



(51) International Patent Classification:

A62B 7/14 (2006.01) A62B 9/02 (2006.01)
A62B 9/00 (2006.01) B64D 10/00 (2006.01)

(21) International Application Number:

PCT/EP2011/065158

(22) International Filing Date:

1 September 2011 (01.09.2011)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

PCT/IB2011/000781

28 February 2011 (28.02.2011)

IB

(71) Applicant (for all designated States except US): **INTER-TECHNIQUE** [FR/FR]; 61, rue Pierre Curie, F-78370 Plaisir (FR).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **FROMAGE, Matthieu** [FR/FR]; 4, rue du chapeau rouge, F-78730 Saint-Arnoult-En-Yvelines (FR).

(74) Agents: **PRIEUR, Patrick** et al.; Cabinet Plasseraud, 52 rue de la Victoire, F-75440 Paris Cedex 09 (FR).

(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, RW, 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, 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).

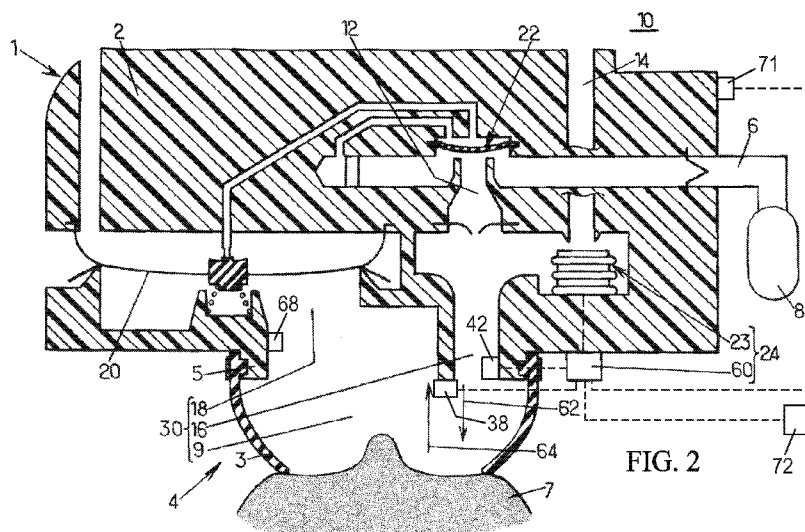
Declarations under Rule 4.17:

— of inventorship (Rule 4.17(iv))

Published:

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

(54) Title: METHOD FOR PROTECTING AIRCRAFT OCCUPANT AND BREATHING MASK



(57) Abstract: Method for protecting aircraft occupant comprising the steps of: – providing a user (7) with a breathing mask (4) for aircraft occupant, – providing a respiratory gas (62) including a mixture of breathable gas and dilution gas to the user (7), – sensing partial pressure or rate of oxygen or carbon dioxide in exhalation gas (64) generated by the user (7), – adjusting (60) the rate of oxygen in the respiratory gas (62).

Method for protecting aircraft occupant and breathing mask**Field of the invention**

The present invention relates to a breathing mask for aircraft demand regulator and a dilution regulation method for protecting the occupant
5 (passengers and/or crewmembers) of an aircraft against the risks associated with high altitude depressurization and/or smoke and fume in the cabin.

In particular, the invention relates to the adjustment of the respiratory gas supplied to a user to satisfy the needs of the user, using a source of breathable gas supplying pure oxygen (oxygen cylinder, chemical generator or
10 liquid oxygen converter) or gas highly enriched in oxygen such as an on-board oxygen generator system (OBOGS).

To ensure the protection of the passengers and/or crewmembers in case of depressurization and/or occurrence of smoke in the aircraft, the demand regulators shall deliver a respiratory gas which is a mixture of dilution
15 gas (generally ambient air) and breathable gas depending of cabin altitude. After a depressurization, the cabin altitude reaches a value close to the aircraft altitude. The pressure value of the cabin is often referred to as the cabin altitude. Cabin altitude is defined as the altitude corresponding to the pressurized atmosphere maintained within the cabin. This value differs from the
20 aircraft altitude which is its actual physical altitude. Correspondence between pressure and conventional altitude are defined in tables. The minimum rate of oxygen in the respiratory gas according to the cabin altitude is set for civil aviation by the Federal Aviation Regulations (FAR).

Background of the invention

25 Most of the current crew breathing masks protecting aircraft crewmember from hypoxia are equipped with oxygen regulators using pneumatic technology for controlling using an open loop the partial pressure of oxygen in the breathing gas. In this technology, ambient air is sucked through a dilution gas supply line by a Venturi which provides suction by high velocity
30 flow of breathable gas. An aneroid capsule (called also altimeter capsule) regulates the altimetric oxygen enrichment by adjusting the section of the

dilution gas supply line. Such demand regulators are known from the documents US 6,994,086, FR 1 484 691 or US 6,796,306. As the oxygen enrichment depends on the section of the dilution gas supply line controlled by the aneroid capsule clearance, the oxygen consumption cannot be optimal for
5 all of the cabin altitude range and/or for all of the breathing ventilation.

The need to save oxygen has lead to the development of electro-pneumatic regulator as described in the documents US 4,336,590, US 6,789,539, US 2007/0107729 or US 2009/O277449. These equipments performed a close loop control of the breathing gas using a measure of the
10 "inspired gas content". These equipments which are interested only by the content of the gas provided to the pilot and not to the physiological state of the pilot need fast sensor and actuator in order to perform an accurate "real time" control of the inspired gas.

Other publication such as patent WO 2008/068545 uses the
15 measure of the arterial blood oxygen saturation (SaO_2) in order to adjust the breathing gas content. This physiological parameter corresponds to the ratio of the amount of oxygen transported by the blood to the maximal theoretical amount of gas transportable. It is linked to the oxygen partial pressure in the arterial blood (PaO_2) thanks to the Barcroft Curve or haemoglobin dissociation
20 curve shown in FIG. 1, which may vary depending on several factors such as the blood pH (saturation decreasing with pH), the partial pressure of carbon dioxide in the alveoli PaCO_2 (SaO_2 decreases when PaCO_2 increases) and the temperature (SaO_2 decreases when the blood temperature increases).

PaO_2 is a difficult datum to measure on the opposite SaO_2 may be
25 easily measure using a pulse oximeter. But once the PaO_2 reaches 80 hPa the curve is almost flat, indicating there is little change in saturation above this point. This is not a problem for passenger hypoxic protection where the targeted PaO_2 level is below 80 hPa but this is not adapted for accurate crewmember hypoxic protection where the targeted PaO_2 level is around
30 100 hPa.

Summary of the invention

The purpose of this invention is to provide a demand regulator which is reliable, quite cheap, simple to settle and supplies an oxygen rate in compliance with the minimum required while being close to the minimum required.

5 For this purpose the invention provides a method for protecting aircraft occupant comprising the steps of:

- providing a user with a breathing mask for aircraft occupant,
- providing a respiratory gas including a mixture of breathable gas and dilution gas to the user,
- 10 – sensing partial pressure or rate of oxygen or carbon dioxide in exhalation gas generated by the user,
- adjusting the rate (fraction/percentage/concentration) of oxygen (or breathable gas) in the respiratory gas.

The measurement of the oxygen partial pressure in the exhalation
15 gas gives a quite good reliable estimation of the oxygen partial pressure in the alveoli P_{AO_2} . This physiological parameter which expresses the oxygen partial pressure in the lung is close to the partial pressure in the arterial blood P_aO_2 when the cabin altitude is high.

Use of the P_{AO_2} for adjusting the rate of oxygen in the in the
20 respiratory gas by controlling the dilution valve take into account the physiology of the user which may differ between users. This allows a more accurate delivering of oxygen according to physiological need and regulation constraints. So, the risk of hypoxia of the aircraft occupant (in particular pilot or crewmember) and the consumption of oxygen can be reduced.

25 It should be noticed that rate, fraction, percentage or concentration are different words referring to quite the same feature.

So, according to supplementary feature, the method preferably comprises adjusting (regulating in closed loop) the rate of oxygen in the respiratory gas in accordance with the partial pressure or rate of oxygen or
30 carbon dioxide in the exhalation gas.

Therefore, the consumption of oxygen is optimised in function of the requirement of the user.

According to another feature, the method preferably comprises:

- sensing partial pressure or rate of oxygen in exhalation gas generated by the user, and
 - adjusting the rate of oxygen in the respiratory flow in accordance
- 5 with the partial pressure or rate of oxygen in exhalation gas.

Indeed, it has appeared that adjusting the rate of oxygen in the respiratory flow in accordance with the partial pressure or rate of oxygen in exhalation gas is more satisfying than in accordance with the partial pressure or rate of carbon dioxide in exhalation gas.

10 However, according to a supplementary advantageous feature, the method further comprises:

- sensing partial pressure or rate of oxygen and carbon dioxide in exhalation gas generated by the user, and
 - adjusting the rate of oxygen in the respiratory flow in accordance
- 15 with the partial pressure or rate of oxygen and carbon dioxide in exhalation gas.

Indeed, partial pressure or rate of oxygen and carbon dioxide in exhalation gas generated by the user enables to further optimise the consumption in oxygen, in particular by increasing the rate of oxygen in the respiratory gas when the carbon dioxide partial pressure PCO_2 in the exhalation

20 gas decreases under a determined threshold.

