(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 127 802 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
**08.02.2017 Bulletin 2017/06**

(21) Application number: **14835678.5**

(22) Date of filing: **31.12.2014**

(51) Int Cl.:
***B63G 8/22*** *(2006.01)* ***B63G 8/26*** *(2006.01)*

(86) International application number:
**PCT/IB2014/067447**

(87) International publication number:
**WO 2015/140612 (24.09.2015 Gazette 2015/38)**

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR**
Designated Extension States:
**BA ME**

(30) Priority: **18.03.2014 PT 10752214**

(71) Applicant: **Friday, Ciência E Engenharia Do Lazer, SA**
**3030-199 Coimbra (PT)**

(72) Inventor: **RAMA SEABRA SANTOS, Fernando Jorge**
**P-3030-199 Coimbra (PT)**

(74) Representative: **Patentree, Lda.**
**Edificio Net**
**Rua de Salazares, 842**
**4149-002 Porto (PT)**

(54) **DEVICE FOR AUTOMATIC CONTROL OF BUOYANCY, HEEL, TRIM, DEPTH AND ALTITUDE IN SUBMERSIBLE VEHICLES**

(57) The present device falls within solutions of motion and equilibrium control of submersible vehicles, namely in terms of heel, trim, depth and altitude. An embodiment comprises 3 or more flexible buoys or tanks of liquid ballast, each one with an air inlet valve and an air outlet valve, with electrically controlled opening and closing; an electronic control unit for independent opening and closing of the air inlet and outlet valves of the tanks of liquid ballast; a reservoir for storing compressed air connected to the air inlet valves of the tanks of liquid ballast; wherein said tanks of liquid ballast comprise a free communication with the exterior of the tank via one or more holes placed on the inferior part of the tank. The solution considerably reduces size and weight of the equipment and improves manoeuvrability of the vehicle.

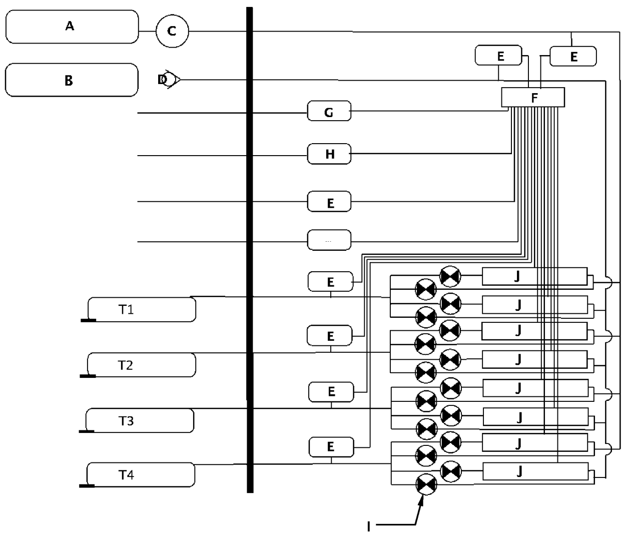


Fig. 2

EP 3 127 802 A1

## Description

### Technical field

**[0001]** The present description falls within the technical field of solutions of motion and equilibrium control of submersible vehicles, namely in terms of their heel, trim, depth and altitude, evidencing an automated operation solution of that type of vehicles.

### Technical Background

**[0002]** Upon completion of immersion manoeuvres, submersible vehicles are subject to various factors which can affect their stabilization in the liquid mass, making their navigation or their operability difficult and putting at risk the comfort or even the safety of their occupants.

**[0003]** The most common causes of change of the equilibrium conditions are variation of the density of the aquatic environment, as a result of temperature and/or pressure and/or water salinity changes, loss of vehicle weight by the elimination of products or consumables loss and the variation of their volume as a consequence of the modification the external pressure caused by the depth variation. In addition, the variation of the internal distribution of weights during a mission, either by the movement of movable weights (e.g. crew), or by the differentiated or not conveniently compensated consumption of materials (e.g. diesel or compressed air), can cause changes to the trim and heel angles which are also drawbacks to the vehicle navigation.

**[0004]** The technical solutions aiming at the correction of these imbalances usually consist of filling in or emptying of air buoys or tanks of liquid ballast, as it is necessary to, respectively, increase or decrease buoyancy. Likewise, the differentiated operation of the stern and bow tanks allows the correction of the trim angle, while the differentiated operation of the port and starboard tanks allows acting on the heel angle.

**[0005]** These manoeuvres, carried out manually, are very demanding and require time and attention to the extent that the factors which determine these manoeuvres, though always present, are variable and often unpredictable.

**[0006]** Thus, in a small submersible vehicle with low capacity, it means that one person has to reserve a significant amount of her/his time to maintain the vehicle equilibrium, having less availability to other tasks or simply to enjoy the dive.

**[0007]** The analysis to the state of the art in this field shows the existence of some documents with similar goals to the one here presented. Some aim at the automatic compensation but not the control of the trim and heel angles.

**[0008]** For instance, document GB191422337A describes a trim compensation system, via tanks situated towards the bow and the stern of a submarine, the trim compensation being secured by water pumping to said tanks. However, the automatic correction of the heel and trim angles are not predicted nor can be achieved with this document, what highly reduces the interest of its application to small submarines, submarine vehicles remotely operated and autonomous submarine vehicles.

**[0009]** Document US2012/0128425 A1 describes a device to buoyancy compensation which allows a diver or a submersible object to reach or keep a predetermined depth, regardless of the orientation ordirection of said diver or submersible object. However, also here, the automatic correction of the heel and trim angles are not predicted nor can be achieved with this document, what highly reduces the interest of its application to small submarines, submarine vehicles remotely operated and autonomous submarine vehicles.

