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(54) **SYSTEM AND METHOD FOR SUPPLYING BREATHING GAS TO A DIVER**

(75) Inventors: **Pierre Bühlmann**, Lidingö (SE); **Imre Botos**, Tystberga (SE)

Correspondence Address:
**MARSHALL, GERSTEIN & BORUN LLP**
**233 S. WACKER DRIVE, SUITE 6300**
**SEARS TOWER**
**CHICAGO, IL 60606 (US)**

(73) Assignee: **INTERSPIRO AB**, Lidingo (SE)

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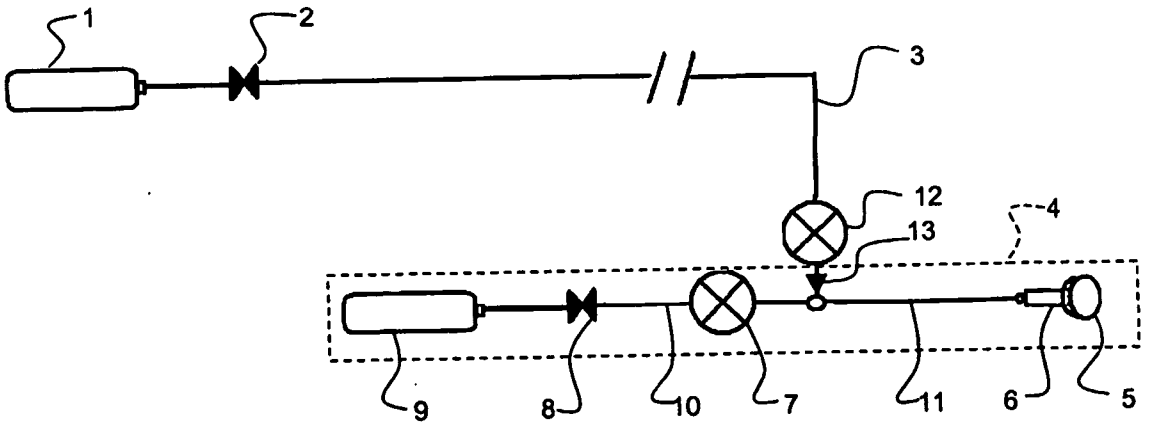
(57) **ABSTRACT**

The invention concerns a system and a method for supplying breathing gas to a diver. The system is of the open circuit type and comprises a gas source consisting of a pressurized container (**1**), which is intended to be placed at a distance from the diver and which delivers breathing gas under a high pressure, a breathing apparatus (**4**) which is intended to be carried by the diver and a flexible tube (**3**), which connects the gas source with the breathing apparatus. The flexible tube is of the high-pressure type, the gas is conducted through the flexible tube under a pressure, which is essentially equal to the pressure delivered from the gas source, and the gas source is arranged to be able to deliver breathing gas at a pressure, which exceeds approx. 30 bars.



