 5
PRIOR ART



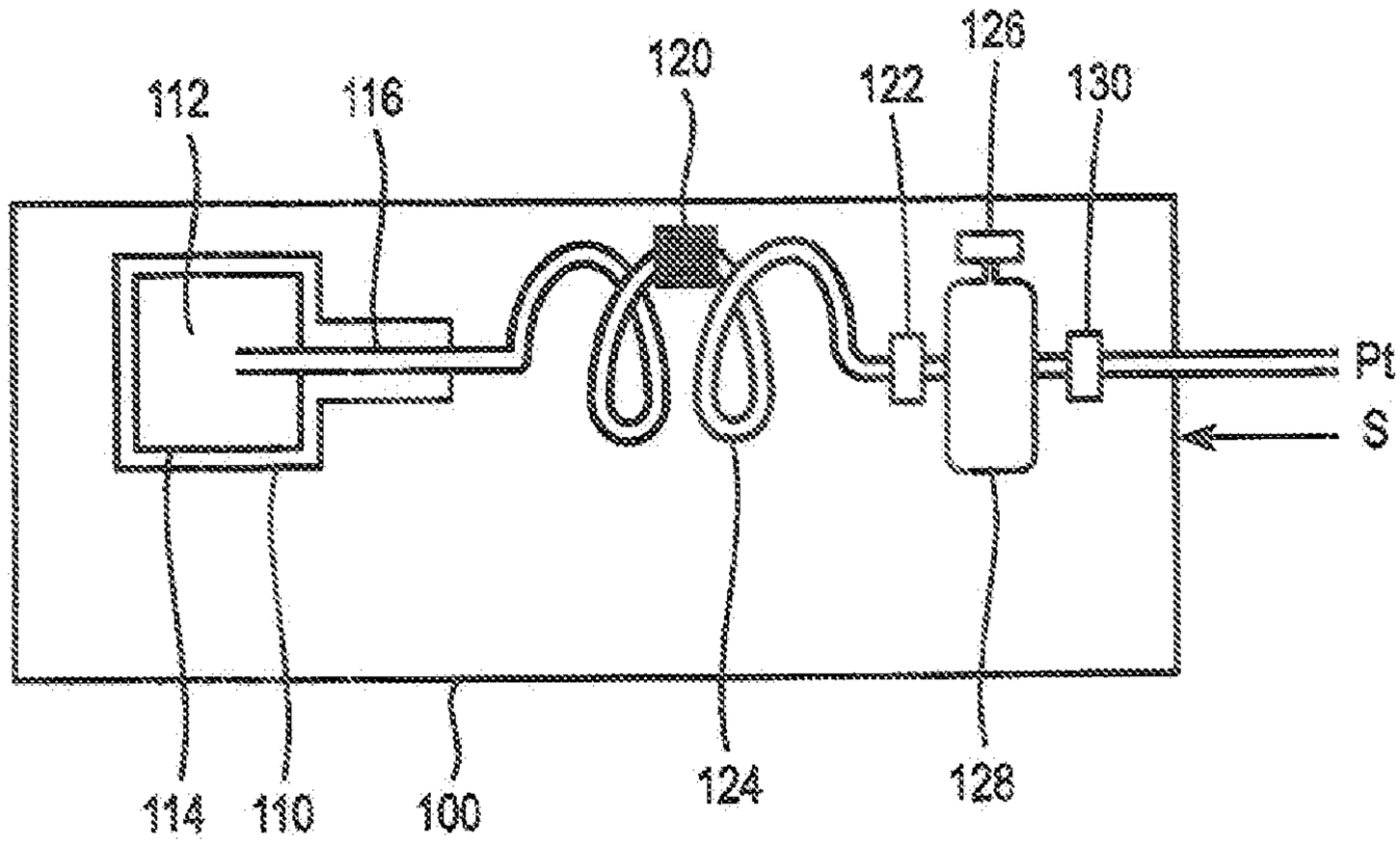