### General description

**[0010]** The present solution allows automatically reset the neutral buoyancy of submersible vehicles, as well as automatically correct the heel and trim of a submersible vehicle and, thus, automatically achieve and/or maintain a certain depth or altitude.

**[0011]** In the context of the present solution, trim shall be understood as the rotation around the transversal horizontal axis of the submersible vehicle; and heel as the rotation around the longitudinal horizontal axis of the same vehicle.

**[0012]** The state of the art known to date does not allow to conjugate the automatic maintenance of the neutral buoyancy with the automatic correction of the heel and trim angles, or if that conjugation is allowed, the alternative is excessively heavy, energetically costly and therefore not suitable to its application in submersible vehicles.

**[0013]** The existing systems are based on the water pumping among tanks which can be subject to an important pressure differential between the exterior and the interior (hard ballast) and have therefore to be pressurised tanks (pressure vessels). On the one side, for a very same drained flow, the electrovalves used in water drainage have to have considerably higher dimensions and weight than the ones used in air drainage. Or, as an alternative, assuming the equivalent dimensions and weight of the equipment, the operation duration would be up to thirty times longer than the one achieved by the now proposed solution.

**[0014]** The now presented solution is based on the drainage control of compressed air. As air density is much inferior to water density in the same temperature and pressure conditions; and a much superior pressure differential being able to be imposed, the air drainage is much faster and has lesser energy losses than the water drainage.

**[0015]** The advantages of the present inventon are, thus, evident. It allows dispensing the existence of a water pump and of electrovalves for water drainage, thus enabling the considerable reduction of the dimensions and weight of the equipment to use. It also allows the use of flexible buoys or non-pressurised tanks (working with a very low pressure differential between the interior and the exterior) and therefore less demanding from the structural point of view. The possibility of significantly limiting the use of mechanical equipment in direct contact with sea water, also adds to the straightforward advantage of dimension and weight reduction of these equipment.

**[0016]** The present solution finds application in the submersible vehicles construction industry, like, for instance, submersible vehicles, remotely operated submersible vehicles, submersible autonomous vehicles.

**[0017]** The solution now described aims at automatically reseting neutral buoyancy, as well as automatically correcting the heel and trim of a submersible vehicle and, thus, automatically achieving and/or maintaining a certain depth or altitude.

**[0018]** The following are the component elements in a preferred embodiment of the present device:

- Flexible buoys or non-pressurised tanks of liquid ballast, which freely communicate with the exterior through a hole near their base, judiciously distributed over the submersible vehicle, each one containing two solenoid type valves, one for air entry and the other for air exhaustion, to be operated by the automatic control unit;
- Automatic control unit for independent opening and closing of the various valves, comprising the acquisition and processing of data through the various sensors (gyroscope, depth gauge and CTD - conductivity, temperature and pressure);
- Production or storage of compressed air device (reservoir) for system feeding;
- Dashboard, capable of showing in real time the correction operations that the system makes and of enabling the operator to introduce manual changes, if desired.

**[0019]** In case flexible buoys are chosen, these can be automatically and in an autonomous way partially or totally filled in or emptied, increasing or decreasing the buoyancy of the whole, or even transferring buoyancy from any of them to any other.

**[0020]** In case tanks of liquid ballast are chosen, these can be automatically and in an autonomous way ballasted or unballasted, increasing or decreasing the weight of the whole, or even transferring weight from any of them to any other.

**[0021]** The flexible buoys or tanks of liquid ballast option is, in most of the embodiments below, equivalent. Therefore, for simplification purposes and whenever it is not necessary to distinguish them, only tanks will be referred to in the text.

**[0022]** The control unit evaluates and processes the relevant information given by the sensors, calculating the corrections to be made and acting on the solenoide valves to establish the adequate air circuits, during the time frame needed.

**[0023]** In an embodiment to automatically reset neutral buoyancy, as well as to automatically correct the heel and the trim of a submersible vehicle and, thus, automatically achieve and/or maintain a given depth or altitude, it will be necessary to predict, at least, four tanks of liquid ballast: for instance, two at the stern and two at the bow, two at starboard side and two at port side.

**[0024]** In another embodiment, the buoyancy compensation and the trim correction are made with two ballast tanks. One of the ballast tanks is located on the submersible vehicle stern, while the second ballast tank is located on the bow of the submersible vehicle.

**[0025]** In another embodiment, the buoyancy compensation and the heel correction are made with two tanks, one of the ballast tanks being now located on the port side of the submersible vehicle, and the second ballast tank located on the starboard side of the submersible vehicle.

**[0026]** Still in another embodiment, if only buoyancy compensation and depth or altitude definition or maintenance is desired, a ballast tank is sufficient, the device being taken to embodiments already known.

**[0027]** Three tanks only placed along two axis clearly allow controlling both the trim and the heel of the submersible vehicle. It is also clear that 4 tanks allow an easier control of the trim and of the heel.

**[0028]** It is described a device for automatic control of buoyancy, heel, trim, depth and/or altitude in submersible vehicles, comprising:

- 3 or more flexible buoys or tanks of liquid ballast, each with an air inlet valve and an air outlet valve, with electrically controlled opening and closing;
- an electronic control unit for independent opening and closing of the air inlet and outlet valves of the tanks of liquid ballast;
- a reservoir for storing compressed air connected to the air inlet valves of the tanks of liquid ballast;

wherein said tanks of liquid ballast comprise a free communication with the exterior of the tank via one or more holes placed on the inferior part of the tank;

and wherein said flexible buoys or tanks of liquid ballast are to be in different sections of the submersible vehicle placed along two directions of the horizontal plane of the submersible vehicle.