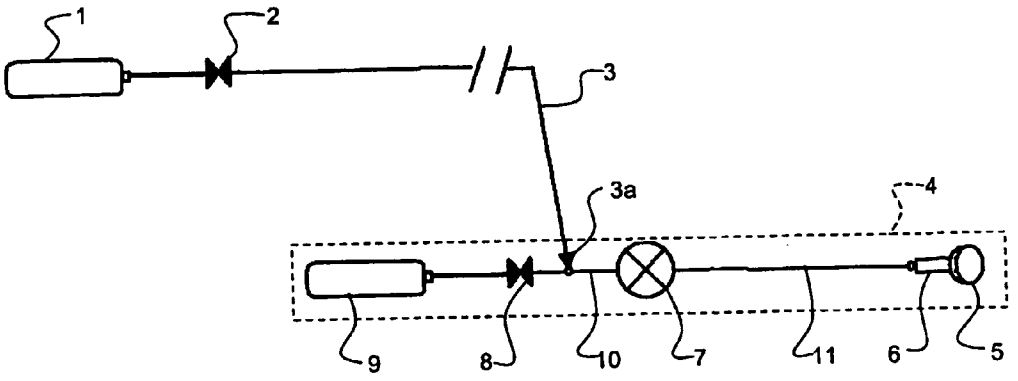



Fig. 1

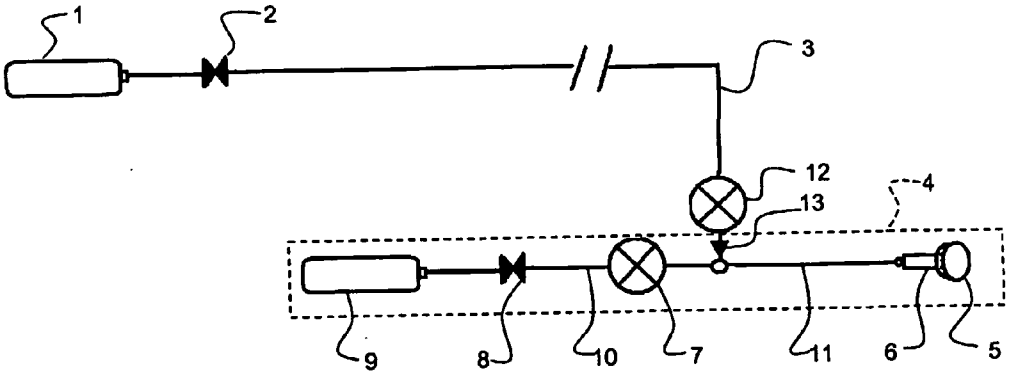



Fig. 2

# SYSTEM AND METHOD FOR SUPPLYING BREATHING GAS TO A DIVER

## FIELD OF THE INVENTION

[0001] The invention relates to a system for providing a diver with breathing gas, the system being an open system and comprising an external gas source in the form of a pressurized container which is intended to be located at a distance from the diver and which delivers breathing gas under high pressure, a breathing device which is intended to be worn by the diver, and a hose which connects the external gas source to the breathing device. The invention also relates to a method for providing a diver with breathing gas.

[0002] The system can be used in, for example, what is known as surface-supplied diving or deep diving, the diver, via a hose, being provided with breathing gas from pressurized gas containers located above the surface of the water or in a space which may be located below the surface of the water. The system can also be used in smoke-helmeted firefighting or other hose diving where the user or diver is provided with breathing gas via a hose from a gas source which is located outside the area where the user/diver is active.

## BACKGROUND OF THE INVENTION

[0003] Generally, such hose-diving systems can be divided into two different types, namely open and closed systems. In the open systems, the diver breathes in the breathing gas which is delivered through the hose, after which the exhalation gas is conveyed out to the environment surrounding the diver. In the more complicated closed systems, or push-pull systems, on the other hand, the exhalation gas is returned through a second hose to the gas source for regeneration of breathing gas.

[0004] Hose-diving systems have considerable advantages compared with other systems where the diver himself/herself carries the gas source with him/her, usually in the form of a pressurized gas container. For example, the diver does not have to come up to the surface or leave the working area in order to replenish the gas supply. In the case of hose-diving, such replenishment can take place by assistants at the gas source coupling a new container to the hose when the gas in the previously used container has been used up. The diver can continue to work during this operation, and the length of the working period is therefore not dependent on the size of the gas supply the diver would otherwise carry with him/her. Another advantage of hose-diving systems is that the diver does not have to carry heavy, unwieldy gas containers. This contributes to increased mobility and a reduced risk of hose-diver fatigue.

[0005] Hose-diving is therefore often used for-protracted and complicated work, such as underwater repairs and rescue work in smoke-filled premises. Hose-diving systems are also often used in rescue operations in other situations, for example in caves with poisonous or otherwise dangerous atmosphere.

[0006] In order for it to be possible for a hose-diver/user to perform good, effective work, it is therefore of vital importance that the mobility of the diver/user is impaired to the minimum possible extent. It is also important that the equipment the diver/user carries weighs as little as possible and is easy to handle. Another important aspect, especially in the case of rescue operations, is that the entire system is simple to transport, even over rough terrain. In this connection, it is furthermore of great importance that the system can be set in operation quickly and that the diver/user can transfer rapidly and unhindered from the installation site where the gas source is located to the area where the rescue operation is to be effected. Another important aspect is that the system has great reliability and includes as few components as possible, which may suffer breakdown or malfunction.