According to another feature the method preferably comprises:

- sensing partial pressure or rate of oxygen in the exhalation gas generated by the user,
 - sensing partial pressure or rate of oxygen in respiratory gas, and
 - determining coherence between the partial pressure or rate of
- 25 oxygen sensed in the exhalation gas and the partial pressure or rate of oxygen in respiratory gas sensed for detecting failure (in particular a failure in the dilution adjusting device).

This check is much more accurate and more reliable than usual

30 check consisting in out of range alarm on the oxygen sensor for monitoring failure in the regulating process

According to supplementary feature in accordance with the invention, preferably the method further has the following steps:

- sensing barometric pressure in the aircraft, and
- determining coherence between the partial pressure or rate of oxygen sensed in the exhalation gas and the partial pressure or rate of oxygen in respiratory gas thanks to a coherence equation including:
 - the partial pressure or rate of oxygen sensed in the exhalation gas,
 - the partial pressure or rate of oxygen in respiratory gas,
 - and
 - the barometric pressure.

The relation between these features enables to determine a failure quite easily and is particularly efficient.

According to another supplementary feature in accordance with the invention, preferably said coherence equation is:

$$P_{AO_2} = F_{IO_2} \cdot (P_B - P_{AH_2O}) - P_{ACO_2} \cdot (F_{IO_2} + (1 - F_{IO_2}) / R), \text{ with:}$$

- P_{AO_2} is the oxygen partial pressure sensed in the exhalation gas,
- P_B is the barometric pressure in the aircraft,
- P_{ACO_2} is the partial pressure of carbon dioxide in the exhalation gas,
- P_{AH_2O} is the partial pressure of water in the exhalation gas,
- F_{IO_2} is rate of oxygen or the partial pressure of oxygen sensed in the respiratory gas,
- R is a constant between 0.1 and 1.2 corresponding to respiratory quotient.

According to another supplementary feature in accordance with the invention, preferably the method further comprises sensing the partial pressure of carbon dioxide in the exhalation gas.

The determination of failure is more accurate.

According to another supplementary feature in accordance with the invention, preferably the partial pressure of water in the exhalation gas is replaced by a constant.

According to another feature in accordance with the invention, the method comprises (alternatively) sensing the partial pressure or rate of oxygen in the exhalation gas and the partial pressure or rate of oxygen in respiratory gas sensed with a sole (the same) gas sensor.

5 The determination of failure is reliable while requiring few elements (means).

The invention also relates to a breathing mask for aircraft occupant including a demand regulator, said regulator comprising:

- a breathable gas supply line to be connected to a source of
10 breathable gas and supplying a flow chamber with breathable gas,
- a dilution gas supply line to be connected to a source of dilution gas and supplying the flow chamber with dilution gas,
- a dilution adjusting device adjusting the rate of dilution gas in the respiratory gas supplied to the flow chamber, the dilution adjusting device
15 comprising a dilution valve, a gas sensor adapted to sense partial pressure or rate of oxygen or carbon dioxide and a control device controlling the dilution valve in accordance with a dilution signal generated by the gas sensor in function of the partial pressure or rate of oxygen or carbon dioxide.

In advantageous embodiments, the breathing assembly preferably
20 further has one or more of the following features:

Brief description of the drawings

Other features and advantages of the present invention will appear in the following detailed description, with reference to the appended drawings in which:

- 25 – FIG. 1 represents the arterial blood saturation in accordance with the partial pressure of oxygen in the arterial blood,
- FIG. 2 shows a breathing mask comprising a flow chamber,
- FIG. 3 schematically represents a first flow and a second flow in the flow chamber of the breathing mask, according to first embodiment of a
30 sensing device,
- FIG. 4 represents variations of the first flow in the flow chamber during the time,

- FIG. 5 represents variations of the second flow in the flow chamber during the time,
- FIG. 6 represents measurements provided by gas sensors placed in the flow chamber,
- 5 – FIG. 7 represents a second embodiment of a sensing device in accordance with the invention,
- FIG. 8 represents a third embodiment of a sensing device in accordance with the invention,
- FIG. 9 represents a fourth embodiment of a sensing device in
10 accordance with the invention,
- FIG. 10 represents a fifth embodiment of a sensing device in accordance with the invention,
- FIG. 11 represents a step of a method according to the invention using the sensing device of the fifth embodiment,
- 15 – FIG. 12 is a flowchart representing different steps of a method for using the sensing device of the fifth embodiment,
- FIG. 13 represents partial pressure of oxygen according to the method for using the sensing device of the fifth embodiment,
- FIG. 14 represents partial pressure of oxygen according to an
20 alternative method for using the sensing device of the fifth embodiment.

Detailed description of the invention

FIG. 2 discloses main functions of a breathing mask 4 for occupant of an aircraft, in particular for pilot disposed in a cabin 10 of an aircraft.

The breathing mask 4 comprises a demand regulator 1 and an
25 oronasal face piece 3 fixed to a tubular connecting portion 5 of the regulator 1. When a user 7 dons the breathing mask 4, the oronasal face piece 3 is put to the skin of the user face 7 and delimits a respiratory chamber 9.

The demand regulator 1 has a casing 2 including a breathable gas supply line 12, a dilution gas supply line 14 and a respiratory gas supply line 16.
30 The respiratory gas supply line 16 has a downstream end in fluid communication with the respiratory chamber 9.

The breathable gas supply line 12 is supplied at its upstream end with pressurized oxygen by a source of breathable gas 8 through a feeding duct 6. In the embodiment shown, the pressurized source of breathable gas 8 is a cylinder containing pressurized oxygen. The breathable gas supply line 12
5 supplies the respiratory chamber 9 with breathable gas through the respiratory gas supply line 16, the downstream end of the breathable gas supply line 12 being directly in fluid communication with the upstream end of the respiratory gas supply line 16.

The dilution gas supply line 14 is in communication by its upstream
10 end with a source of dilution gas. In the illustrated embodiment, the dilution gas is air and the source of dilution gas is the cabin 10 of the aircraft. The dilution gas supply line 14 supplies the respiratory chamber 9 with dilution gas through the respiratory gas supply line 16, the downstream end of the dilution gas supply line 14 being directly in fluid communication with the upstream end of
15 the respiratory gas supply line 16. So, in the embodiment illustrated in FIG.2, the breathable gas and the dilution gas are mixed in the respiratory gas supply line 16 of the casing 2, i.e. before supplying the respiratory chamber 9 through the tubular connecting portion 5. Therefore a flow 62 of respiratory gas flows in the respiratory gas supply line 16 and the respiratory chamber 9, the respiratory
20 gas including breathable gas and dilution gas mixed.

The regulator 1 further comprises an exhaust line 18 and an exhaust valve 20. The exhaust valve 20 is disposed between the downstream end of the exhaust line 18 and the cabin 10 (ambient air). The upstream end of the exhaust line 18 is in communication with the respiratory chamber 9 of the
25 oronasal face piece 3 through the tubular connecting portion 5 and receives a flow 64 of gas exhaled by the user. Concerning the exhaust of the exhalation gas 64, the exhaust valve 20 functions as a check valve which opens under the pressure of the exhalation gas 64 and closes for preventing air of the cabin 10 from entering into the flow chamber 30.

30 The user 7 breathes in and breathes out in the respiratory chamber 9. The exhalation line 18 is in communication directly or through the respiratory chamber 9 with the respiratory gas supply line 16. Therefore, the gas supply

line 16, the respiratory chamber 9 and the exhalation line 18 define a flow chamber 30 without separation.

The demand regulator 1 further has a pressure adjusting device 22 and a dilution adjusting device 24.

5 The pressure adjusting device 22 adjusts the pressure in the flow chamber 30 and in particular in the respiratory chamber 9. In the embodiment illustrated in FIG.2, the pressure adjusting device 22 comprises in particular a main valve disposed between the feeding duct 6 and the respiratory gas supply line 16.

10 The dilution adjusting device 24 adjusts the rate of oxygen in the respiratory gas flow 62. In the embodiment illustrated, the dilution adjusting device comprises in particular a dilution valve 23, a control device 60, a flow direction sensor 38, an oxygen sensor 42, an optional carbon dioxide sensor 68, a cabin altitude sensor 71 and an optional aircraft altitude sensor 72. The
15 dilution valve 23 is disposed between the dilution gas supply line 14 and the respiratory gas supply line 16. The control device 60 controls the dilution valve 23. The flow direction sensor 38, the oxygen sensor 42, the carbon dioxide sensor 68, the cabin altitude sensor 71 and the aircraft altitude sensor 72 provide information to the control device 60 to adjust the rate of oxygen in the
20 respiratory gas 62 by actuating the dilution valve 23. The cabin altitude sensor 71 senses the barometric pressure, i.e. the ambient (absolute) pressure (in the cabin 10 of the aircraft). The aircraft altitude sensor 72 senses the pressure outside the cabin 10. During normal operation, equipment pressurises the cabin 10 at the cabin altitude, so the pressure is higher than the pressure outside the
25 cabin and conversely the cabin altitude is lower than the aircraft altitude.

Demand regulators start supplying first gas mixture (respiratory gas) in response to the user of the breathing mask breathing in and stops supplying respiratory gas when the user stops breathing in.

One can refers to prior art, such as for example to document
30 US 6,789,539 for a more detailed description of a demand regulator. The present invention is also applicable to other types of dilution adjusting device

24, such as the dilution adjusting device disclosed in patent application PCT/IB2011/000772 or US 6,789,539 included by reference.