**[0029]** In an embodiment, the flexible buoys or tanks of liquid ballast are 4.

**[0030]** In an embodiment, the two directions of the horizontal plane are orthogonal directions.

**[0031]** In an embodiment, the sections of the submersible vehicle where said tanks of liquid ballast are placed are sections of:

stern and starboard; stern and port; bow and starboard; and bow and port; or
central stern, central bow, central starboard and central port;

or any of the intermediate arrangements between the two previous arrangements.

**[0032]** In an embodiment, the electronic control unit is configured to proceed with the opening and closing of the air inlet and outlet valves for moving up, moving down, maintaining depth, maintaining altitude, obtaining a predefined depth, obtaining a predefined altitude.

**[0033]** In an embodiment, the electronic control unit is configured to proceed with the opening and closing of the air inlet and outlet valves for correcting the trim and heel angles.

**[0034]** In an embodiment, the valves are solenoid type valves electrically controlled by the electronic control unit.

**[0035]** In an embodiment, the inlet valve and the outlet valve of a flexible buoy or tank of liquid ballast are in the same valve body.

**[0036]** An embodiment additionally comprises circuits with manually operated valves in parallel with each of the electrically controlled circuits.

**[0037]** It is also described a submersible vehicle comprising any of the previous devices for automatic control of buoyancy, heel and trim in submersible vehicles.

**[0038]** In an embodiment, the submersible vehicle is a submarine with crew or a remotely operated submersible vehicle or a submersible autonomous vehicle.

**[0039]** It is also described a method of operating any of the previous devices for automatic control of buoyancy, heel and trim in submersible vehicles, comprising by the automatic control unit:

calculating the corrections to be made and the corresponding actions on the valves to obtain the desired buoyancies in each of the tanks of liquid ballast;
acquiring and processing the data collected by the sensors comprising gyroscope, depth gauge and CTD;

visualising in real time the corrections that the device proposes and/or makes.

**[0040]** An embodiment comprising three procedure modes: continuing automatic mode; one shot automatic mode, assisted manual mode,
relating to a preselected correction or definition procedure comprising buoyancy correction, trim correction, heel correction, depth definition, altitude definition, or their combinations; wherein:

the continuing automatic mode comprises initiating and permanently activating one or more (preselected) procedures, and wherein the procedures are automatically restarted with a previously defined periodicity or whenever they excessively deviate from the preselected correction or definition;
wherein the one shot automatic mode comprises performing simultaneously and at once one or more times preselected correction or definition procedures;
wherein the assisted manual mode comprises automatically performing a preselected correction or definition isolated procedure, according to the values defined by the pilot out of the system proposals.

**[0041]** In an embodiment, the one shot automatic mode can be repeated at the initiative of the operator.

**[0042]** It is also described an automatic control unit configured for operating a device according to any of the previous methods.

**[0043]** It is also described a computer program for operating a device according to any of the previous methods.

**[0044]** It is also described a computer readable non-transitory medium for storing code executable by a computer processor for operating a device according to any of the previous methods.

**[0045]** In an embodiment of the solution and for security purposes and to avoid systems redundancy, the possibility of performing an automatic operation can be deactivated, thus initiating the operation procedure in manual mode and performing the procedures as they are usually performed nowadays, i.e. manually opening or closing mechanical valves and keeping them activated by estimate, by feeling, of the quantities of ballast to move, or until the visual observation of the measurement instruments indicates that the manoeuvre goal has been achieved.

**[0046]** The following data are the system permanent inputs, i.e. typical of every submersible vehicle:

- Underwater displacement: $D$
- Metacentric height: $\overline{MG}$
- Plan area: $A_p$
- Form factor: $C_d$
- Trim correction arm: $B_t$
- Heel correction arm: $B_h$

**[0047]** A set of sensors permanently feeds a central controller with values of the different navigation parameters. At each time, with a sampling period which depends of each measurement apparatus but which typically is of around the tenths or hundredths of a second, the following parameters are measured and stored:

- Liquid ballast volume in tank T1;
- Liquid ballast volume in tank T2;
- Liquid ballast volume in tank T3;
- Liquid ballast volume in tank T4;
- Vertical velocity;
- Water temperature;
- Water salinity;
- Trim angle;
- Heel angle;
- Depth;
- Altitude.

**[0048]** The system predefines a calculation range (Δt) that the pilot can confirm or modify according to his/her experience or sensitivity. From the measurements made to the instantaneous values of each variable within the sampling interval (between t-Δt and t), the board computer calculates, based on that interval, projects on the screen and permanently updates the average values of the following variables (Fig. 1):

- Liquid ballast volume in tank T1: $v_1$
- Liquid ballast volume in tank T2: $v_2$
- Liquid ballast volume in tank T3: $v_3$
- Liquid ballast volume in tank T4: $v_4$
- Vertical velocity: $V_v$
- Trim angle: $A_t$
- Heel angle: $A_h$
- Water density: $d$
- Depth: $h$
- Altitude: $H$

**[0049]** For the selected time interval (Δt), the board computer also calculates, at each instant, the average values of the following variables:

- Buoyancy, given, in N, by $F = 500 \times d \times C_d \times A_p \times V_v \times |V_v|$;
- Proposed buoyancy compensation, in litres, given by:

$$C_f = F/9{,}81/d, \text{ also dividing by the four tanks.}$$

  also dividing by the four tanks.
  We shall have, $C_{f1} = C_{f2} = C_{f3} = C_{f4} = C_f/4$;
- Trim imbalance arm given, in meters, by:

$$b_t = sin\ A_t \times \overline{MG}$$

- Heel imbalance arm given, in meters, by:

$$b_h = sin\ A_h \times \overline{MG}$$

- Trim proposed correction given, in litres, by:

$$C_t = 1000 \times d \times D \times b_t / B_t;$$

We shall have, $C_{t1} = C_{t2} = C_t/2$ and $C_{t3} = C_{t4} = -c_t/2$;

- Heel proposed correction given, in litres, by:

$$C_h = 1000 \times d \times D \times b_h / B_h.$$

We shall have, $C_{h1} = C_{h3} = C_h/2$ and $C_{h2} = C_{h4} = -C_h/2$;

- Global correction proposed, in litres, at each time, for each tank,

$$C_1 = C_{f1} + C_{t1} + C_{h1}$$

$$C_2 = C_{f2} + C_{t2} + C_{h2}$$

$$C_3 = C_{f3} + C_{t3} + C_{h3}$$

$$C_4 = C_{f4} + C_{t4} + C_{h4}$$

**[0050]** These last values, which refer accordingly to tanks T1 to T4, are also posted on the dashboard (Fig. 1), in the interior of the corresponding buttons. In this example, meter and litre are respectively used as length and volume units. Any other unit system is, of course, possible.