[0007] In known open hose-diving systems, such as the system described in U.S. Pat. No. 4,986,267, the gas source often consists of a pressurized gas container. When filled completely with breathing gas, the container is usually pressurized to a maximum of around 300 bar. A first pressure regulator is arranged in direct proximity to the container. A breathing device worn by the diver comprises a breathing valve with a mouthpiece through which the diver breathes. The first pressure regulator is arranged to reduce the pressure from the container, so that the pressure in the hose between the first pressure regulator and the breathing device is around 10 bar plus around 1 bar above the ambient pressure applying around the diver. The breathing device often also comprises a second pressure regulator, for fine adjustment of the pressure between this second pressure regulator and the breathing valve. Finally, the breathing valve reduces the pressure to a breathing pressure which is approximately the same as the ambient water or atmospheric pressure.

[0008] As the breathing gas is conveyed from the first pressure regulator via the hose to the breathing device under a reduced pressure of around 10 bar plus around 1 bar above the ambient pressure around the diver, a certain minimum inner cross-sectional area of the hose is required in order to ensure a sufficiently great flow of breathing gas through the hose. In particular in the case of long hoses, this causes considerable problems as the hose has to be designed with a relatively large inner cross-sectional area. This results in the hose having to be made relatively thick, which in turn leads to the hose being heavy and unwieldy to handle. Moreover, such a thick hose constitutes considerable wind resistance when it is used outdoors on land, which of course makes it more difficult for the user to move unhindered. This problem is even worse for a diver because a thick hose constitutes great water resistance and because the action of the water on the hose results in great forces which are difficult to deal with but have to be overcome and resisted by the diver. It is especially disadvantageous and even dangerous to use a thick hose in water with underwater currents because such currents can pull the hose along with such force that the diver cannot resist it but is instead pulled away from the working area.

[0009] U.S. Pat. No. 4,037,594 and U.S. Pat. No. 3,370,585 describe two closed hose-diving systems. These closed systems are considerably more complicated than the open systems and comprise a gas source in the form of a regeneration apparatus for regenerating fresh breathing gas from used exhalation gas and a pump for conveying the breathing gas through a first hose to the diver. The breathing gas is conveyed through the hose under a pressure which is slightly higher than the ambient pressure in order to feed the gas to the diver. The exhalation gas is conveyed back to the gas

source through a second hose. In the closed systems, the problems of the hose hindering the diver in his or her work are of course even greater because the relatively low feed pressure requires a large cross-sectional area of the feed hose and because the system itself requires two hoses or alternatively a heavy coaxial hose.

## OBJECTS OF THE INVENTION

[0010] One object of the invention is therefore to produce a system and a method of the kind indicated in the introduction, which substantially increase the freedom of movement of the diver.

[0011] Another object is to produce such a system and method which are reliable and where the number of components included is minimized.

[0012] A further object is to produce such a system and method which allow a relatively thin and light hose to be used in order to minimize the negative effect of the hose on the freedom of movement of the diver.

## SUMMARY OF THE INVENTION

[0013] According to the invention, these and other objects are achieved with a system of the kind indicated in the first paragraph of this description, which is characterized in that the hose is of the high-pressure type and in that the breathing gas is conveyed through the hose from the gas source to the breathing device under essentially the pressure which is delivered from the gas source.

[0014] By virtue of the fact that the breathing gas is conveyed through the hose under the high pressure which is delivered from the gas source, a sufficiently great gas flow through the hose can be ensured even if the hose is designed with a relatively small inner cross-sectional area. With a suitable choice of hose material, the outer circumference of the hose can then also be kept small, the hose then constituting during use considerably smaller wind or water resistance than was previously possible. The small cross-sectional dimension of the hose also reduces the weight of the hose, which makes both the work at the site of the diver and transport, installation and setting in operation of the system easier. A hose with a small cross-sectional dimension is moreover more flexible and easier to handle, which also makes both the work of the diver at the site and letting-out and hauling-in of the hose easier.