FIG. 3 schematically represents a sensing device 100 comprising a flow direction sensor 38, two gas sensors: an oxygen sensor 42 and an optional
5 carbon dioxide sensor 68. The sensing device 100 is a portion of the breathing mask 4 represented in FIG. 2. The oxygen sensor 42 and the carbon dioxide sensor 68 are placed in the flow chamber 30 forming a sensing chamber 40 in which alternatively flows a first gas mixture 32 and a second gas mixture 34. In order to adjust the rate of oxygen to deliver to the user 7, a characteristic (in
10 particular the partial pressure or percentage of a gaseous) of a gaseous constituent (in particular oxygen or carbon dioxide) of at least the first gas mixture 32 is to be detected by the oxygen sensor 42 and the carbon dioxide sensor 68.

The flow direction sensor 38, the oxygen sensor 42 and the carbon
15 dioxide sensor 68 are connected to the control device 60. The flow direction sensor 38 detects if the flow direction in the flow chamber 30 corresponds to the direction of the first flow mixture 32. The flow direction sensor 38 may also detect if the flow direction in the flow chamber 30 corresponds to the direction of the second flow mixture 34.

20 Indeed, the first gas mixture 32 may be either the respiratory gas 62 or the exhalation gas 64, which means that the characteristic of the gaseous constituent to sense may be either in the respiratory gas or in the exhalation gas. So, the first gas mixture 32 flows from the tubular connecting portion 5 to (the mouth or nose of) the user 7 or from the user 7 to the tubular connecting
25 portion 5. Conversely, the second gas mixture 34 may be either the exhalation gas 64 or the respiratory gas 62.

The oxygen sensor 42 is adapted to determine in particular partial pressure (or percentage) in oxygen of the gas contained in the sensing chamber 40 whereas the carbon dioxide sensor 68 is adapted to determine in
30 particular partial pressure (or percentage) in carbon dioxide of the gas contained in the sensing chamber 40.

The flow direction sensor 38 includes in particular a pressure sensor, a pressure gauge sensor, a pressure differential sensor, thermistances, a sensor of the state of a check valve or a piezo sensor device comprising a flexible sheet and detecting the direction of the curvature of the flexible sheet.

5 As represented schematically in FIG. 4, between the time 0 and the time T_1 , the gas content in the flow chamber 30 reaches the gas content of the first gas mixture flow 32 and then between the time T_1 and the time $T_1 + T_2$, the first gas mixture flow 32 becomes absent from the flow chamber 30.

 As represented schematically in FIG. 5, between the time 0 and the
10 time T_1 , the second gas mixture flow 34 becomes absent from the flow chamber 30 and then, between the time T_1 and the time $T_1 + T_2$, the gas content in the flow chamber 30 reaches the gas content of the second gas mixture flow 34.

 It should be noticed that in FIGS. 4 and 5 the time for filling the flow
15 chamber 30 is neglected.

 So, it may be considered by simplification that successively during a T_1 period the first gas mixture 32 flows in the flow chamber 30 in a first direction, then during a T_2 period the second gas mixture 34 flows into the flow chamber 30 in a second direction opposite to the first direction, then the first
20 gas mixture 32 flows again in the flow chamber 30 during another T_1 period, and so on. The T_1 period may be considered as equal to the T_2 period, and called T.

 The gaseous content of the first gas mixture 32 being different from the second gas mixture 34, the second gas mixture 34 disturbs the
25 measurement of the characteristic of the gaseous content of the first gas mixture 32. It should be understood that the first gas mixture and the second gas mixture may content the same constituents (at least some identical constituents), and only differ in the percentage of some of the constituents (in particular percentage of oxygen, carbon dioxide and steam).

30 FIG. 6 presents three measurements 42a, 42b, 42c provided by oxygen sensors 42 having different response times T_r for the above described

example. The measurements 42a, 42b, 42c correspond to oxygen sensors having a response time respectively equal to $T/10$, $T/2$ and $2T$.

It appears that the oxygen sensor providing measurements 42a, 42b are suitable for the present example. Therefore, when the flow direction sensor 38 detects the exhalation gas 64, the oxygen sensor 42 determines the partial pressure (or percentage) in oxygen in the exhalation gas 64 and conversely when the flow direction sensor 38 detects the respiratory gas 62, the oxygen sensor 42 determines the partial pressure (or percentage) in oxygen in the respiratory gas 62. Therefore, the oxygen sensor 42 provides the control device 60 with the oxygen partial pressure in the exhalation gas 64 and with the oxygen partial pressure in the respiratory gas 62. As the cabin altitude sensor 71 provides the control device 60 with the barometric pressure (total pressure in the cabin 10), the control device 60 determines the fraction of oxygen in the respiratory gas, since the oxygen partial pressure in the respiratory gas is equal to the product of the barometric pressure and the fraction of oxygen in the respiratory gas.

The oxygen sensor providing measurement 42c is not appropriate. So, the shorter the response time of the gas sensor is, the more accurate the measurement is. But, a gas sensor with a short time response is generally more expensive than a sensor with a longer time response, and sometimes a gas sensor with a time response satisfying for a particular application does not exist.

FIG. 7 represents a second embodiment of a sensing device 100 in accordance with the invention. The sensing device 100 comprises a flow direction sensor 38, a shutter 50, a driving device 51 and an oxygen sensor 42 placed in a sensing chamber 40 in fluid communication with the flow chamber 30 through a passage 66. A carbon dioxide sensor 68 may be placed in the sensing chamber 40 instead of the oxygen sensor 42 or in addition to the oxygen sensor 42, in order to determine in particular partial pressure (or percentage) in carbon dioxide of the gas contained in the sensing chamber 40.

The flow direction sensor 38 and the oxygen sensor 42 are connected to the control device 60. The flow direction sensor 38 detects if the

flow direction in the flow chamber 30 corresponds to the direction of the first flow mixture 32. In variant, the flow direction sensor 38 may detect if the flow direction in the flow chamber 30 corresponds to the direction of the second flow mixture 34.

5 The shutter 50 is movable between an active position in which it closes the passage 66 and an inactive position in which it is away from the passage 66.

 The control device 60 controls the driving device 51 in order to place the shutter 50 in open position when the flow direction sensor 38 detects the first gas flow 32, so that the first gas mixture flow 32 (partially) enters in the sensing chamber 40. Moreover, the control device 60 controls the driving device 51 in order to place the shutter 50 in closed position when the flow direction sensor 38 does not detect the first gas flow 32, so that the second the second gas mixture flow 34 is prevented from entering in the sensing chamber 40.

 Therefore, the sensing chamber 40 contains only gas mixture of the first gas mixture flow 32 at any time. So, the oxygen sensor 42 transmits a dilution signal which accuracy is not influenced by the second gas mixture flow 34. The control device 60 controls the dilution valve 24 in accordance with the dilution signal generated by the oxygen sensor 42.

 The oxygen sensor 42 is adapted to determine in particular partial pressure (or percentage) in oxygen of the gas contained in the sensing chamber 40.

 The flow direction sensor 38 includes in particular a pressure sensor, a pressure gauge sensor, a pressure differential sensor, thermistances, a sensor of the state of a check valve or a piezo sensor device comprising a flexible sheet and detecting the direction of the curvature of the flexible sheet.

 FIG. 8 represents a third embodiment of a sensing device 100 in accordance with the invention.

30 In this third embodiment, the characteristic of the gaseous constituent to sense is in the respiratory gas 62, so that the first gas mixture

flow 32 is the respiratory gas flow and the second gas mixture flow 34 is the exhalation gas flow.

An isolation valve 36 is inserted between the respiratory gas supply line 16 and the respiratory chamber 9. The oxygen sensor 42, in connection with the control device 60, is placed in the respiratory chamber 16 which forms the sensing chamber 40. The isolation valve 36 prevents gas from entering into the sensing chamber 16, 40 from the respiratory chamber 9. In an alternative embodiment, the flow direction sensor 38 may detect if the flow direction in the flow chamber 30 corresponds to the direction of the second flow mixture 34.

10 In the embodiment illustrated, the isolation valve 36 is a check valve. In variant, it may be an inspiration valve similar to the exhaust valve 20.

FIG.9 represents a fourth embodiment of a sensing device 100 in accordance with the invention.

15 In this fourth embodiment, the characteristic of the gaseous constituent to sense is in the exhalation gas, so that the first gas mixture flow 32 is the exhalation gas flow 64 and the second gas mixture flow 34 is the respiratory gas flow 62.

20 An isolation valve 36 is inserted between the respiratory chamber 9 and the exhalation line 18. The oxygen sensor 42, in connection with the control device 60, is placed in the exhalation line 18 which forms the sensing chamber 40. The isolation valve 36 prevents gas from entering into the respiratory chamber 9 from the exhalation line 18. The carbon dioxide sensor 68 may be placed in the sensing chamber 40 instead of the oxygen sensor 42 or in addition to the oxygen sensor 42.

25 In the embodiment illustrated, the isolation valve 36 is a check valve. In variant, it may be an inspiration valve similar to the exhaust valve 20.

FIG. 10 represents a fifth embodiment of a sensing device 100 in accordance with the invention.

30 The oxygen sensor 42 comprises a pumping plate 44, a first disk of solid ionic conductor 45, a common plate 46, a second disk of solid ionic conductor 47 and a sensing plate 48.