**[0051]** The correction in water volume by each tank is obtained by the compressed air injection or exhaustion.

**[0052]** The system interface with the user is done through a panel, as presented in Fig. 1.

**[0053]** The operation starts with the selection, by the operator, of the kind of manoeuvre which is intended to be performed. There are five options of manoeuvres that can be selected:

- Buoyancy compensation to cancel any vertical speed which has been installed;
- Trim correction to eliminate any trim angle which has been installed;
- Heel correction to eliminate any heel angle which has been installed;
- Definition of a fixed dive depth, which automatically manoeuvres the submersible vehicle until it reaches this depth and sequently maintains it at this depth;
- Definition of a fixed dive altitude (distance until the bottom), which automatically manoeuvres the submersible vehicle until it reaches this altitude and sequently maintains it at this depth;

**[0054]** In an embodiment, after selection of the intended type of manoeuvre, the system presents three acting modes, namely (Fig 1):

- Continuing automatic mode;
- One shot automatic mode (One shot), made by initiative of the pilot, according to the parameters proposed by the system;
- Assisted manual mode (Assisted), automatically controlled but started by initiative of the pilot, according to the parameters the pilot selects from the values proposed by the system.

**[0055]** An embodiment allows choosing the continuing automatic mode. The continuing automatic mode (Automatic) and (Go) allows starting and leaving permanently activated the correction procedure of the selected effect(s) (buoyancy compensation, trim correction, heel correction, depth definition or altitude definition). This procedure is automatically restarted with a previously defined periodicity (for instance, every 2 minutes), or whenever the concerned variable is too distant from the previously defined value.

**[0056]** In another embodiment, the selection of the one shot automatic mode (One shot) and (Go) allows performing at once the simultaneous correction of the selected effect(s), and according to the values posted at the time of activation (Go). It can be repeated by initiative of the pilot, whenever he/she so desires.

**[0057]** Still in another embodiment, the choice of the assisted manual mode (Assisted), is only applicable to the three first manoeuvre options (buoyancy compensation, trim correction, heel correction) and allows the pilot to manually define the following points:

- The selection of the correction to be performed (compensation, trim or heel), acting separately in one of these buttons or commands;
- The liquid ballast origin (Tank 1 and/or Tank 2 and/or Tank 3 and/or Tank 4, or exterior);
- The liquid ballast destiny (Tank 1 and/or Tank 2 and/or Tank 3 and/or Tank 4, or exterior);
- The volume to be shifted, in litres.

**[0058]** After performing the options, in an embodiment, the key (Go) activates the selected procedure which is performed only once.

**[0059]** In any of the modes, in an embodiment, the key (Go) starts the procedures necessary to the transfer(s) of liquid ballast in the conditions defined by the selected mode. The control unit calculates the predictable flow for each solenoid valve according to the pressure differential and to the other parameters, and will then activate the opening of the adequate valves, as long as needed.

**[0060]** All the system valves are, in an embodiment, of two positions (2V/2P) and of the N/C type (usually closed. The answer of the submersible vehicle is permanently monitored through the sensors, whose information can determine the interruption of the operation as soon as the goals are reached. As previously mentioned, the system can also be deactivated, referring to a type of a fully manual piloting, from mechanical valves.

**[0061]** In case it is considered to be of advantage, each 2V/2P type valve can be substituted by other equivalent valve, for instance each set of two 2V/2P valves can be substituted by one 3V/3P valve.

Brief description of the drawings

**[0062]** For an easier understanding of the embodiment there are attached figures, which represent preferred embodiments, which however, are not intended to limit the scope of the present embodiment.

**Figure 1:** Schematic representation of the control panel of an embodiment of the automatic compensation device and of automatic correction of the trim and of the heel.

**Figure 2:** Operating scheme of an embodiment of the device with 4 tanks wherein each tank is connected to two air collectors, wherein one is of high pressure (pressure higher than the external ambient pressure) and another of low pressure (pressure lower than the external ambient pressure), via solenoid valves.

**Figure 3:** Schematic representation of the control panel of an embodiment of the compensation device and automatic correction of the trim and of the heel.

**Figure 4:** Operating scheme of an embodiment of the ballast transfer module among compensation tanks.

**Detailed description**

**[0063]** Figure 1 shows a possible arrangement of the command screen of the system now revealed. At the top of the screen, in a first row, the different manoeuvre types which can be performed are depicted:

i) Buoyancy compensation;
ii) Trim correction;
iii) Heel correction;
iv) Imposition of a dive depth;
v) Imposition of a dive altitude.

**[0064]** The second row allows the choice of the desired automation level, among three possible ones:

- Continuing automatic mode (Automatic),
- One shot automatic mode (One Shot) and
- Assisted manual mode (Assisted).

**[0065]** Right below, in the central part, the system depicts the current values of the relevant navigation parameters: depth, altitude, vertical velocity, liquid density, and trim and heel angels.