[0015] Another advantage of the system according to the invention is that the number of components included can be kept to a minimum because no pressure regulator is necessary at the gas source. The risk of malfunctioning of the system is thus reduced.

[0016] Other advantages of the invention emerge from the dependent claims. For example, the hose can be made wholly or partly of polyamide fibers, such as Kevlar. Such a high-strength material ensures that the hose can withstand the high pressures of up to 700 bar or 300 bar which are delivered by the gas source. Moreover, if it is made from such a material, the hose can, in addition to serving as a gas line, also be designed so as itself to constitute a lifeline with which the diver/user can, for example, be pulled up to the surface or out of smoke-filled premises in the event of an accident. In this way, an otherwise necessary separate lifeline is eliminated.

[0017] The system also allows flexibility with regard to how the breathing gas is coupled to the conventional breathing device which is worn by the diver. According to one embodiment, for example, the hose can be coupled to the breathing device so that the breathing gas delivered from the gas source can be used in order to fill a reserve gas container under high pressure which is carried by the diver.

[0018] The invention also relates to a method for conveying breathing gas to a diver. The method is defined in independent patent claim **13**, and further features and advantages of the method emerge from subordinate patent claims **14** to **20**.

## DESCRIPTION OF PREFERRED EMBODIMENTS

[0019] Different illustrative embodiments are described below with reference to the accompanying figures, in which:

[0020] FIG. **1** shows a diagrammatic sketch of a first embodiment of the invention, and

[0021] FIG. **2** shows a corresponding diagrammatic sketch of a second embodiment.

[0022] FIG. **1** shows a first embodiment of a system according to the invention. The system comprises a gas source in the form of a pressurized container **1** which contains breathing gas, for example air or nitrox. The container is of the standard type found on the market. These standard containers have different maximum pressure for different markets. The maximum pressure, which corresponds to the pressure in the container when it is full, is 200 bar on some markets, for example, while it is 300 bar on other markets. Containers with a maximum pressure of 700 bar are also found. All these different standard containers, but also other containers which deliver breathing gas under high pressure, can be used in the system according to the invention. The main point is that the container can deliver exhalation gas under a pressure which is considerably higher than the ambient pressure surrounding the diver.

[0023] The container is connected, via a shut-off valve **2**, to a high-pressure hose **3**. During normal use, the shut-off valve **2** is open, so that the pressure prevailing in the container **1** also prevails in the hose **3**. The shut-off valve is closed, for example, when the container **1** is exchanged, so as to maintain the high pressure in the hose **3**, and after work is completed, when the system is demounted. The hose **3** is made from a high-strength material and is designed to withstand the high container pressures. In other words, the high-pressure hose **3** is constructed and manufactured so as to be capable of with a good margin supporting internal pressures of 300 bar and in some applications 700 bar without risk of the high pressure damaging the hose. The hose **3** can, for example, comprise an inner gastight layer, an intermediate pressure-absorbing layer and an outer durable layer. The intermediate layer can, for example, consist of or contain carbon fibers, such as Kevlar, or braided metal.

[0024] At its other end, via a non-return valve **3***a*, the hose **3** is coupled to a breathing device **4** which is worn by the diver (not shown). The breathing device **4** comprises a mouthpiece **5** through which the diver breathes, a breathing valve **6**, a pressure-reducing valve **7**, a shut-off valve **8** and a reserve gas container **9**.

[0025] During use, the breathing gas is conveyed from the container **1** under unregulated container or bottle pressure via the hose **3** to the breathing device **4**. In other words, the pressure prevailing in the container **1** at any time also prevails in the hose **3**. The shut-off valve **8** of the breathing device **4** is normally closed. The unregulated bottle pressure also prevails in the line **10** between this shut-off valve **8** and the pressure-reducing valve **7**. The pressure-reducing valve **7** is arranged so as, irrespective of the pressure upstream of it, that is to say in the container **1**, the hose **3** and the line **10**, to keep the pressure in the line **11** at around **10** bar. This pressure is reduced further by the breathing valve **6**, so that the pressure prevailing in the mouthpiece is approximately the same as or slightly higher than the ambient water or atmospheric pressure.