The pumping plate 44, the common plate 46 and the sensing plate 48 are electrodes preferably made of platinum films.

The pumping plate 44, the common plate 46 and the sensing plate 48 are of substantially annular form. Therefore, the sensing chamber 40 is delimited by the common plate 46, the first ionic conductor 45 and the second ionic conductor 47.

A current source 39 is inserted between the pumping plate 44 and the common plate 46. The common plate 46 and the sensing plate 48 are connected to the control device 60, as well as the flow direction sensor 38.

The pumping plate 44, the first solid ionic conductor 45 and the common plate 46 define a pumping electrochemical cell 56. The common plate 46, the second solid ionic conductor 47 and the sensing plate 48 define a sensing electrochemical cell 58.

The ionic conductors 45, 47 define solid electrolyte. They are preferably made in dioxide zirconium suitably adapted for the conduction of ions of oxygen O_2 .

The oxygen sensor 42 further comprises an optional filter 49 surrounding the pumping electrochemical cell 56 and the sensing electrochemical cell 58. The filter 49 prevents particles from entering into the sensor 42. Therefore, the oxygen sensor 42 includes a buffer chamber 41 extending between the flow chamber 30 and the pumping electrochemical cell 56 (and the sensing electrochemical cell 58).

The oxygen sensor 42 may be placed either in the respiratory chamber 9, in the respiratory gas supply line 16 or in the exhalation line 18, and of any of the first to fourth embodiment described above.

As illustrated in FIG. 11, when the electrical power supply 39 outputs a pumping current i at the value I_p , oxygen ions are transported through the ionic conductors 45 from the sensing chamber 40 to the buffer chamber 41. Therefore, an evacuation phase 28 corresponds to a phase of pumping current i equal to I_p . So, the partial pressure in Oxygen PO_2 in the sensing chamber 40 decreases. The voltage V_s between the sensing plate 48 and the common plate, called Nerst voltage, increases.

When the electrical power supply 39 outputs a pumping current i at the value $-I_p$, oxygen ions are transported through the ionic conductor 45 from the buffer chamber 41 to the sensing chamber 40. Therefore, a pressurisation phase 26 corresponds to a phase of pumping current i equal to $-I_p$. So, the partial pressure in Oxygen PO_2 in the sensing chamber 40 increases and the Nerst voltage V_s between the sensing plate 48 and the common plate 46 decreases.

In operation, the control device 60 causes a repetitive sequence where the oxygen pumping current I is successively reversed to maintain the Nerst voltage V_s between to predetermined values V_1 , V_2 .

Therefore, the partial pressure of Oxygen in the sensing chamber 40 varies between two values PO_{2low} and PO_{2high} .

The period of oscillation T_p is proportional to the oxygen partial pressure in the buffer chamber 41. Therefore, period of the pumping cycle is used to determine the ambient oxygen partial pressure.

The transportation of the oxygen through the ionic conductor 45 during the pressurisation phase 26 creates a pressure drop in the buffer chamber 41. The low porosity of the external filter 49 limits the entry of the ambient gas into the sensor and is responsible of the main delay (high response time) in the oxygen partial pressure measurement.

The response time of the oxygen sensor 42 generates an error in the measurement of the oxygen partial pressure in the first gas mixture flow 32, due to the second gas mixture flow 34.

As shown in FIG. 12, in order to limit the error in the measurement of the oxygen partial pressure in the first gas mixture flow 32, the direction of the flow in the flow chamber 30 is sensed by the direction gas sensor 38. During step S38, based on the signal provided by the flow direction sensor 38, the control device 60 determines if the flow in the flow chamber 30 is in the direction of the first gas mixture flow 32. If Yes, during a measurement period 52, the pressurization phase 26 and the evacuation phase 28 repetitively and alternatively follow one another, as shown in FIGS. 13 and 14. If No, as shown in FIG. 13, during a period without measurement 54, the pressurisation of the

sensing chamber 40 is stopped, no pressurisation phase 26 occurring during the period without measurement 54. Consequently, diffusion of the second gas mixture flow 34 into the gas sensor buffer 41 is reduced and the sensing accuracy of the oxygen sensor 42 is improved. For example, the gas sensor measurement process is active during inspiration of the user and stopped during exhalation of the user if the characteristic of the gaseous component to be sensed is in the respiratory gas.

In a variant shown in FIG. 14, during the period without measurement 54, preferably at the beginning, an evacuation phase 28 is achieved. During the evacuation phase 28 of the period without measurement 54, as shown in FIG. 14, the pumping current i is preferably lower than during the evacuation phase 28 of the measurement period 52, i.e. lower than I_p . Therefore, the evacuation phase 28 of the period without measurement 54 lasts during all the period without measurement 54 or at least more than half of the period without measurement 54.

Moreover, the respiratory gas 62 and the exhalation gas 64 are preferably successively (alternatively) considered as the first gas mixture flow 32 and the gas second mixture flow so that the oxygen partial pressure is successively measured in the respiratory gas 62 and the exhalation gas 64.

Since the oxygen partial pressure in the respiratory gas is equal to the product of the barometric pressure sensed by the cabin altitude sensor 71 and the fraction of oxygen in the respiratory gas 62, the control device 60 determines the fraction of oxygen in the respiratory gas 62 and the oxygen partial pressure in the exhalation gas 64.

Concerning the operating of the regulator 1 using the , the dilution adjusting device 24 adjusts the rate of oxygen in the respiratory gas 62 in accordance with the oxygen partial pressure PO_2 or rate of oxygen in the exhalation gas 64, sensed by the oxygen sensor 42 of one of the sensing devices 100 above described.

It should be noticed that the oxygen sensors currently available can provide directly either the oxygen partial pressure or the rate of oxygen, and

that oxygen partial pressure PO_2 is equal to the rate of oxygen multiplied by the barometric pressure sensed by the cabin altitude sensor 71.

The dilution valve 23 is preferably controlled in closed loop with a Proportional Integral Derivative (PID) controller included in the control device 60, in order to adjust the oxygen partial pressure PO_2 in the exhalation gas 64 sensed by the oxygen sensor 42 in accordance with the cabin altitude sensed by the cabin altitude sensor 71, optionally in accordance with the aircraft altitude sensed by the aircraft altitude sensor 72 and preferably in accordance with the carbon dioxide partial pressure PCO_2 in the exhalation gas 64 sensed by the carbon dioxide sensor 68. Preferably, the rate of oxygen in the respiratory gas 62 has to be increased when the carbon dioxide partial pressure PCO_2 in the exhalation gas 64 decreases under a determined threshold.

The measurement of the oxygen partial pressure in the exhalation gas 64 gives a quite good reliable estimation of the oxygen partial pressure in the alveoli P_{AO_2} . This physiological parameter which expresses the oxygen partial pressure in the lung is close to the partial pressure in the arterial blood P_aO_2 when the cabin altitude is high.

Use of the P_{AO_2} for adjusting the rate of oxygen in the in the respiratory gas 62 by controlling the dilution valve take into account the physiology of the user which may differ between users. This allows a more accurate delivering of oxygen according to physiological need and regulation constraints. So, the risk of hypoxia of the aircraft occupant (in particular pilot or crewmember) and the consumption of oxygen can be reduced.

Moreover the content of respiratory gas delivered by the dilution adjusting device 24, 38, 42, 60 is diluted inside the lung capacity. As the P_{AO_2} is a "slow" variable needing several breathing cycles before change, the dynamic of the dilution adjusting device 24, 38, 42, 60 using a close loop control may be very slow (around 0.1 Hz). Consequently this will simplify dilution valve 23 and the oxygen sensor 42.

The adjusting device 24 and in particular dilution valve may be advantageously replaced by at least one more sophisticated adjusting device

such as disclosed in the patent application PCT/IB2011/000772 incorporated herein by reference.

Otherwise, the control device determines coherence between the fraction of oxygen in the respiratory gas 62 and the oxygen partial pressure in the exhalation gas 64. As mentioned above the control device 60 determines the fraction of oxygen in the respiratory gas 62 and the oxygen partial pressure in the exhalation gas 64. Moreover, the fraction of oxygen in the respiratory gas 62 and the oxygen partial pressure in the exhalation gas 64 are linked by the following alveolar gas equation:

$$P_A O_2 = F_I O_2 (P_B - P_A H_2O) - P_A CO_2 (F_I O_2 + \frac{1 - F_I O_2}{R}), \text{ with}$$

P_{AO_2} is the partial pressure of oxygen in the alveolar gas

P_B is the barometric pressure in the cabin 10 of the aircraft

P_{ACO_2} is the partial pressure of carbon dioxide in the exhalation gas

P_{AH_2O} is the partial pressure of water in the exhalation gas

$F_I O_2$ is the rate of oxygen in the respiratory gas 62

R is a constant corresponding to respiratory quotient.

The partial pressure of oxygen in the alveolar gas may be approximated to partial pressure of oxygen in the exhalation gas 64.

The partial pressure of carbon dioxide P_{ACO_2} in the exhalation gas 64 is preferably sensed by the carbon dioxide sensor 68. Otherwise, the partial pressure of carbon dioxide P_{ACO_2} may be replaced by a constant close to 53 hPa, as it is generally quite close to this value.

The partial pressure of water P_{AH_2O} in the exhalation gas 64 may be replaced by a constant close to 63 hPa at the temperature of the alveolar gas (estimated to 37°C).