**[0066]** On the left side the four tanks are represented, each one posting the current volume of ballast and the volume proposed by the system for transfer. On the right side, a similar scheme reveals in each tank the final ballast volume (the manoeuvre being supposedly concluded).

**[0067]** On the second last command line, the left-hand side button shows the quantity of water needed to ballast the submarine, in case the vertical speed is positive or when the increase of diving depth or altitude decrease is intended.

**[0068]** The inferior right-hand side button shows the quantity of water needed to deballast the submarine, if the vertical speed is negative or when the decrease of diving depth or altitude increase is intended.

**[0069]** In the centre, below the navigation parameters, two dials with two triangular buttons each allow the manual definition of the requested volumes for each transfer or the depth or altitude level at which navigation is intended, in the event of the assisted manual manoeuvre option.

**[0070]** The central inferior key (Go), allows starting the selected procedure, in the defined conditions. Finally in the last row, there are two buttons to the left and to the right to cancel the selected definition or the whole previous programming, respectively.

**[0071]** Figure 2 briefly shows the general scheme of the device, in a configuration wherein there are four tanks (T1 to T4). It is represented in the figure: A - Compressed air reservoir; B - Air exhaustion; C - Pressure reduction valve; D - Non-return valve; E - Digital manometer (pressure transmitter); F - Acquisition, data processing and control unit; G - CTD - conductivity, temperature and depth; H - DVL - Doppler velocity logger; I - Manual mechanical valve; J - Solenoid valve 2P/2V.

**[0072]** Each tank is connected to two air collectors, wherein one is of high pressure (pressure higher than the external ambient pressure) and another of low pressure (pressure lowerthan the external ambient pressure), via two solenoid valves (J). These valves and also the measurement instruments are connected to a controller, or electronic control unit, which commands their status (open or closed) and the activation time.

**[0073]** Figure 3 represents a (schematic) control panel of an embodiment of the automatic compensation device and of automatic correction of the trim and of the heel.

**[0074]** Figure 4 represents an operating scheme of an embodiment of the ballast transfer module among compensation tanks via water pumping.

**[0075]** The above described embodiments are combinable.

**[0076]** Although in the present invention only particular embodiments have been represented and described, the person with ordinary skill in the art will be able to introduce modifications and substitute some technical characteristics by other equivalent ones, depending on the requisites of each situation, without departing from the protection scope as defined in the appended claims.

**[0077]** The following claims set out particular embodiments of the invention.

## Claims

1. Device for automatic control of buoyancy, heel, trim, depth and/or altitude in submersible vehicles, comprising:

    3 or more flexible buoys or tanks of liquid ballast, each with an air inlet valve and an air outlet valve, with electrically controlled opening and closing;
    an electronic control unit for independent opening and closing of the air inlet and outlet valves of the tanks of liquid ballast;
    a reservoir for storing compressed air connected to the air inlet valves of the tanks of liquid ballast;

    wherein said tanks of liquid ballast comprise a free communication with the exterior of the tank via one or more holes placed on the inferior part of the tank; and wherein said flexible buoys or tanks of liquid ballast are to be in different sections of the submersible vehicle placed along two directions of the horizontal plane of the submersible vehicle.

2. Device according to the previous claim wherein the flexible buoys or tanks of liquid ballast are 4.

**3.** Device according to any of the previous claims wherein the two directions of the horizontal plane are orthogonal directions.

**4.** Device according to the previous claim wherein the sections of the submersible vehicle where said tanks of liquid ballast are placed are the sections of:

stern and starboard; stern and port; bow and starboard; and bow and port; or
central stern, central bow, central starboard and central port;

or any of the intermediate arrangements between the two previous arrangements.

**5.** Device according to any of the previous claims wherein the electronic control unit is configured to proceed with the opening and closing of the air inlet and outlet valves for correcting the trim angle and correcting the heel angle.

**6.** Device according to any of the previous claims wherein the electronic control unit is configured to proceed with the opening and closing of the air inlet and outlet valves for moving up, moving down, maintaining depth, maintaining altitude, obtaining a predefined depth, obtaining a predefined altitude.

**7.** Device according to any of the previous claims wherein the valves are solenoid type valves electrically controlled by the electronic control unit.

**8.** Device according to any of the previous claims wherein the inlet valve and the outlet valve of a flexible buoy or tank of liquid ballast are in the same valve body.

**9.** Device according to any of the previous claims additionally comprising circuits with manually operated valves in parallel with each of the electrically controlled circuits.

**10.** Submersible vehicle comprising the device according to any of the previous claims.

**11.** Submersible vehicle according to the previous claim wherein the submersible vehicle is a manned submarine or a remotely operated submersible vehicle or a submersible autonomous vehicle.

**12.** Method of operating the device referred to in any of the previous claims comprising, by the automatic control unit:

calculating the corrections to be made and the corresponding actions on the valves to obtain the desired weight in each of the tanks of liquid ballast;
acquiring and processing the data collected by the sensors comprising gyroscope, depth gauge and CTD;
visualising in real time the corrections that the device proposes and/or makes.

**13.** Method according to the previous claim comprising three procedure modes:

continuing automatic mode; one shot automatic mode, assisted manual mode, relating to a preselected correction or definition procedure comprising buoyancy correction, trim correction, heel correction, depth definition, altitude definition, or their combinations; wherein:

the continuing automatic mode comprises initiating and permanently activating one or more preselected procedures, and wherein the procedures are automatically restarted with a previously defined periodicity or whenever they excessively deviate from the preselected correction or definition;
wherein the one shot automatic mode comprises performing simultaneously and at once one or more times preselected correction or definition procedures;
wherein the assisted manual mode comprises automatically performing a preselected correction or definition isolated procedure, according to the values defined by the pilot out of the system proposals.

**14.** Method according to the previous claim wherein the one shot automatic mode can be repeated at the initiative of the operator.