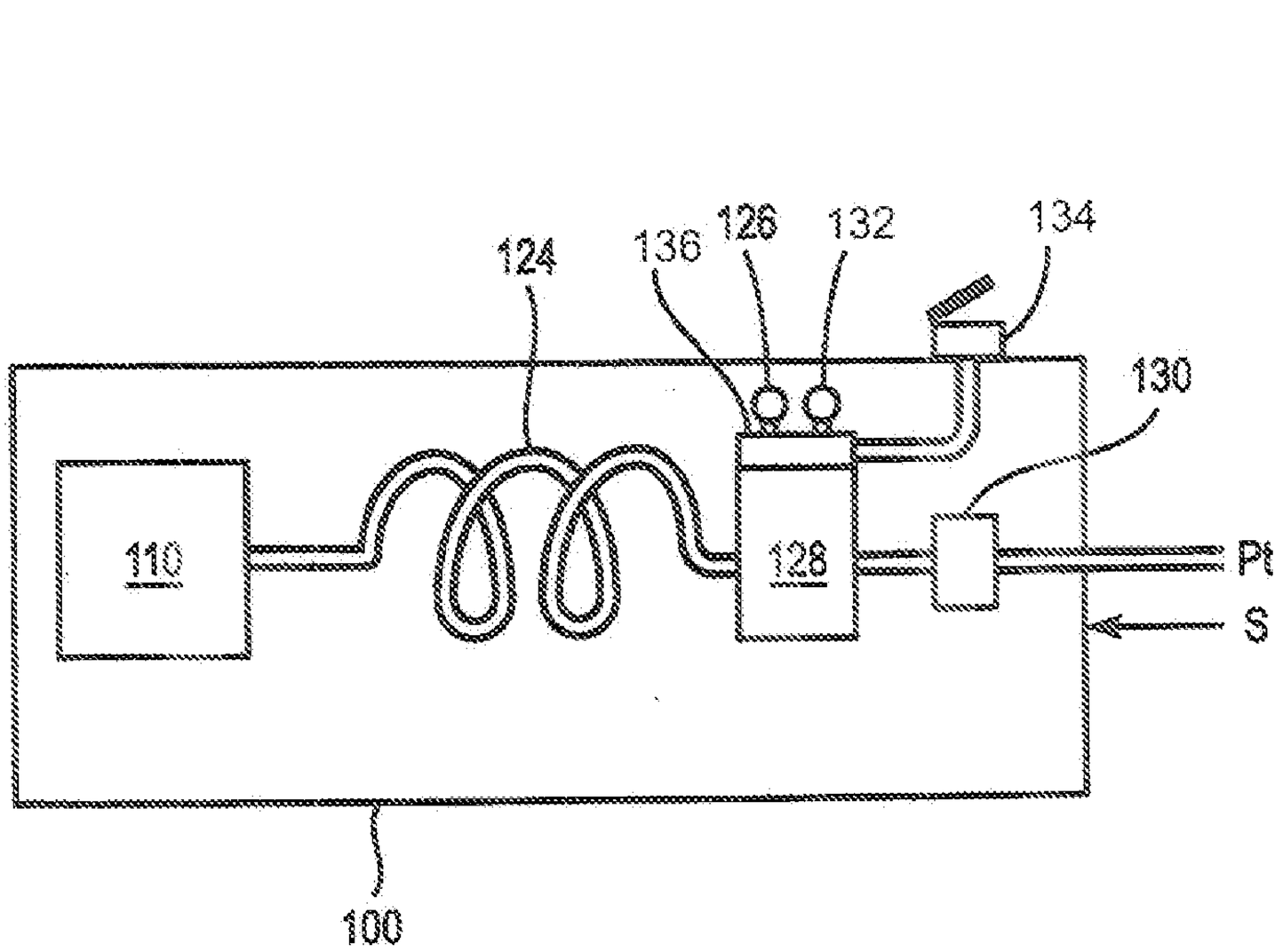