R may be estimated between 0.1 and 1.2, preferably close to 0.83 in normal conditions.

So, the alveolar gas equation may be simplified into a following coherence equation:

$$P_{AO_2} = F_I O_2 \cdot (P_B - K_1) - P_{ACO_2} \cdot (F_I O_2 + (1 - F_I O_2) / K_2),$$

with K_1 , K_2 and K_3 constants

or further simplified into:

$$P_{AO_2} = F_{IO_2} \cdot (P_B - K_1) - K_3 \cdot (F_{IO_2} + (1 - F_{IO_2}) / K_2).$$

Failure is determined by comparison with a range value with a ratio between the measured value and the value estimated (partial pressure of oxygen in the in the exhalation gas 64 or the rate of oxygen in the respiratory gas 62) by the coherence equation. In case of failure determined a warning alarm is activated.

A data consistency check in real time monitoring of the elements of the dilution adjusting device 24 is therefore performed. This check is more accurate and more reliable than usual check consisting in out of range alarm on the oxygen sensor for monitoring failure in the regulating process. Indeed, with usual check if the ratio between the real pressure and the pressure sensed may be high before being detected.

Preferably, the partial pressure of oxygen in the exhalation gas 64 is sensed with the same gas (oxygen) sensor 42 as the oxygen sensor 42 which enables the control device 60 to determine the rate of oxygen in the respiratory gas 62 by sensing the partial pressure of oxygen in the respiratory gas 62.

Indeed, if a failure occurs concerning the oxygen sensor 42, since there is a ratio substantially away from 1 between the oxygen partial pressure in the respiratory gas 62 and the oxygen partial pressure in the exhalation gas 64, and since the above coherence equation is not linear, the failure of the oxygen sensor 42 should be detected.

CLAIMS

1. Method for protecting aircraft occupant comprising the steps of:
 - providing a user (7) with a breathing mask (4) for aircraft occupant,
 - 5 – providing a respiratory gas (62) including a mixture of breathable gas and dilution gas to the user (7),
 - sensing partial pressure or rate of oxygen or carbon dioxide in exhalation gas (64) generated by the user (7),
 - adjusting (60) the rate (fraction/percentage/concentration) of
 - 10 oxygen (or breathable gas) in the respiratory gas (62).
2. The method according to claim 1, comprising:
 - adjusting (60) the rate of oxygen in the respiratory gas (62) in accordance with the partial pressure or rate of oxygen or carbon dioxide in the exhalation gas (64).
- 15 3. The method according to claim 1 or claim 2, comprising:
 - sensing partial pressure or rate of oxygen in exhalation gas (64) generated by the user (7),
 - adjusting (60) the rate of oxygen in the respiratory flow (62) in accordance with the partial pressure or rate of oxygen in exhalation gas (64).
- 20 4. The method according to claim 3, comprising:
 - sensing partial pressure or rate of oxygen and carbon dioxide in exhalation gas (64) generated by the user (7),
 - adjusting (60) the rate of oxygen in the respiratory flow (62) in accordance with the partial pressure or rate of oxygen and carbon dioxide in
 - 25 exhalation gas (64).
5. The method according to according to any one of the preceding claims further comprising:
 - sensing partial pressure (PO_2) or rate of oxygen in the exhalation gas (64) generated by the user (7),
 - 30 – sensing partial pressure (PO_2) or rate of oxygen (FIO_2) in respiratory gas (62),

– determining coherence between the partial pressure or rate of oxygen sensed in the exhalation gas (64) and the partial pressure or rate of oxygen in respiratory gas (64) sensed for detecting failure.

6. The method according to the claim 5 further comprising:

- 5 – sensing barometric pressure (71) in the aircraft and
- determining coherence between the partial pressure or rate of oxygen sensed in the exhalation gas (64) and the partial pressure or rate of oxygen in respiratory gas (64) thanks to a coherence equation including:
 - 10 • the partial pressure or rate of oxygen sensed in the exhalation gas (64),
 - the partial pressure or rate of oxygen in respiratory gas (64), and
 - the barometric pressure (P_B).

7. The method according to the claim 6 wherein said coherence equation is:

$$P_{AO_2} = F_{IO_2} \cdot (P_B - P_{AH_2O}) - P_{ACO_2} \cdot (F_{IO_2} + (1 - F_{IO_2}) / R), \text{ with}$$

P_{AO_2} is the oxygen partial pressure sensed in the exhalation gas (64)

P_B is the barometric pressure in the aircraft

P_{ACO_2} is the partial pressure of carbon dioxide in the exhalation gas

20 P_{AH_2O} is the partial pressure of water in the exhalation gas

F_{IO_2} is rate of oxygen or the partial pressure of oxygen sensed in the respiratory gas (62)

R is a constant between 0.1 and 1.2 corresponding to respiratory quotient.

25 8. The method according to the claim 7 further comprising:

– sensing the partial pressure of carbon dioxide in the exhalation gas (64).

9. The method according to claim 7 or claim 8 wherein the partial pressure of water in the exhalation gas is replaced by a constant.

30 10. The method according to any one of the claims 5 to 9 wherein the coherence is determined by comparison of a range value and a ratio

between the measured value and the value estimated by the coherence equation.

11. The method according to any one of claims 5 to 10 further comprising sensing the partial pressure or rate of oxygen in the exhalation gas (64) and the partial pressure or rate of oxygen in respiratory gas (64) sensed
5 with a sole (the same) gas sensor (42).

12. A breathing mask (4) for aircraft occupant including a demand regulator (1), said regulator (1) comprising:

- a breathable gas supply line (12) to be connected to a source of
10 breathable gas (8) and supplying a flow chamber (30) with breathable gas,
- a dilution gas supply line (14) to be connected to a source of dilution gas (10) and supplying the flow chamber (30) with dilution gas,
- a dilution adjusting device (24, 38, 42, 60, 68) adjusting the rate of dilution gas in the respiratory gas (62) supplied to the flow chamber (30), the
15 dilution adjusting device comprising a dilution valve (24), a gas sensor (42) adapted to sense partial pressure or rate of oxygen or carbon dioxide and a control device (60) controlling the dilution valve (24) in accordance with a dilution signal generated by the gas sensor (42) in function of the partial pressure or rate of oxygen or carbon dioxide.

20 13. The breathing mask according to claim 12 wherein the gas sensor (42) is adapted to sense partial pressure or rate of oxygen or carbon dioxide in exhalation gas (64) generated by the user (7).

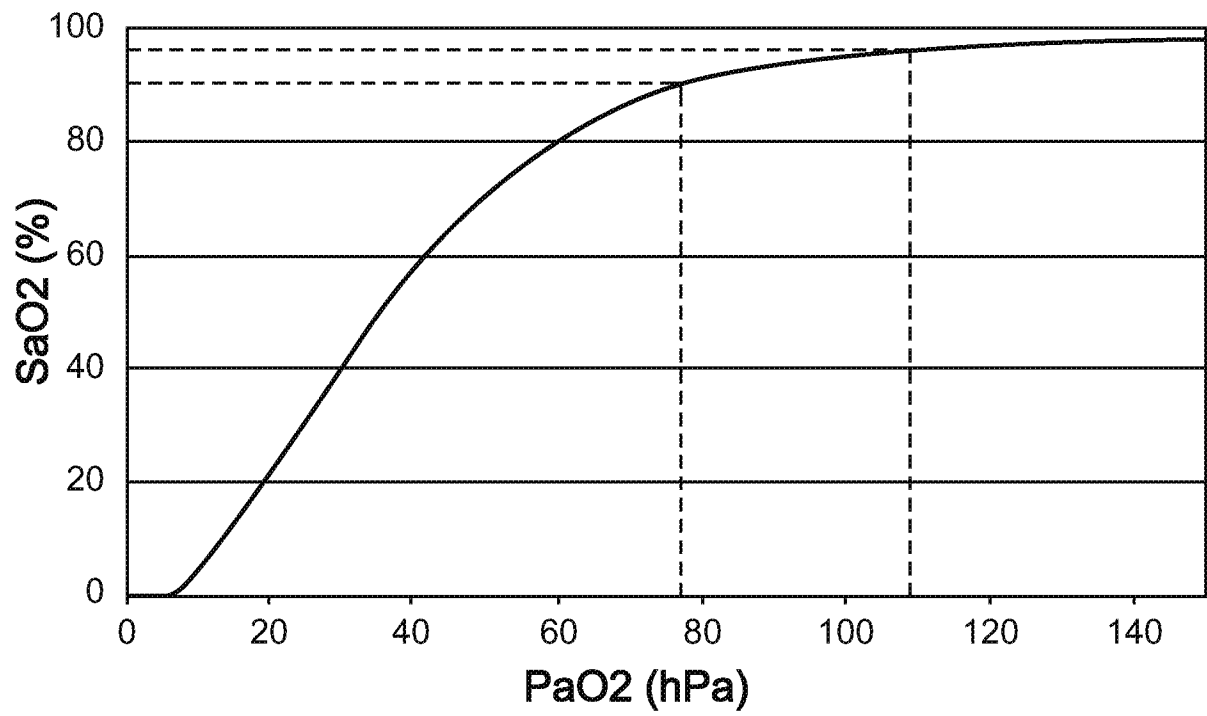
14. The breathing mask according to claim 12 or claim 13 wherein the gas sensor (42) is adapted to sense partial pressure or rate of oxygen.