**15.** Automatic control unit configured for operating a device according to the method of any of the claims 12-14.

**16.** Computer program for operating a device according to the method of any of the claims 12-14.

**17.** Computer readable non-transitory medium for storing code executable by a computer processor for operating a device according to the method of any of the claims 12-14.

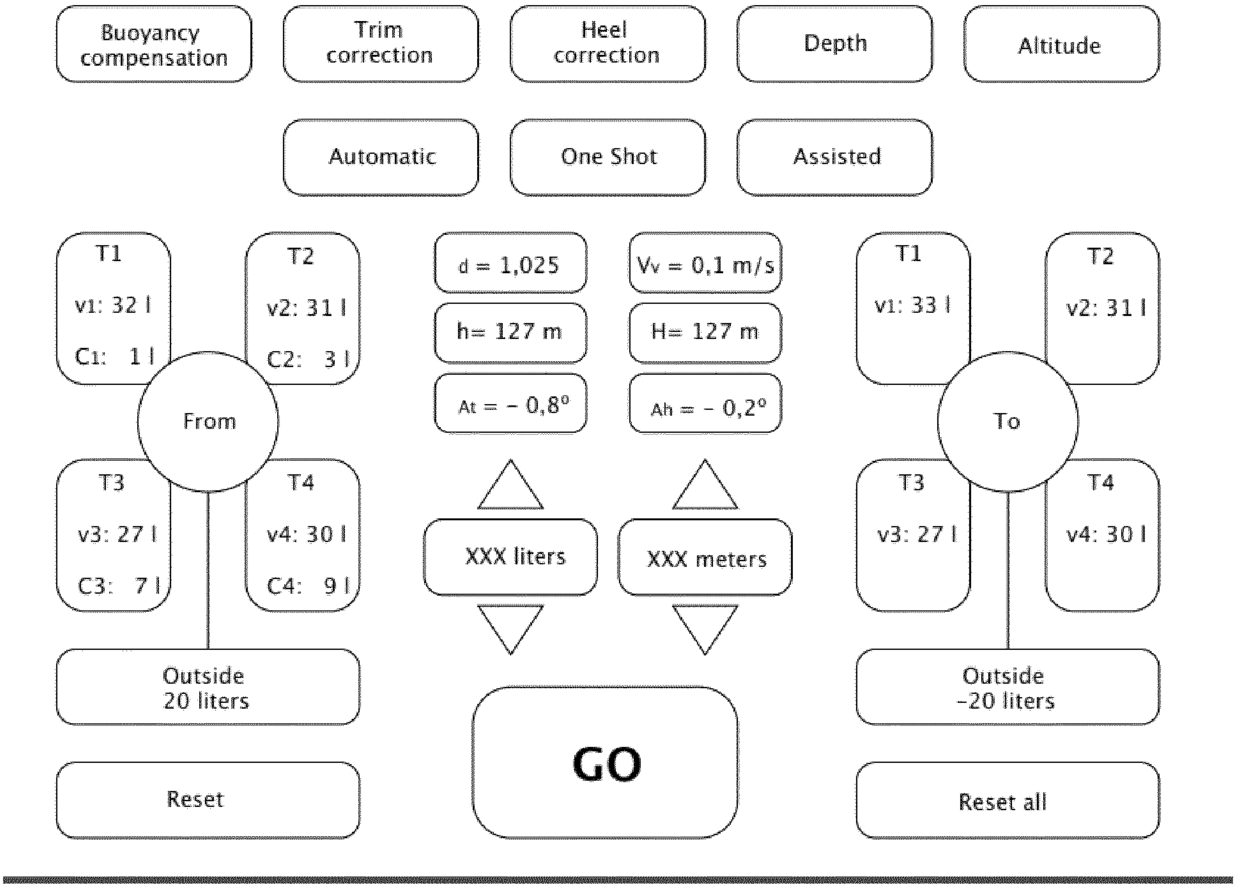
Buoyancy compensation
Trim correction
Heel correction
Depth
Altitude
Automatic
One Shot
Assisted
T1
v1: 32 l
C1: 1 l
T2
v2: 31 l
C2: 3 l
From
T3
v3: 27 l
C3: 7 l
T4
v4: 30 l
C4: 9 l
d = 1,025
h= 127 m
At = − 0,8°
Vv = 0,1 m/s
H= 127 m
Ah = − 0,2°
XXX liters
XXX meters
T1
v1: 33 l
T2
v2: 31 l
To
T3
v3: 27 l
T4
v4: 30 l
Outside
20 liters
Outside
-20 liters
Reset
GO
Reset all