112
116
120
122
126
130
Pt
S
114
110
100
124
128

FIG. 6A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126
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130
110
128
Pt
S
100

FIG. 6B

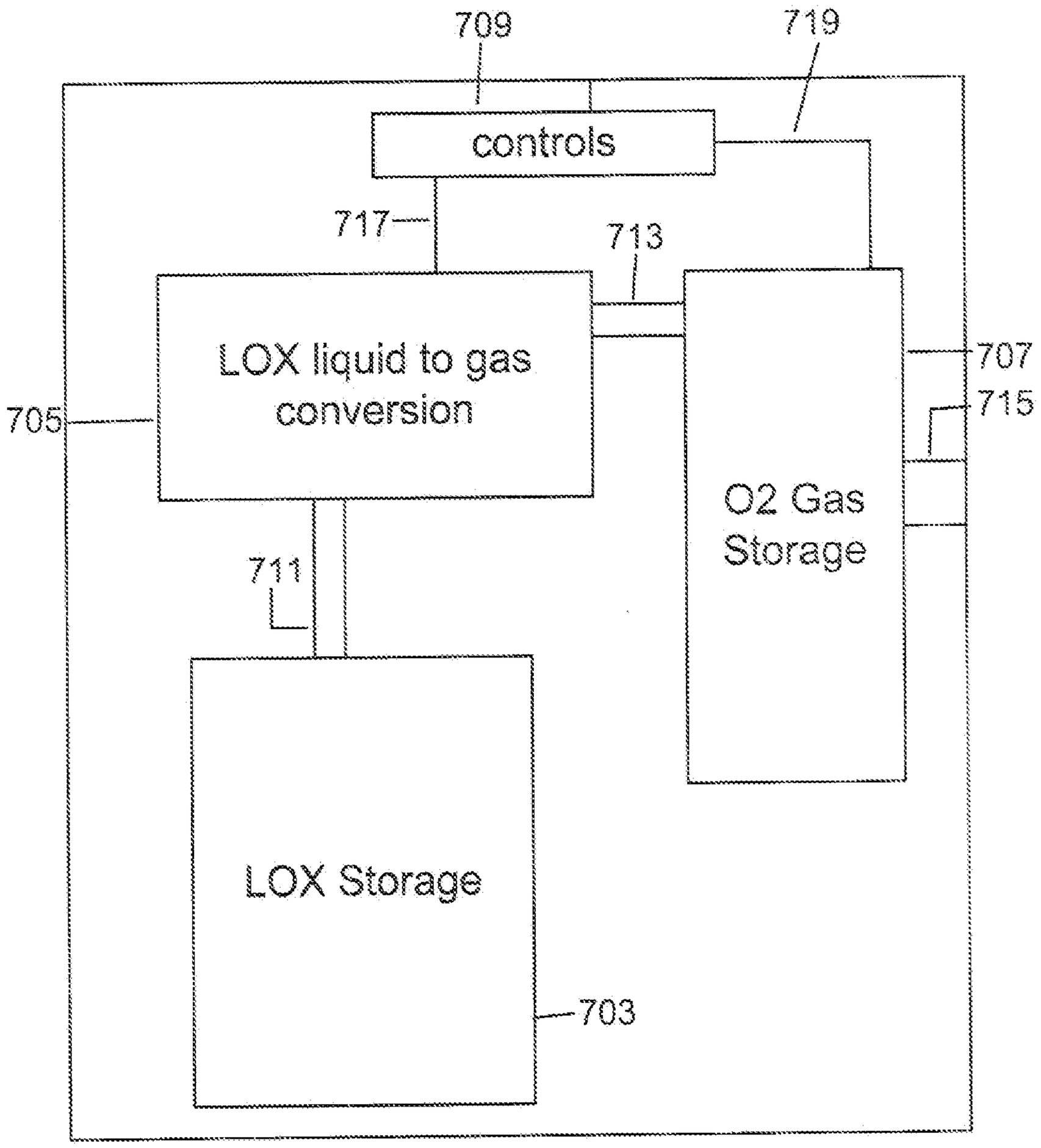

709
719
controls
717
713
LOX liquid to gas conversion
705
707
715
O2 Gas Storage
711
LOX Storage
703
701

