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(72) Inventor: **The designation of the inventor has not yet been filed**

(74) Representative: **Schulze, Mark**
Von Lieres Brachmann Schulze
Patentanwälte in Partnerschaft
Dietramszeller Str. 22
83624 Otterfing (DE)

(71) Applicant: **Blue Spirit Aero SAS**
92500 Rueil-Malmaison (FR)

(54) **FLUID STORAGE TANK, FILLING METHOD AND AIRCRAFT**

(57) A fluid storage tank (1) comprises an elongated rigid storage compartment (2), having a first tank port (8-1) at a first end and a second tank port (8-2) at a second end. A method relates to filling a fluid storage tank, wherein the fluid storage tank is simultaneously filled with fluid (F) through both tank ports. An aircraft (A) comprises multiple fluid storage tanks, wherein their first tank ports (8-1) are interconnected by a first fluid distribution network (10-1) and their second tank ports (8-2) are inter-

connected by a second fluid distribution network (10-2), each distribution network comprises at least one refilling port (11-1, 11-2) for the fluid (F), and the first and second distribution networks (10-1, 10-2) are interconnected via at least one remotely controllable inter-network valve (12). The invention is particularly useful for storing and distributing hydrogen, in particular in hydrogen fuelled, electrically propelled aircraft.

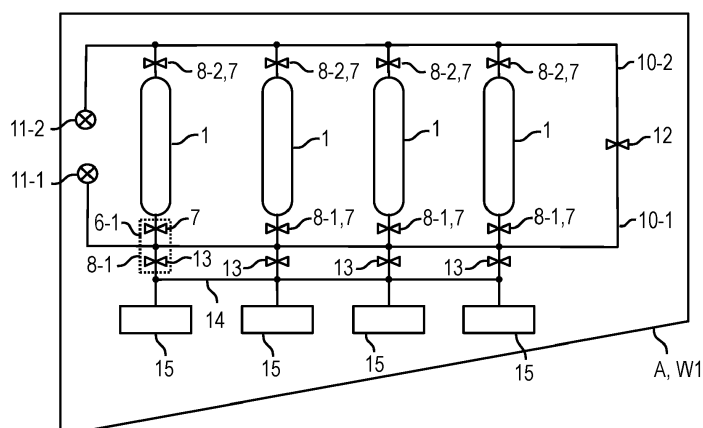


Fig.3

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Description

[0001] The invention relates to a fluid storage tank, comprising an elongated rigid storage compartment for storing fluid, having a tank port for introducing the fluid into and extracting the fluid from the storage compartment. The invention also relates to a method filling the storage tank with fluid. The invention further relates to an aircraft comprising multiple fluidically interconnected fluid storage tanks. The invention is particularly useful for storing and distributing hydrogen, in particular in hydrogen fuelled, electrically propelled aircraft.

[0002] Currently, as shown in **Fig. 1**, a fluid storage tank in form of a gas bottle 101 is widely used. The gas bottle 101 comprises a cylindrical rigid storage compartment 102 made of a metallic or composite core for storing pressurized fluid. Its inner surface is covered by a liner 103 to create a barrier against leaks. On one end, the storage compartment 102 comprises a threaded connection tube 104 having an entry valve 105 to limit the flow rate and a shut-off cock (not shown) for opening and closing the connection tube 104. Typically, a bottle head 106 may be screwed onto the connection tube 104. Often, the bottle head 106 comprises an adjustable mass flow valve 107 to adjust the flow rate of the fluid leaving the gas bottle 101.

[0003] Typically, a bottle-head 106 is equipped with a Thermal Pressure Relief Device, TPRD, (not shown) comprising one temperature sensor which is situated at the end where the gas enters into the bottle-head 106 during refilling. Conventionally, the TPRDs use these temperature sensors as a safety feature to trigger a blow-off (i.e., release gas) to lower the pressure in the storage compartment if the sensed temperature reaches or exceeds a certain threshold.