Fig. 1

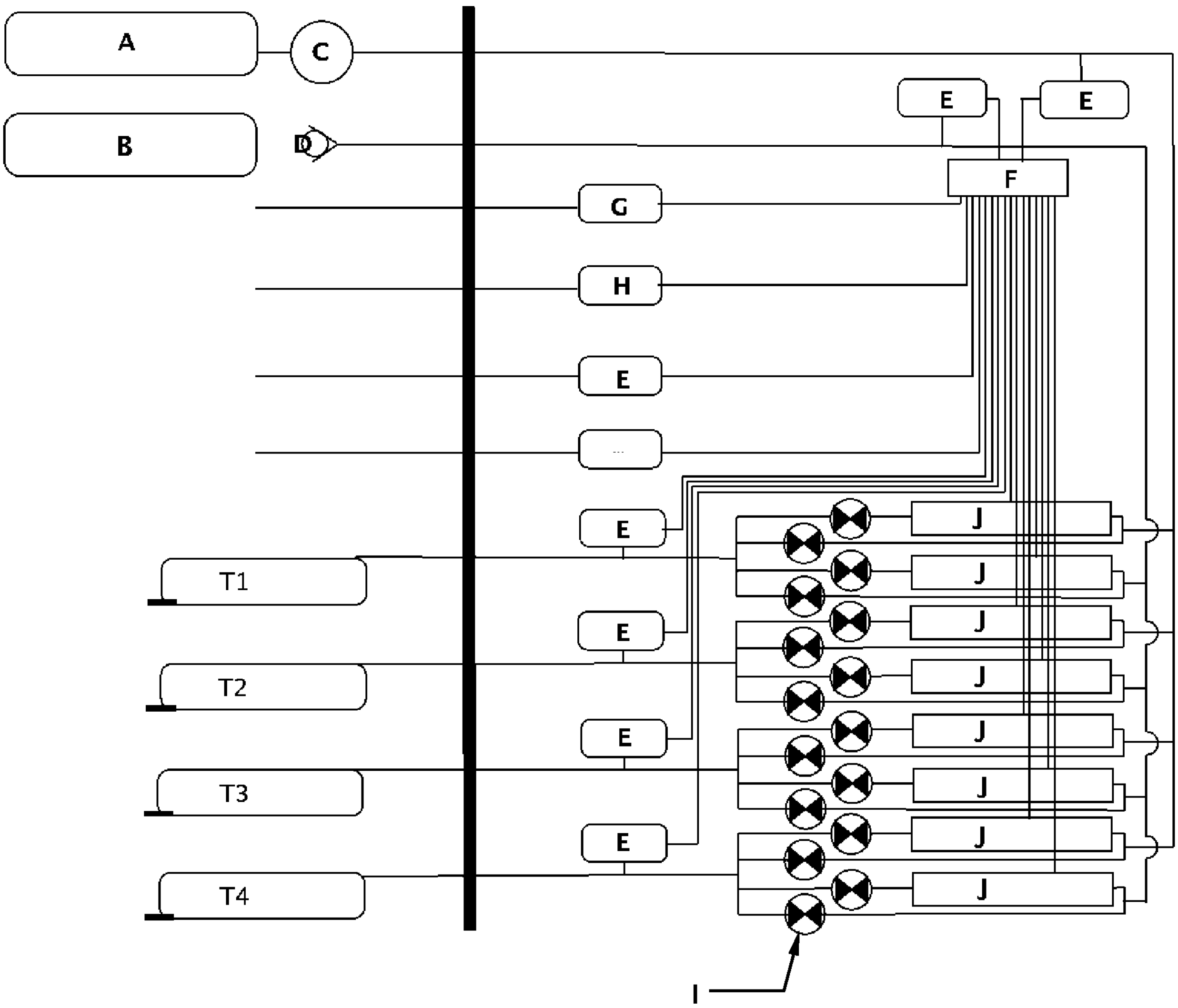


Fig. 2

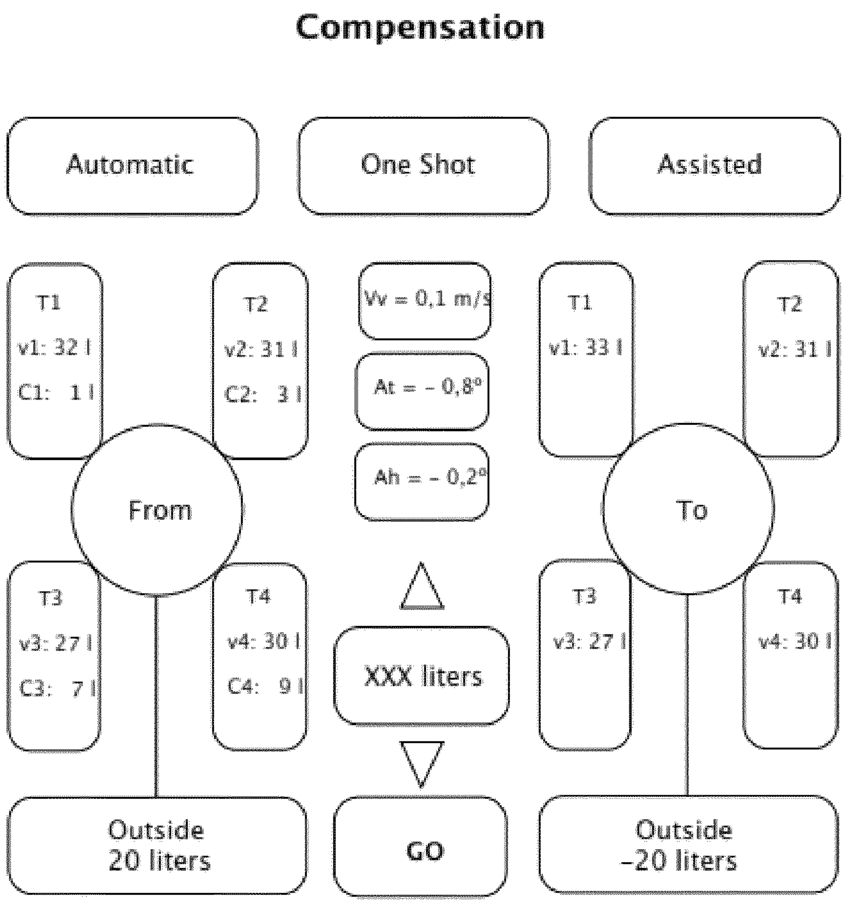
Compensation
Automatic
One Shot
Assisted
T1
v1: 32 l
C1: 1 l
T2
v2: 31 l
C2: 3 l
From
T3
v3: 27 l
C3: 7 l
T4
v4: 30 l
C4: 9 l
Vv = 0,1 m/s
At = - 0,8°
Ah = - 0,2°
XXX liters
GO
T1
v1: 33 l
T2
v2: 31 l
To
T3
v3: 27 l
T4
v4: 30 l
Outside
20 liters
Outside
-20 liters