FIG. 7

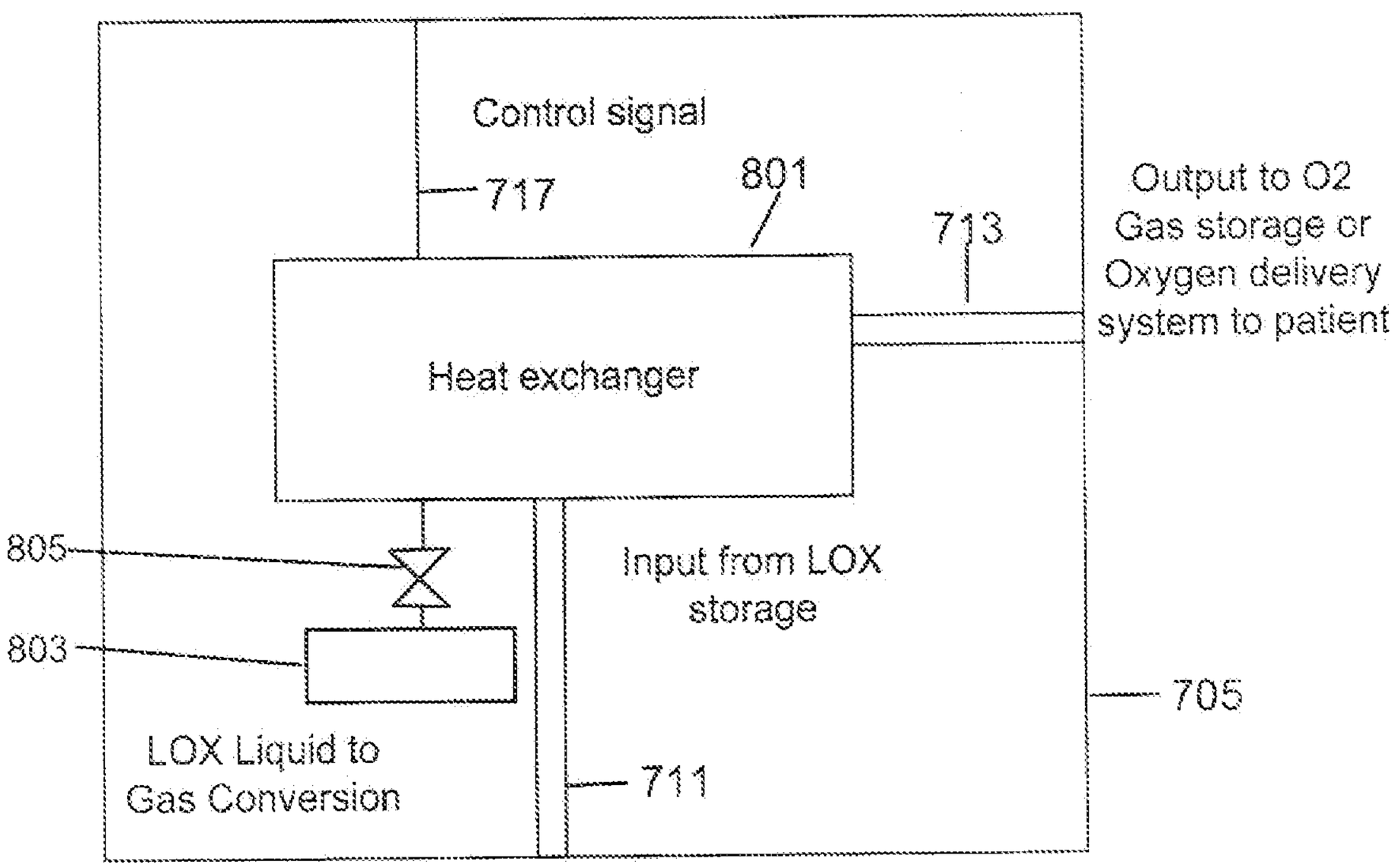

Control signal
717
801
713
Output to O2
Gas storage or
Oxygen delivery
system to patient
Heat exchanger
805
803
Input from LOX
storage
705
LOX Liquid to
Gas Conversion
711