[0004] When refilling the gas bottle 101 (with the bottle head 106 removed), there may disadvantageously occur significant temperature changes of the storage compartment 102. These temperature changes are caused by the injection of high-pressure gaseous fluid F through the connection tube 104 into the empty - and thus low-pressure, storage compartment 102. This results in the fluid molecules impacting the other end of the storage compartment 102 with high momentum. Since the storage compartment 102 is rigid, the only way for the molecules to dissipate their kinetic energy is by transforming it into thermal energy, which, in turn, is absorbed by the storage compartment 102. Disadvantageously, the storage compartment 102 does not have the ability to effectively dissipate heat due to the thermal properties of the composite materials. Therefore, the ends of the storage compartment tend to heat up significantly. This is particularly disadvantageous since, for metallic tanks, the connection tubes 104 are typically welded to the storage compartment 102, which creates weak points that could be negatively affected by high thermal and kinetic loads. Moreover, the material of the liner 103 is very temperature sensitive and may melt if a certified maximum temperature

is exceeded or may crack if the temperature is too low. In these cases, the storage compartment 102 must be replaced.

[0005] Currently, for hydrogen as the fluid F, three different refilling mass flow rates are typically used, namely 30 grams/second, 60 grams/second, and 120 grams/second, each corresponding to a hydrogen pressure of 350 bar, 350 bar and 700 bar, respectively, at a reference temperature of 15°C. The greater the pressure, the higher the temperature of the storage compartment 102 will rise.

[0006] Heat generated during a refilling process using 700 bar may cause the internal temperature of the storage compartment 102 to increase up to 85 °C. At these high temperatures, the internal pressure is no longer 700 bar but may increase up to 875 bar. In order to refill the storage compartment 102 properly and maintain a constant mass flow rate, an increase of the supply pressure (corresponding to a counter pressure difference) at the connection tube 104 is necessary. This results in a needed supply pressure of 950 bar. Additionally, it is standard practice to use an operational margin of 10 % over the minimum required pressure, such that the hydrogen gas is often pressurized over 1050 bar. The heat generation caused by the gas molecules impacting the closed end of the storage compartment 102 thus also disadvantageously increases the need for higher supply pressures.

[0007] One prior art solution to reduce overheating is to precool the hydrogen gas at - 40°C which allows an increase of the mass flow rate while keeping the temperature at an end section of the storage compartment on an appropriate level at the end of the refilling process. Furthermore, the higher the quantity of hydrogen in the storage compartment 102, the slower the temperature rise of the storage compartment 102 since there is more fluid to absorb the kinetic energy of the injected hydrogen molecules.

[0008] Thus, there is currently the disadvantage that the refilling process is rather complex and prone to overheating of the storage compartment 102.

[0009] It is the **object** of the present invention to at least partially overcome the problems associated with the prior art. It is a particular object of the present invention to provide a possibility to fill gas bottles with fluid with less danger of overheating.

[0010] The object is achieved according to the features of the independent claims. Advantageous embodiments can be found, e.g., in the dependent claims and/or in the description.

[0011] The object is achieved by a fluid storage tank, comprising an elongated rigid storage compartment for storing fluid, the storage compartment having a first port (in the following called a "first tank port") at a first end and a second port (in the following called a "second tank port") at a second end.

[0012] This fluid storage tank gives the advantage that simultaneous filling the storage compartment from both ends through the respective tank ports with gaseous fluid

is enabled. This achieves that the gas flows injected from each end collide with each other in the storage compartment, thus creating a turbulent flow in a mixing zone distanced from the ends of the storage compartment. In the mixing zone, the kinetic energy of the colliding gas molecules is transformed into heat. Contrary to the prior art, the heat is advantageously mostly generated in the fluid of the mixing zone and not at the inner surface of the storage compartment. Also, the heat generation is advantageously less abrupt and less localized but more homogeneous and extends over a larger area. Furthermore, the heat can advantageously better spread to both ends of the storage compartment which advantageously causes a stronger heat transfer from the mixing zone. The above effects advantageously reduce local temperature spikes and avoid exceeding maximum temperature limits of the storage compartment. The integrity of the liner material is much easier to maintain.