[0026] During use of the system, the pressure in the container **1** falls gradually as the breathing gas is used up. When the container pressure falls below a certain value, a sufficient flow through the hose can no longer be guaranteed on account of the pressure drop along the hose. Personnel at the container **1** then close the shut-off valve **2**, the pressure in the system downstream of this valve **2** then being maintained in a controlled manner, so that the container **1** can be exchanged. In order to ensure a good gas supply, this is done when the pressure in the container and the hose reaches a lower limit value. This limit value can be related to the ambient pressure surrounding the diver, for example to the ambient pressure around the diver plus around 30 bar. In practice, a fixed limit value can be set at around 50 bar. During the time it takes to exchange the container, the quantity of breathing gas present in the hose is sufficient for supplying the diver. When the container **1** has been exchanged, the valve **2** is opened again, the hose **3** then being repressurized to the unregulated bottle pressure.

[0027] In the event of, for example, the high-pressure hose **3** breaking, or if the supply of breathing gas from the container **1** should stop for any other reason, the non-return valve **3***a* guarantees that the pressure in the breathing device does not fall in an uncontrolled manner. The diver can then open the shut-off valve of the breathing device **4**, breathing gas from the reserve container **9** then being received.

[0028] In the embodiment shown in FIG. **1**, an opportunity is also afforded for refilling the reserve container **9** in the course of working. In this connection, the shut-off valve **8** of the breathing device **4** is opened, the high unregulated container pressure in the hose **3** and the line **10** overcoming the pressure in the reserve gas container **9**, so that breathing gas from the container **1** can fill the reserve container **9**.

[0029] FIG. **2** shows an alternative embodiment. The components which have an equivalent in FIG. **1** have the same reference number in FIG. **2** as well. The embodiment shown in FIG. **2** differs from that in FIG. **1** in that the breathing gas from the container **1** is supplied to a breathing device **4** downstream of the pressure-reducing valve **7** of the breathing device **4**. For this, a further pressure-reducing valve **12** is arranged at the end of the high-pressure hose **3** at or in proximity to the breathing device **4**. This pressure-reducing valve **12** is adapted so as, irrespective of the pressure in the container **1** and the hose **3**, to keep the pressure in the line **11** at around 10 bar. A non-return valve **13** is arranged between this pressure regulator **12** and the line **11** in order to prevent uncontrolled pressure drop in the breathing device **4** in the event of, for example, the hose **3** breaking. Alternatively, the pressure-reducing valve **12** and the non-return valve **13** can consist of one and the same component.

[0030] The embodiment shown in FIG. **2** has inter alia the advantage that connection to the breathing device **4** is easier to carry out because the connection takes place on the low-pressure side of the breathing device.

[0031] According to an embodiment which is not shown, fastening means are arranged in proximity to the downstream end of the hose. These fastening means are designed to be fastened to, for example, a harness which is worn by the diver or to the diving suit. The fastening means also have load-relievers so that the gas-conveying coupling between the hose and the breathing device is not loaded even if great forces arise between the hose and the diver. With the aid of the fastening means, the diver is therefore attached securely to the hose, so that the hose can be used as a lifeline in order, for example, to hoist a diver up through the water or to pull a smoke-helmeted firefighter out of smoke-filled premises. In this way, a separate lifeline, which should otherwise always form part of a hose-diving system for safety reasons, is eliminated completely. Fastening means with load-relievers can of course also be arranged at the upstream end of the hose in order to secure the hose/the lifeline against being pulled loose.

[0032] In the example shown, the maximum container pressure is around 300 bar, and the total length of the hose is around 100 m. In order to ensure a sufficient gas flow through the hose to the diver, the high-pressure hose has an inner diameter of around 3 mm. If, as in the example, the hose is made wholly from Kevlar, the outer diameter of the hose can than be kept as small as 9 mm. This is to be compared with conventional systems where the pressure in the hose is reduced from 300 bar to around 10 bar plus around 1 bar above the ambient pressure around the diver and where the inner diameter of the hose, with the same hose length, is usually around 9 mm in order to provide a sufficient flow. This minimum permitted inner diameter gives an outer hose diameter of around 22 mm. With the system according to the invention, it is therefore possible considerably to reduce the cross-sectional dimension of the hose, which results in the advantages described above.