FIG. 8

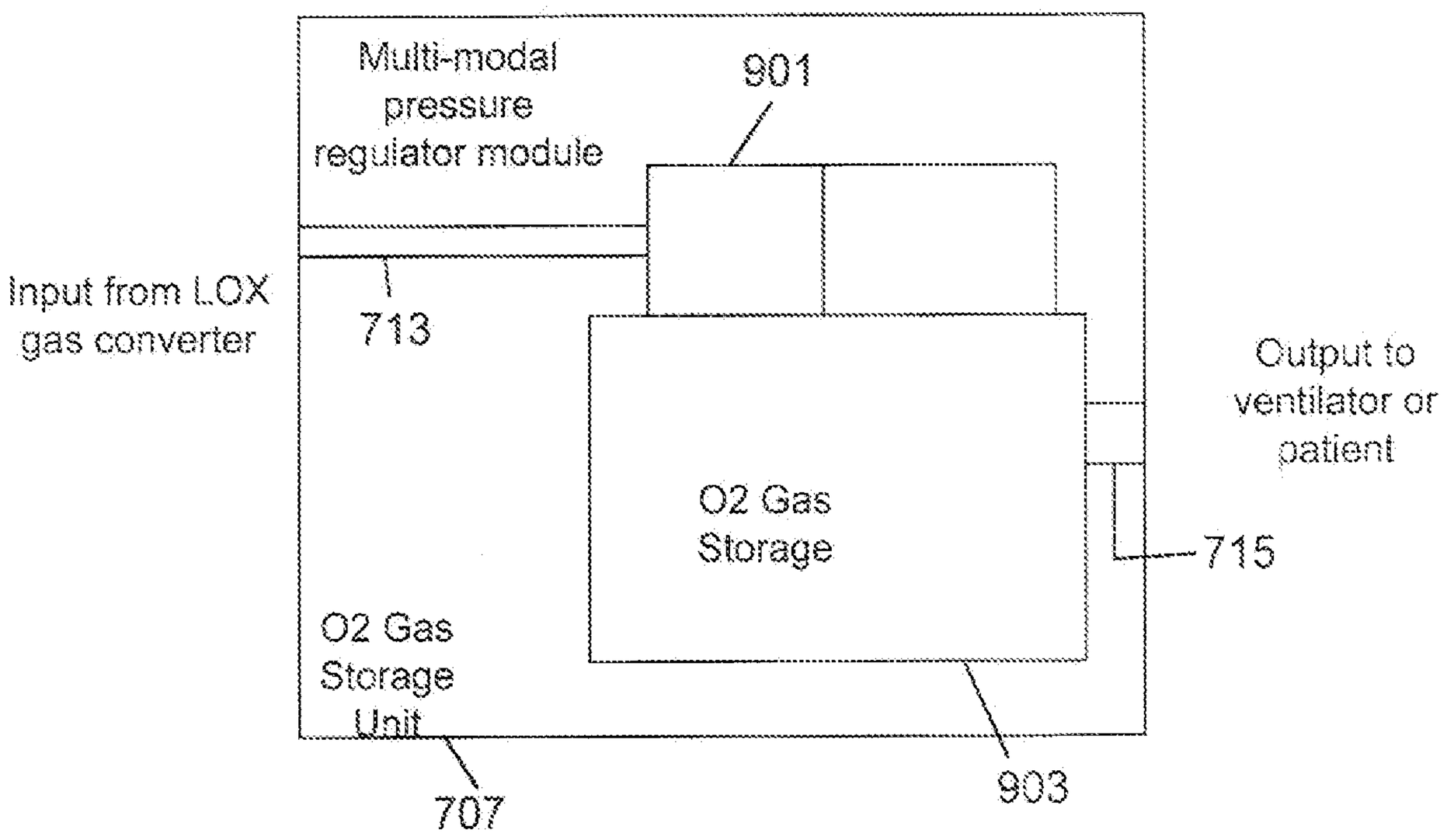

Multi-modal pressure regulator module
901
Input from LOX gas converter
713
Output to ventilator or patient
O2 Gas Storage
715
O2 Gas Storage Unit
707
903