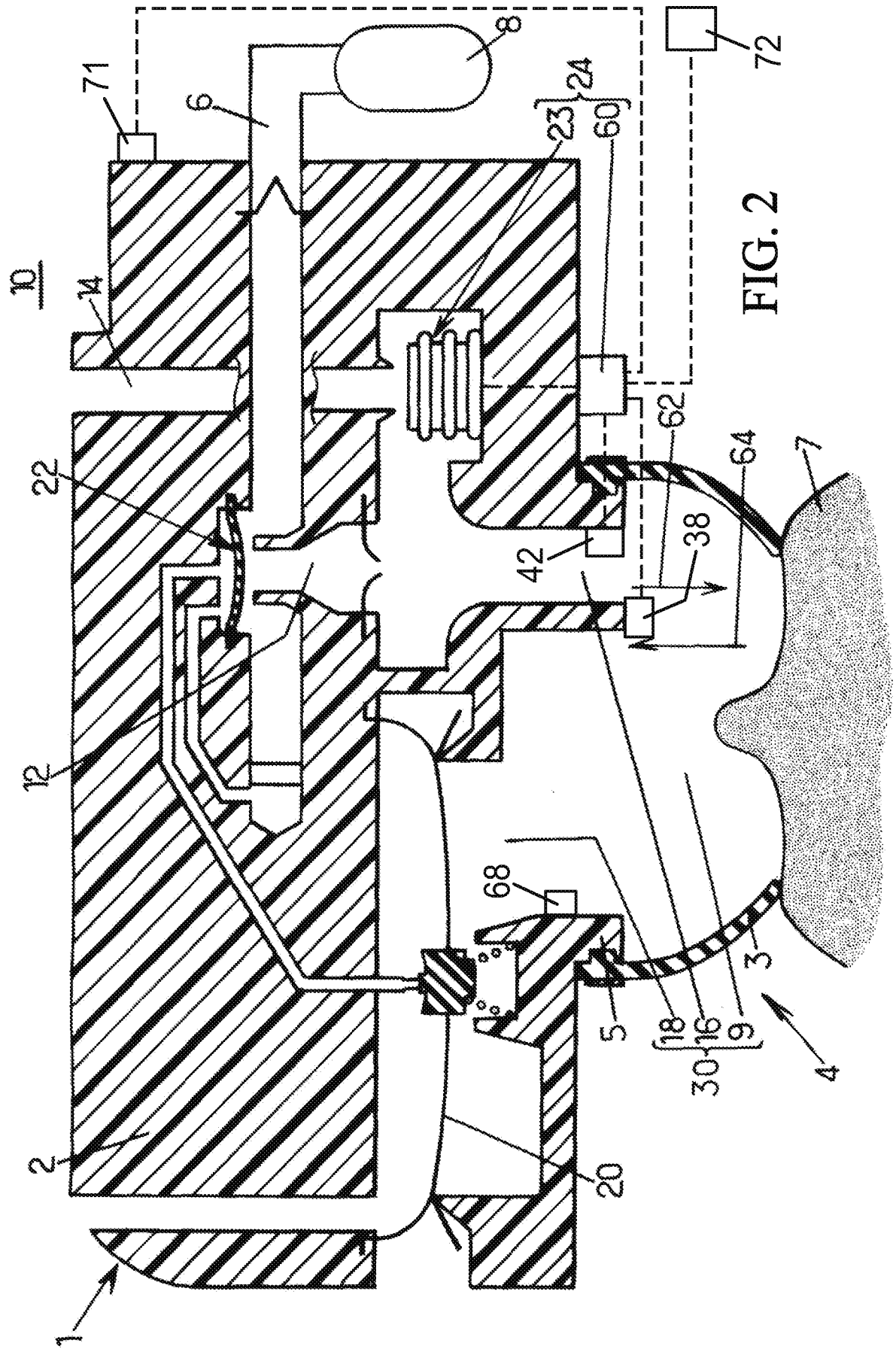
25 15. The breathing mask according to claim 14 wherein the dilution adjusting device further comprises a carbon dioxide gas sensor (68).

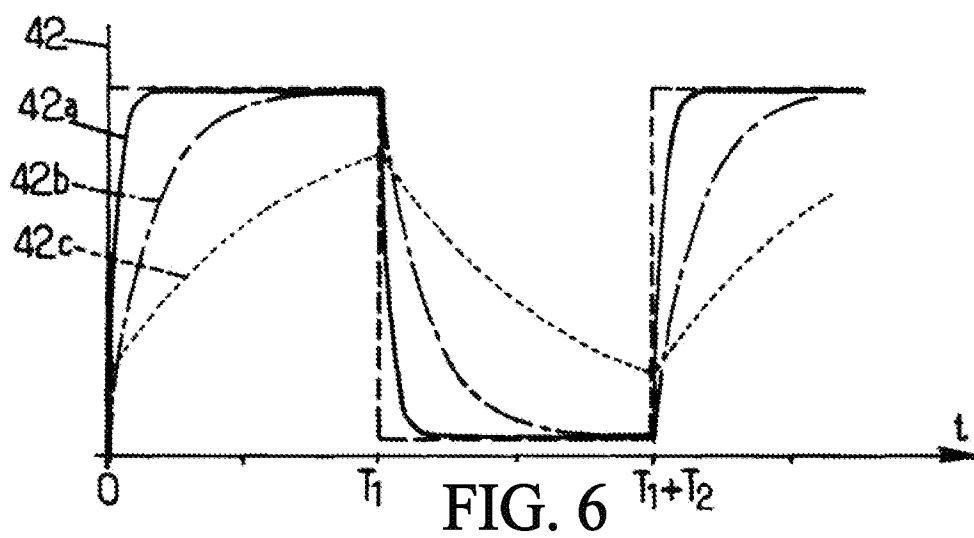
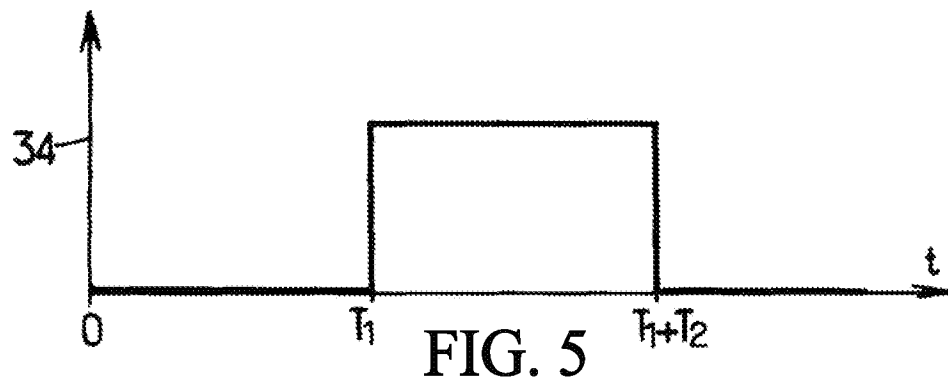
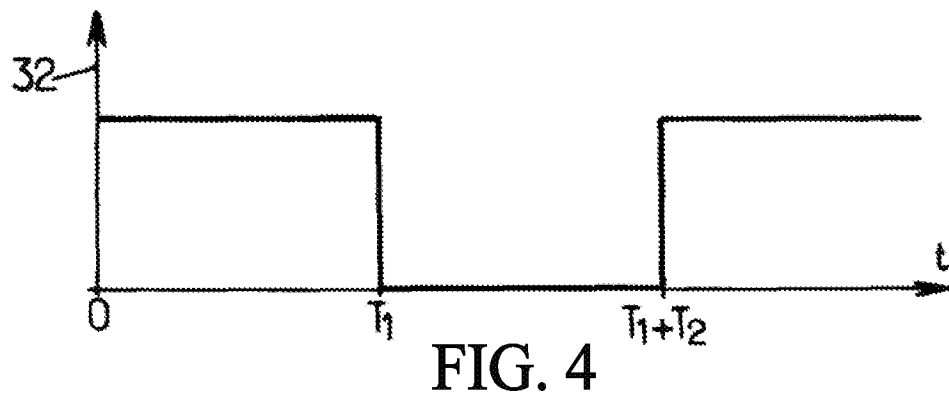
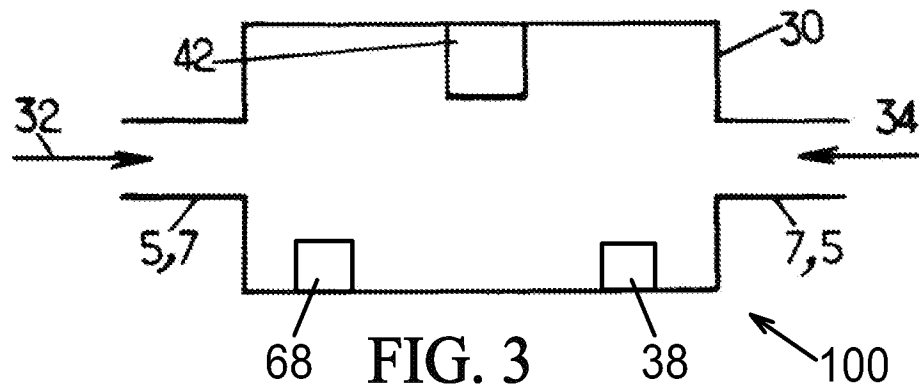
16. The breathing mask according to any one of the claims 12 to 15 wherein the dilution adjusting device further comprises a gas flow direction sensor (38).