Fig. 3

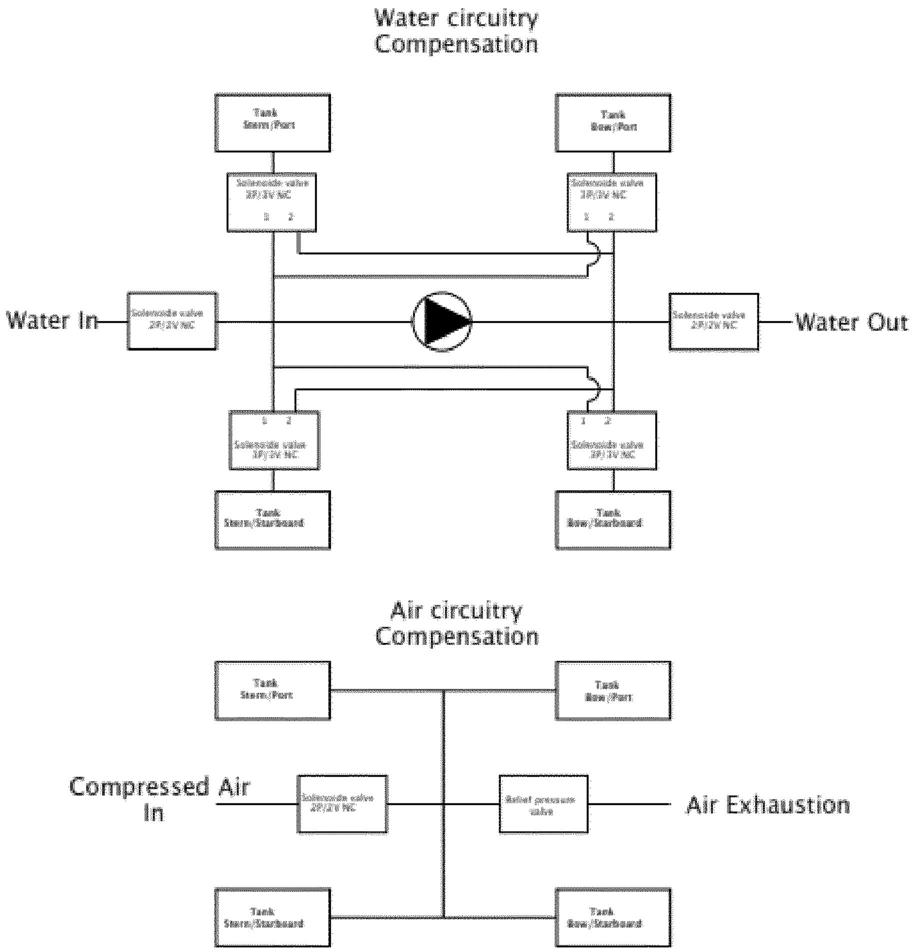
Water circuitry
Compensation
Water In
Water Out
Air circuitry
Compensation
Compressed Air
In
Air Exhaustion

**Fig. 4**

## INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2014/067447

**A. CLASSIFICATION OF SUBJECT MATTER**
INV. B63G8/22 B63G8/26
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)
B63G

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

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

EPO-Internal, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | US 2012/290164 A1 (HANSON BRUCE [US] ET AL) 15 November 2012 (2012-11-15)<br>paragraphs [0016], [0017], [0050] - [0061], [0067] - [0070]; figures 6-8 | 1,3-6, 10-12, 15-17 |
| X | GB 2 169 570 A (BROWN & ROOT CONST; GOETAVERKEN ARENDAL AB)<br>16 July 1986 (1986-07-16)<br>page 7, line 94 - page 8, line 37; figures 1-4 | 1-6, 10-12,15 |
| X | US 2 887 977 A (MARCEL PIRY)<br>26 May 1959 (1959-05-26) | 1,3,4, 10,11 |
| A | page 3, line 3 - line 69; figures 1,2 | 7 |

-/--

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 21 May 2015 | 05/06/2015 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016 | Mauriès, Laurent |

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

## INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2014/067447

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y | WO 2004/065206 A1 (STOJIC SLOBODAN [YU]) 5 August 2004 (2004-08-05) page 6; figures 1-3,5 | 1-6, 10-12,15 |
| Y | WO 2012/074408 A2 (ENVIRONTEC AS [NO]; ANDERSEN ROBERT [NO]) 7 June 2012 (2012-06-07) page 7, line 4 - page 8, line 2; figures 6,20,21 | 1-6, 10-12,15 |

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

## INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2014/067447

| Patent document cited in search report | | Publication date | Patent family member(s) | | | Publication date |
|---|---|---|---|---|---|---|
| US 2012290164 | A1 | 15-11-2012 | NONE | | | |
| GB 2169570 | A | 16-07-1986 | NONE | | | |
| US 2887977 | A | 26-05-1959 | NONE | | | |
| WO 2004065206 | A1 | 05-08-2004 | EP | 1658219 | A1 | 24-05-2006 |
| | | | WO | 2004065206 | A1 | 05-08-2004 |
| WO 2012074408 | A2 | 07-06-2012 | AU | 2011337346 | A1 | 04-07-2013 |
| | | | EP | 2646314 | A2 | 09-10-2013 |
| | | | NO | 332875 | B1 | 28-01-2013 |
| | | | SG | 190431 | A1 | 31-07-2013 |
| | | | US | 2013263770 | A1 | 10-10-2013 |
| | | | WO | 2012074408 | A2 | 07-06-2012 |

Form PCT/ISA/210 (patent family annex) (April 2005)

## REFERENCES CITED IN THE DESCRIPTION



### Patent documents cited in the description

- GB 191422337 A **[0008]**
- US 20120128425 A1 **[0009]**