[0013] Another advantage resulting from this double end refilling is that the mass flow rate of the gas can be increased, e.g., doubled.

[0014] Another advantage is that standards for filling storage tanks are more reliably met, e.g., French and European standards recommending using the entry valve 105 on a pressure level 10% below its maximum operating pressure in order to avoid unintentional gas release due to the uncertainty of the set pressure threshold.

[0015] Limiting the temperature rise in the above-described manner also reduces the pressure value of the fluid in the storage compartment, e.g., to a value below 875 bar. If the required counter pressure difference does not change, the supply pressure may be reduced, and for the same safety margin of 10% as described above, the total required gas pressure is lower. For instance, a total pressure of 950 bar may be sufficient rather than a total pressure of over 1050 bar. As a result, electrical energy may be saved due to a reduction in power required by pumps and compressors to achieve the required total pressure. This is similar for the required cooling temperature before the gas injection into the storage compartment.

[0016] The elongated rigid storage compartment may be a cylindrical storage compartment. In an embodiment, the storage compartment comprises a core made of composite material. In an embodiment, the core may be a metallic core. An inner surface of the core may be covered by a liner. The storage compartment may be embodied in analogy to a conventional gas bottle but for comprising connection tubes at both ends.

[0017] The fluid stored in the storage compartment may be hydrogen, air, carbon dioxide, helium, or any other suitable fluid. The fluid may be a gas, liquid or a combination of gas and liquid.

[0018] The tank ports are provided to let liquid flow into the storage compartment and out of the storage compartment.

[0019] In an embodiment, a port may be a connection

tube. In an embodiment, a tank port may comprise a connection tube and an adapter connectable with the connection tube, e.g., a bottle head.

[0020] In particular, the tank ports may have an identical design. Alternatively, the first tank port may have a different design from the second tank port.

[0021] It is an embodiment that the storage compartment is equipped with a first temperature sensor positioned in the vicinity of a first end section of the storage compartment and a second temperature sensor positioned in the vicinity of a second end section of the storage compartment. This gives the advantage that the process of (re)filling the storage tank may be even better controlled to avoid local overheating. For example, a significant temperature difference may be an indication that the fluid simultaneously introduced at both tank ports does not meet in the middle of the storage compartment but nearer towards one of the tank ports. To remedy this, the supply pressure of one or both of the tank ports may be altered (i.e., increased or lowered) to shift the mixing zone more to the middle of the storage compartment to allow desired or nominal conditions.

[0022] That a temperature sensor positioned "in the vicinity of an end section" may, e.g., comprise that

- the temperature sensor is located at an inner surface of the core of the storage compartment near the respective tank port, e.g., near or at the mouth of a connection tube;
- the temperature sensor is located at an inner surface of a connection tube; and/or
- the temperature sensor is the temperature sensor of a TPRD, in particular the TPRD of an adapter, in particular bottle head.

[0023] Generally, the temperature sensors measure the temperature variation of the inner surface in the vicinity of a respective end of the core and may exchange information with a refilling station, in particular regarding the integrity of the storage system. If there is any risk of exceeding a maximum temperature, the gas supply can be reduced or stopped.

[0024] It is an embodiment that each of the tank ports, in particular bottle heads, comprises a remotely controllable valve. This gives the advantage that during operation of an entity using the storage tank, e.g., an aircraft, gas can be selectively released from the storage compartment via the first tank port, the second tank port, or both tank ports at the same time. This, in turn, enhances availability of a gas supply from the storage tanks and resilience to failure cases. A remotely controllable valve may advantageously be an electrically controllable valve, but may generally be any remotely controllable valve like a hydraulically, mechanically, etc. controllable valve.

[0025] In one embodiment, a tank port may comprise a remotely controllable, particularly electrically controllable, mass flow rate valve. Such a valve may be electrically controlled to open and close the respective tank port,

and/or to adjust a desired mass flow rate through the tank port by an electric control signal. This mass flow rate valve may be the mass flow rate valve of an adapter, in particular bottle head.