[0033] The embodiments described above are given as examples, and it will be understood that the invention can be varied within the scope of the following patent claims. For example, the reserve containers **9** and the shut-off valves **8** shown in the figures can be dispensed with if deemed appropriate.

[0034] The breathing device can be designed in many different ways, as long as the system comprises pressure-reducing means which are worn by the diver and which reduce the pressure in the hose to a suitable breathing pressure. The breathing device can, for example, comprise a pressure regulator or a nozzle which, on the upstream side, is connected to the high-pressure hose and, on the downstream side, is connected to a helmet, mask or hood which is worn by the diver or to a diving bell in which the diver is located.

**1**. A system for providing a diver/user with breathing gas, the system being an open system and comprising an external

gas source in the form of a pressurized container which is intended to be located at a distance from the diver and which delivers breathing gas under high pressure, a breathing device which is intended to be worn by the diver/user, and a hose which connects the gas source to the breathing device, characterized in that the hose is of the high-pressure type, and in that the breathing gas in conveyed through the hose from the gas source to the breathing device or a pressure-reducing means arranged in proximity to the device under essentially the pressure which is delivered from the gas source.

**2**. The system as claimed in claim 1, the container being pressurized to between around 50 and around 700 bar.

**3**. The system as claimed in claim 1, the container being pressurized to around 200 or around 300 or around 700 bar when it is full.

**4**. The system as claimed in claim 1, the hose being designed to transport the breathing gas under a pressure of up to around 700 bar.

**5**. The system as claimed in claim 1, the hose being made of, or containing, carbon fibers, preferably Kevlar.

**6**. The system as claimed in claim 1, comprising a pressure-reducing valve which is arranged at or in proximity to the breathing device and reduces the pressure downstream of the-valve from the pressure prevailing in the hose.

**7**. The system as claimed in claim 6, the pressure-reducing valve reducing the pressure to around 10 bar.

**8**. The system as claimed in claim 1, the breathing device comprising a breathing valve, a first pressure-reducing valve arranged upstream of the breathing valve, and a reserve gas container arranged upstream of the first pressure-reducing valve, and the hose being connected to the breathing device between the pressure-reducing valve and the reserve gas container.

**9**. The system as claimed in claim 1, the breathing device comprising a breathing valve, a first pressure-reducing valve arranged upstream of the breathing valve, and a reserve gas container arranged upstream of the first pressure-reducing valve, and the hose, via a second pressure-reducing valve, being connected to the breathing device between the breathing valve and the first pressure-reducing valve.

**10**. The system as claimed in claim 1, the breathing device comprising a pressure-reducing valve and being designed to deliver breathing gas to a helmet, mask or hood which is intended to be worn by the diver.

**11**. The system as claimed in claim 1, the hose (**3**) comprising means for being fastened to the diver, so that the hose can constitute a lifeline.

**12**. The system as claimed in claim 1, the breathing gas consisting of air or nitrox.

**13**. A method for providing a diver/user with breathing gas, the breathing gas being conveyed through an open system from a gas source in the form of a pressurized container which is located at a distance from the diver/user through a hose to a breathing device which is worn by the diver, characterized in that the gas is conveyed from the gas source to the breathing device or a pressure-reducing means arranged in proximity to the breathing device through a hose of the high-pressure type under essentially the pressure which is delivered by the gas source.

**14**. The method as claimed in claim 13, the breathing gas being conveyed through the hose under a pressure of between around 50 and around 700 bar.

**15**. The method as claimed in claim 13, the breathing gas being conveyed through the hose under a maximum pressure of around 200 bar.

**16**. The method as claimed in claim 13, the breathing gas being conveyed through the hose under a maximum pressure of around 300 bar.

**17**. The method as claimed in claim 13, the breathing gas being conveyed through the hose under a maximum pressure of around 700 bar.

**18**. The method as claimed in claim 13, the pressurized container being exchanged when the pressure in it falls to a limit value.

**19**. The method as claimed in claim 18, the limit value being around 50 bar.

**20**. The method as claimed in claim 13, the breathing gas consisting of air or nitrox.

* * * * *