FIG. 9

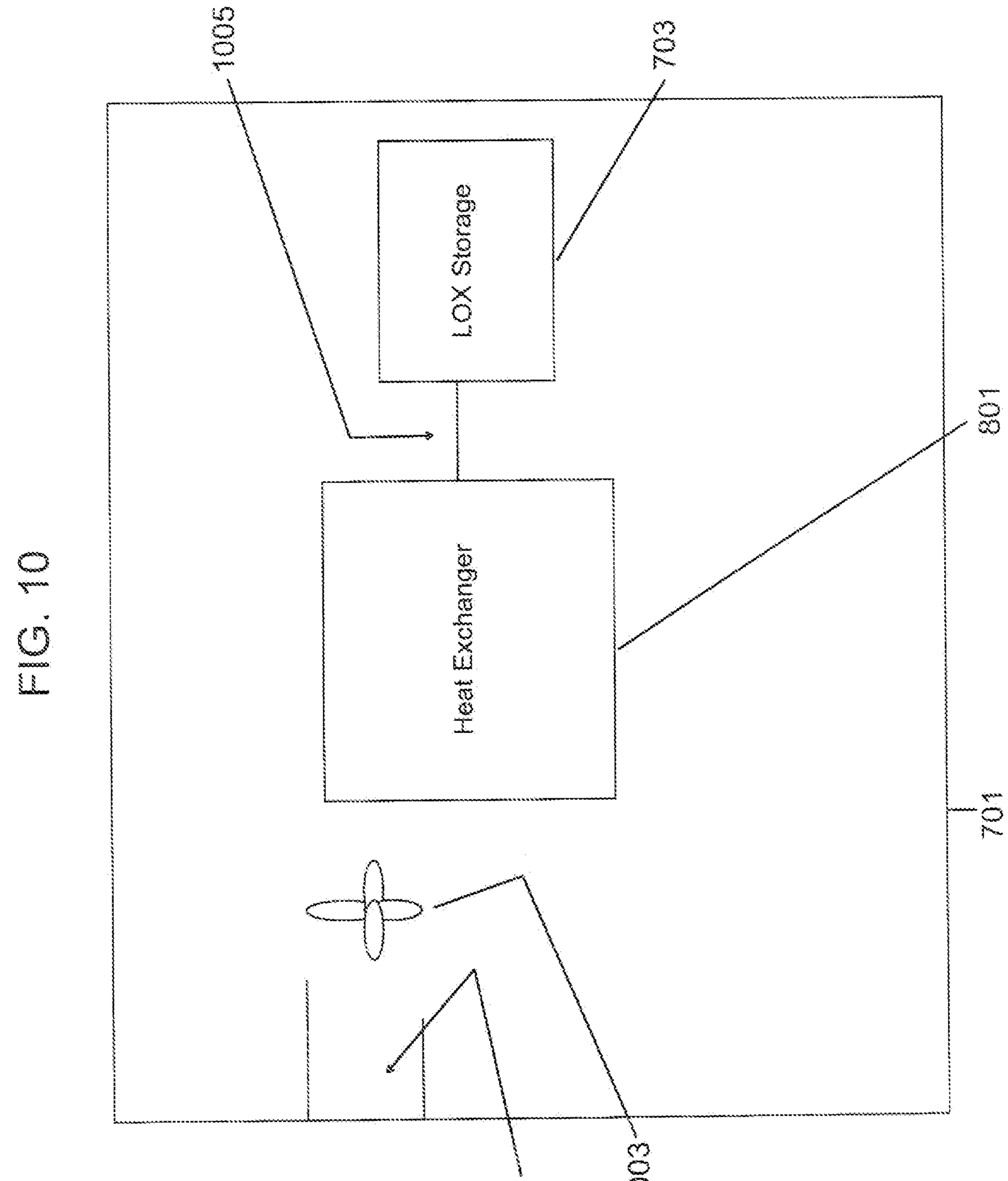
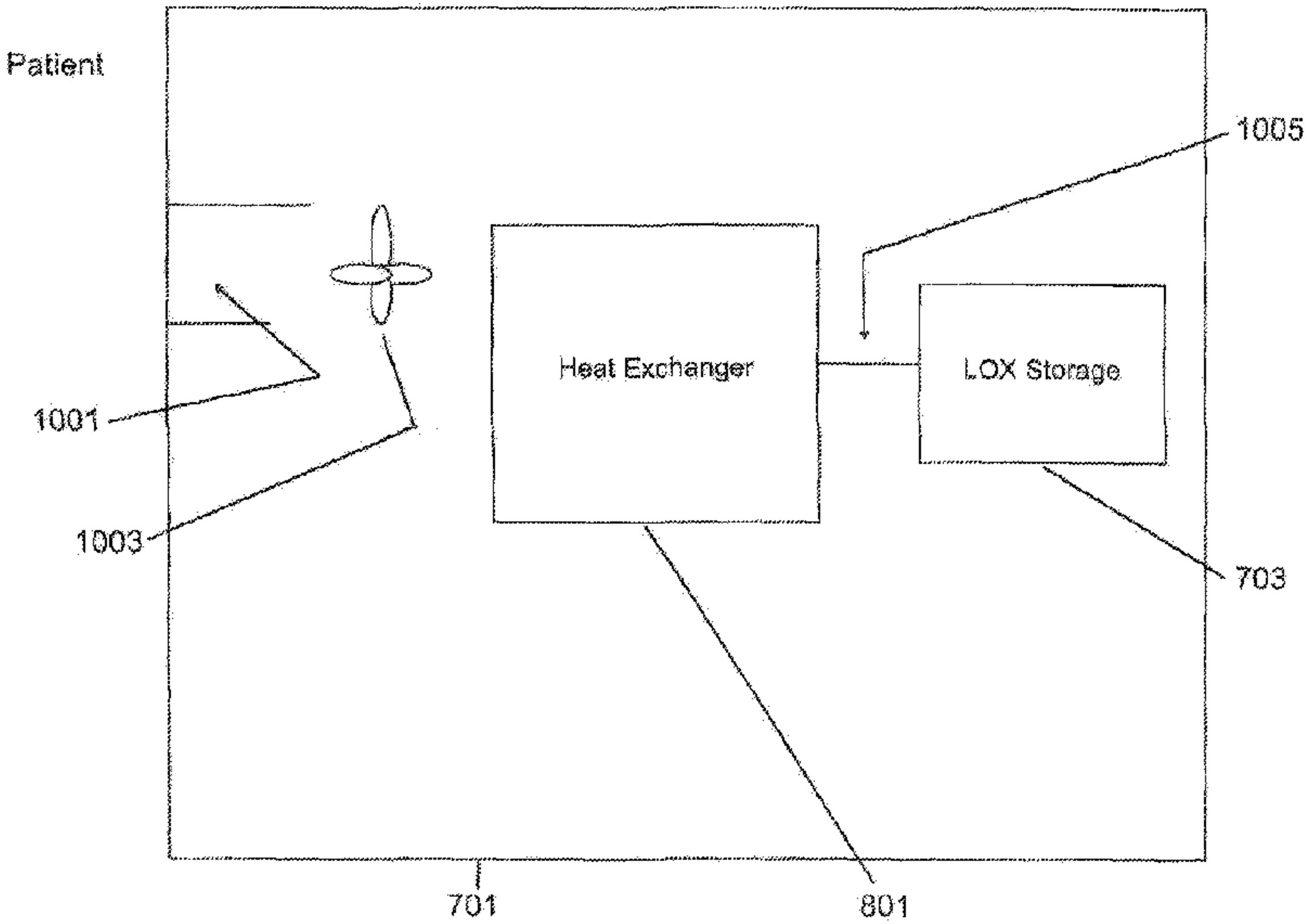

Patient
1005
LOX Storage
Heat Exchanger
703
801
701
1001
103
1003

FIG. 10


Patient
1005
1001
Heat Exchanger
LOX Storage
1003
703
701
801