[0026] In an embodiment the mass flow rate valve may also act as a pressure reducer / pressure reduction stage. Alternatively, a tank port may comprise a separate pressure reducer / pressure reduction stage.

[0027] In an embodiment, a tank port comprises at least two pressure reduction stages. This gives the advantage that fluid can be introduced and/or extracted under different fluid pressure levels.

[0028] In an embodiment, a tank port comprises a first pressure reduction stage, e.g., the above mentions mass flow rate valve, that has a first connection connected to the storage compartment and a second connection, wherein the first pressure reduction stage is adapted to reduce a pressure of the fluid in the rigid storage compartment to a lower pressure level at its second connection. A second pressure reduction stage, e.g., a further mass flow rate valve, comprises a first connection connected to the second connection of the first pressure reduction stage and a second connection, wherein the second pressure reduction stage is adapted to reduce a pressure of the fluid at its first connection to a lower pressure level at its second connection. In an embodiment, both pressure reduction stages are individually remotely controllable, particularly electrically controllable.

[0029] The first pressure reduction stage and the second pressure reduction stage may be integrated with into a single component, e.g., the adapter / bottle head.

[0030] The object is also achieved by a method for filling a fluid storage tank as described above, wherein the fluid storage tank is simultaneously filled with fluid through both tank ports, e.g., directly through the connection tubes or via respective adapters, e.g., bottle heads.

[0031] The method may be embodied in analogy to the fluid storage tank and achieves the same advantages.

[0032] For example, it is an embodiment that the temperatures measured by the first temperature sensor and the second temperature sensor are monitored, and if an unfavourable condition is detected, the mass flow rate through at least one of the tank ports is adjusted. The unfavourable condition may be a temperature difference measured by the first temperature sensor and the second temperature sensor that exceeds a certain threshold. The unfavourable condition may also be encountered when a temperature measured by the first temperature sensor and/or the second temperature sensor exceeds a respective threshold.

[0033] It is an embodiment that the fluid is filled through both tank ports at an equal mass flow rate. This gives the advantage that the mixing zone develops at least roughly in the middle of the storage compartment. This, in turn, is thermally favourable to avoid overheating of the storage tank, in particular at its ends, even at high mass flow rates.

[0034] It is an embodiment that the fluid is filled through both tank ports at a varying mass flow rate difference between the tank ports. This gives the advantage that the mixing zone can be shifted along the fluid compartment during filling to spread heating in the storage compartment. Varying the mass flow rate difference may be achieved by the mass flow rate at one or both tank ports being varied. e.g., in a linear or sinusoidal manner.

[0035] The object is further achieved by an aircraft, comprising multiple fluid storage tanks as described above, wherein

- their first tank ports are interconnected by a first fluid distribution network and their second tank ports are interconnected by a second fluid distribution network,
- each network comprises at least one refilling port for the fluid, and
- the first and second distribution networks are interconnected via at least one remotely, in particular electrically controllable, valve (in the following, without loss of generality, called "inter-network valve").

[0036] This gives the advantage that the storage tanks can be simultaneously filled from both tank ports. Another advantage is that during operation of the aircraft, gas released from the storage tanks can be exchanged between the distribution networks, which enables a particularly flexible and reliable provision of the gas. This may be advantageous, e.g., in the case that one or more of the storage tanks have a malfunctioning tank port. Also, the inter-network valve enables separating the first and second distribution networks from each other which may be advantageously if the second distribution network fails, e.g., bursts or leaks.

[0037] In particular, the first and second tank ports may be interconnected with the first and second fluid distribution network, respectively, via their respective remotely controllable valves, e.g., mass flow valves. This advantageously allows selectively opening and closing a connection between the storage tank and the respective fluid distribution network.

[0038] The inter-network valve may be controlled by a control unit of the aircraft. It may control the inter-network valve to alternatively open or close in order to respectively fluidically separate and connect the first and second distribution networks. The control unit may also control operation of any other of the remotely controllable valves.