30 17. The breathing mask according to 16 wherein the control device (60) comprises:

– a pump electrochemical cell (56) placed in the flow chamber (30) for alternatively sensed the oxygen partial pressure in the respiratory gas and in the exhalation gas.

**FIG. 1**





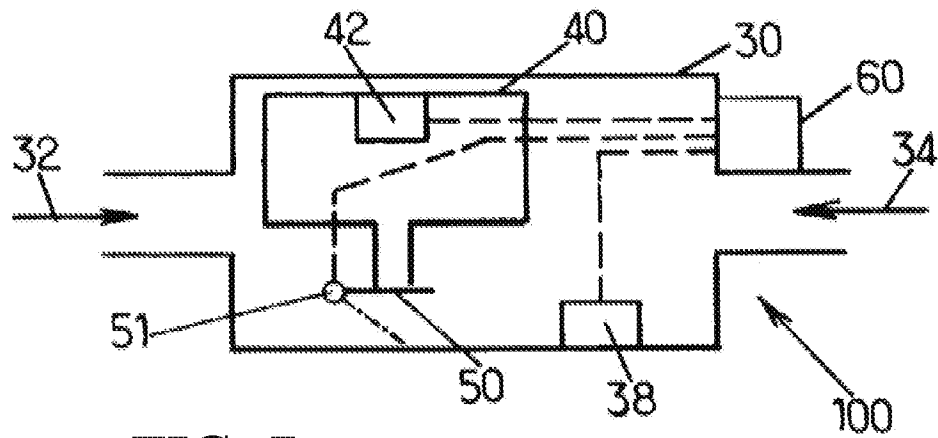


FIG. 7

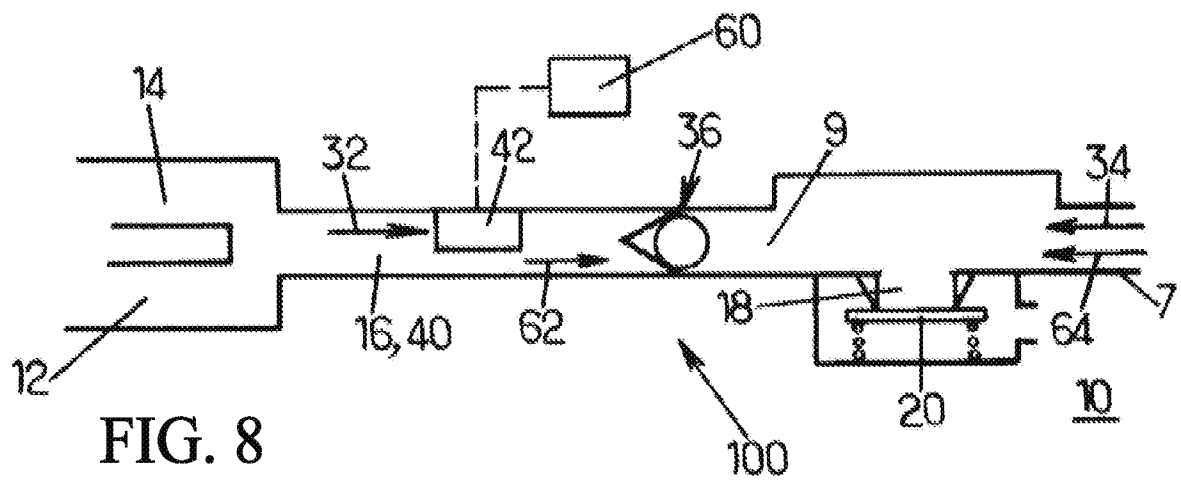


FIG. 8

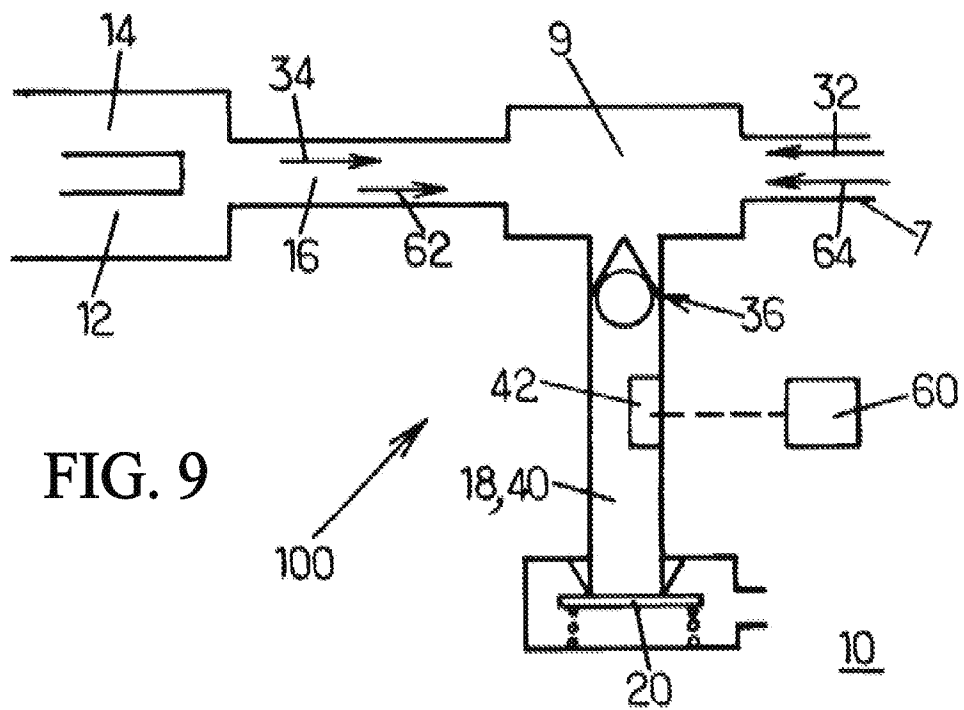


FIG. 9

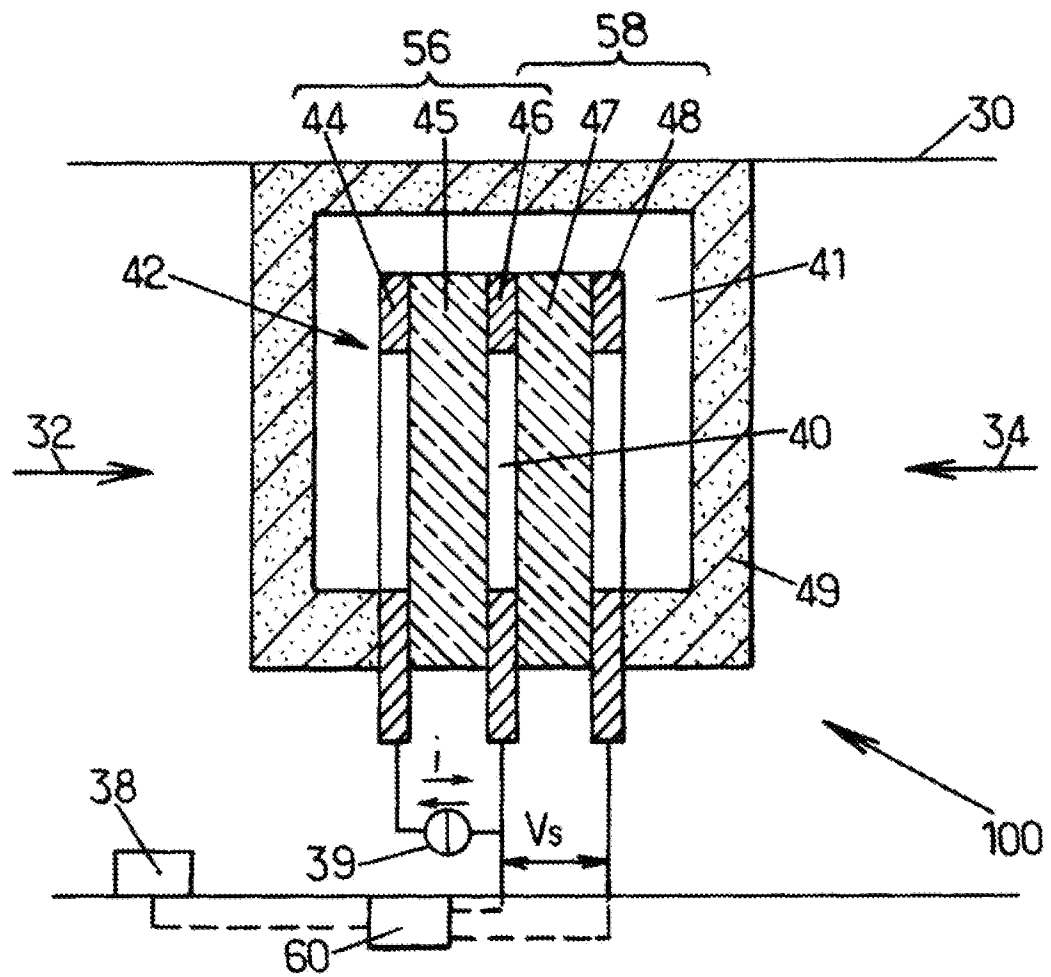


FIG. 10

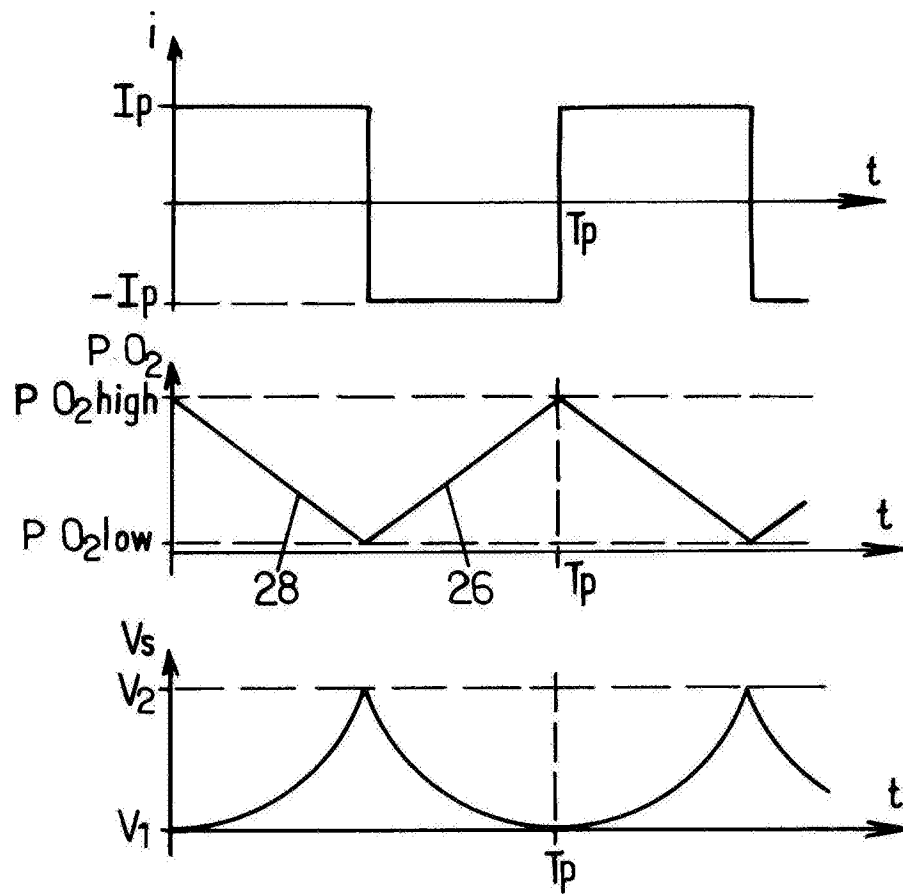


FIG. 11

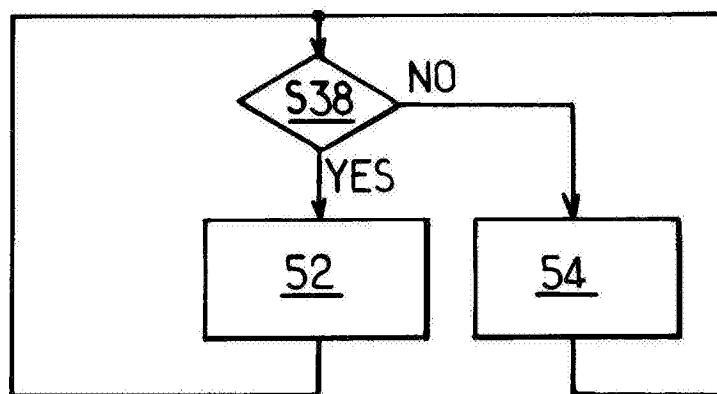


FIG. 12

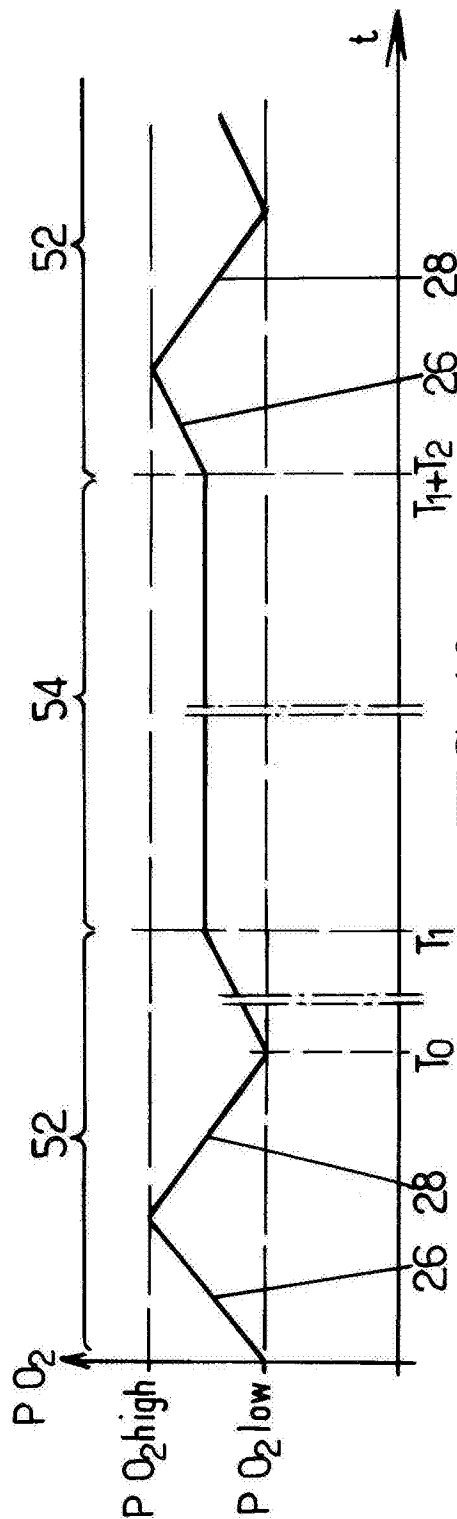


FIG. 13

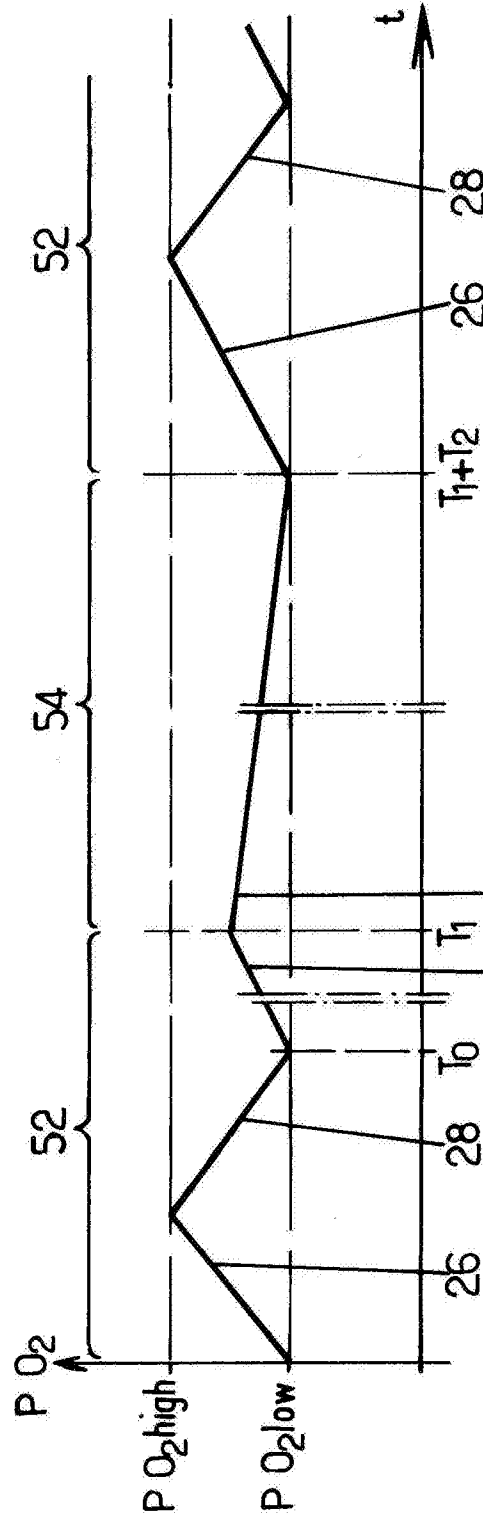


FIG. 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/065158

A. CLASSIFICATION OF SUBJECT MATTER

INV. A62B7/14 A62B9/00 A62B9/02 B64D10/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

A62B B64D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EP0-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3 675 649 A (BASHAM EDGAR WILLIAM JAMES ET AL) 11 July 1972 (1972-07-11)	1-3,
Y	abstract; figures	5-14, 16
	-----	4, 15, 17
X	US 4 121 578 A (TORZALA TERENCE AUGUST) 24 October 1978 (1978-10-24)	1, 2, 12,
Y	abstract; figures	13
	-----	4, 15
Y	US 7 040 319 B1 (KELLY ET AL) 9 May 2006 (2006-05-09)	17
	abstract; figures	
	column 5, line 54 - column 6, line 7	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

11 January 2012

Date of mailing of the international search report

25/01/2012

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Vervenne, Koen

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2011/065158

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 3675649	A	11-07-1972	NONE	

US 4121578	A	24-10-1978	GB 1568866 A	11-06-1980
			US 4121578 A	24-10-1978

US 7040319	B1	09-05-2006	NONE	