[0039] At the end of the refilling process, the distribution networks may be emptied, while the refilled storage tanks keep containing the fluid inside them.

[0040] In an embodiment, the storage tanks are fixedly attached to the aircraft, i.e., not intended to be regularly removed or swapped. However, they may be removed for maintenance or repair. This embodiment gives the advantage that a particularly fast refill of the storage tanks and thus turn-around time for the aircraft is achievable.

[0041] In an embodiment, the storage tanks may be

individually removable from the aircraft, e.g., by service personnel. This gives the advantage that empty storage tanks may also be easily removed and swapped for full storage tanks which advantageously enables easy exchange in the case of a faulty tank. If the tank ports comprise detachable bottle heads (e.g., bottle heads that can be screwed on and off respective connection tubes), a storage tank being individually removable may comprise removing the storage compartment with its connection tubes while the bottle heads remain connected with the aircraft. Additionally or alternatively, a storage tank being individually removable may comprise removing the storage tank including the bottle heads.

[0042] It is an embodiment that at least one electrochemical converter, ECC, is connected to the first distribution network. This gives the advantage that the least one ECC will be reliably and evenly supplied with gas, in particular hydrogen, out of the first fluid distribution network even in the case that one or more of the storage tanks runs empty and/or a connection between one or more of the storage tanks and the first and/or second distribution networks is inadvertently blocked or disconnected.

[0043] The ECC is adapted to create electric energy from the fluid, in particular hydrogen. The electric energy may be used to power any electrical load of the aircraft, in particular electric motors, actuators, and so on, e.g., an electric aircraft propulsion motor like an electric propeller motor, etc. Particularly in this case, the aircraft may be a hydrogen fuelled, electrically driven aircraft.

[0044] In an embodiment, a fluid inlet of at least one of the ECCs is connected to a valve (in the following called a "supply valve") to advantageously being able to individually shut-off the ECCs from fluid supply, e.g., in case of a failure of the ECC or when an ECC is not needed. In other words, the supply valve is provided to allow or block connection of the supply valve to a distribution network. The supply valve may be a shut-off valve or, advantageously, a mass flow rate valve. In an embodiment, the supply valve is a remotely controllable valve.

[0045] In an embodiment, the aircraft comprises at least one detachable propulsion unit comprising at least one fluid storage tank, at least one ECC suppliable with fluid from the at least one fluid storage tank via the first distribution network, a section of the first distribution network being part of the propulsion unit, and at least one electric aircraft propulsion motor suppliable with electric energy by the at least one ECC. This propulsion unit may be detached from and attached to the aircraft as one unit, in particular from and to a wing of the aircraft.

[0046] It is an embodiment that the first distribution network is fluidically connectable to a third fluid distribution network via at least one remotely controllable valve (in the following referred to as "connection valve"), and at least one ECC is connected to the third distribution network. This gives the additional advantage that the at least one ECC can be fluidically separated from the gas supplied by the first distribution network, in particular hydro-

gen, e.g. to shut off the at least one ECC when there is still gas in the first connected fluid distribution network. The connection valve may be a shut-off valve or a remotely controllable mass flow rate valve.

[0047] It is an embodiment, that each ECC is fluidically connected to a distribution network via a respective connection valve. This gives the advantage that the ECCs can be individually shut off from the fluid. This may be advantageous in the case that a connected electrical load like a motor etc. is to be switched off or when the ECC is faulty.

[0048] It is an embodiment that the first distribution network is connected to the third fluid distribution network via multiple connection valves and each of the first tank ports comprises its mass flow valve and one of the connection valves. This gives the advantage that the third distribution network can be supplied with gas even in the case that one of the connection valves is blocked. Another advantage is that the mass flow valve of the tank port and a connection valve may be integrated into one component of the tank port, e.g., a bottle head, which reduces maintenance and costs.

[0049] It is an embodiment that the connection valve also acts a pressure reduction valve / stage. In an embodiment, the connection valve may be controlled to adjust the pressure reduction between the first distribution network and the third distribution network.

[0050] It is an embodiment that the first distribution network is connected to the third distribution network via exactly one connection valve. Advantageously, this allows for a particularly simple interconnection.

[0051] Generally, the third distribution network may also be connected to the second distribution network, e.g., by at least one valve. However, not providing such a connection may save weight.

[0052] It is an embodiment that the first distribution network comprises a first refilling port and the second distribution network comprises a second refilling port. Having respective refilling ports for the first and second distribution networks advantageously facilitates operation by being able to monitor and adjust the flow rate in /into each distribution network independently. Also, downtime is reduced by being able to refill all storage tanks even if at least one refilling port is inoperable. An open inter-network valve advantageously enables equilibrating the mass flow rates to the tank ports during refilling and/or equilibrating the pressure in the first and second distribution networks. A closed inter-network valve may, on the other hand, advantageously enable maintaining different mass flow rates and/or different pressures to the first tank ports and second tank ports, respectively, during refilling, if so desired. For example, a filling station may adapt the mass flow rate at each refilling port and the closed inter-network valve prevents the natural tendency of pressure to equilibrate.

[0053] It is an embodiment at least one refilling port comprises multiple refilling valves. This advantageously improves the redundancy and the availability of the re-

filling system. If one of the refilling valves is clogged, the other refilling valve(s) are still able to supply fluid to the respective distribution network.

[0054] The refilling valves may be non-return valves, i.e., in their normal state prevent gas from leaving the respective network. In an embodiment, they may be specially operated to release gas from the respective distribution network.

[0055] The mass flow rate through the refilling valves depends on the chosen supply pressure and its valve flow coefficient value, CV. A high mass flow rate in the distribution network is hard to achieve due to the significant pressure drop/loss in the distribution network. The use of multiple refilling valves advantageously circumvents this problem. The single refilling valves may have a lower mass flow rate but used in combination can achieve the required mass flow rate in the distribution network with less pressure drop/loss than a single refilling valve which, in turn, reduces refilling time and saves energy.

[0056] The above-described features and advantages of the invention as well as their kind of implementation will now be schematically described in more detail by at least one embodiment in the context of one or more figures.

- Fig.1 shows a conventional gas bottle;
- Fig.2 shows a fluid storage tank in form of a gas bottle according to the invention;
- Fig.3 shows a wing of an aircraft in a first variant comprising multiple fluid storage tanks according to the invention and first to third fluid distribution networks;
- Fig.4A shows a side view of a refilling nozzle;
- Fig.4B shows a front view of a refilling nozzle;
- Fig.5 shows a wing of an aircraft in a second variant comprising multiple fluid storage tanks according to the invention and first to third fluid distribution networks;
- Fig.6 shows a wing of an aircraft in a third variant comprising multiple fluid storage tanks according to the invention and first and second fluid distribution networks.

[0057] Fig.2 shows a sketch of a fluid storage tank in form of a gas bottle 1 comprising a cylindrical rigid storage compartment 2 made of a composite core for storing pressured fluid. Its inner surface is covered by a liner 3. The gas bottle 1 has a design similar to the gas bottle 101 but now has a first connection tube 4-1 at a first end of the storage compartment 2 and a second connection tube 4-2 at a second end of the storage compartment 2. Each connection tube 4-1, 4-2 may have a reducer (not shown) and a shut-off cock (not shown). Onto the first connection tube 4-1 is attached a first bottle-head 6-1 while onto the second connection tube 4-2 is attached a second bottle-head 6-2.

[0058] Each bottle head 6-1, 6-2 comprises a remotely,

in particular electrically, controllable adjustable mass flow valve 7 which may also act as a pressure reduction stage.

[0059] Each bottle head 6-1, 6-2 further comprises a Thermal Pressure Relief Device, TPRD, comprising a temperature sensor (not shown).

[0060] The first connection tube 4-1 and the first bottle-head 6-1 may be components of a first tank port 8-1, while the second connection tube 4-2 and the second bottle-head 6-2 may be components of a second tank port 8-2.

[0061] When simultaneous filling the storage compartment with hydrogen gas as the fluid F through the tank ports 8-1, 8-2 or through the connection tubes 4-1, 4-2, the injected hydrogen gas flows collide with each other in the storage compartment 2, creating a turbulent flow mostly in a mixing zone 9 which, if the mass flow rates are equal, is located in the middle of the storage compartment 2 in equal distance from the connection tubes 4-1, 4-2. In the mixing zone 9, the kinetic energy of the colliding hydrogen molecules is transformed into heat.

[0062] Fig.3 shows a sketch of a wing W1 of an aircraft A comprising multiple fluid storage tanks, e.g., the storage tanks 1. The storage tanks 1 may be detachable from the wing W1 or may be fixedly attached.

[0063] The first tank ports 8-1 of the storage tanks 1 are connected to a common first fluid distribution network 10-1, e.g., a pipe network, which comprises a first refilling port 11-1. The second tank ports 8-2 of the storage tanks 1 are connected to a common second fluid distribution network 10-2, e.g., a pipe network, which comprises a second refilling port 11-2. The distribution networks 10-1 and 10-2 are connected via a remotely controllable inter-network valve 12.

[0064] The first fluid distribution network 10-1 is connected via multiple connection valves 13 with a third fluid distribution network 14. The connection valves 13 may also act as pressure reduction devices / stages.

[0065] The third fluid distribution network 14 feeds several electro-chemical converters, ECCs 15, e.g., to convert the hydrogen to electric energy. The electric energy may be used, e.g., to power electric propulsion motors (not shown).

[0066] As indicated by the dotted square shown at the leftmost storage tank 1, the first tank ports 8-1 may comprise its mass flow valve 7 and one of the connection valves 13 in its adapter / bottle head 6-1.

[0067] For refilling, the storage tanks 1, refilling guns 16 (see Fig.4A and Fig.4B) of a filling station or such may be connected to the refilling ports 11-1, 11-2. During refilling, the inter-network valve 12 may be open to allow an even pressure distribution over the first and second distribution networks 10-1, 10-2 and thus equal mass flow rates at the tank ports 8-1 and 8-2. Alternatively, inter-network valve 12 may be closed to allow different pressure levels between the first and second distribution networks 10-1, 10-2 and thus different mass flow rates at the tank ports 8-1 and 8-2, respectively.

[0068] While it is possible that the refilling ports 11-1, 11-2 each have one refilling valve, and the refilling gun 16 accordingly has one refilling nozzle, it is advantageous that the refilling ports 11-1, 11-2 each have multiple refilling valves (not shown), and the refilling gun 16 accordingly has the same number of refilling nozzles 17.

[0069] Fig.4A shows a side view of a sketch of a refilling gun 16 having two refilling nozzles 17 that are connected to respective fluid supply lines 18. Fig.4B shows a front view of the refilling gun 16. Alternatively, the refilling gun 16 may have only one supply line and a fluid distribution head (not shown) between the supply line and the refilling nozzles 17.

[0070] Fig.5 shows a wing W2 of an aircraft A comprising multiple fluid storage tanks 1. The wing W2 has a design similar to wing W1 with the exception that one connection valve 13 is used instead of multiple connection valves 13. Consequently, the single connection valve 13 may not be part of a bottle head 8-1.

[0071] Fig.6 shows a wing W3 of an aircraft A comprising multiple fluid storage tanks 1. The wing W3 has a design similar to wings W1 and W2 but does not have a dedicated third distribution network. Rather, the ECCs 15 are directly connected to the first distribution network 10-1.

[0072] To advantageously shut-off the ECCs 15 from fluid supply, they optionally may each (alternatively, in groups, not shown) comprise or being connected to a valve ("supply valve") 19. The supply valve 19 may be a shut-off valve or, advantageously, a mass flow rate valve. The supply valve 19 may be remotely controllable by the aircraft A.

[0073] In an embodiment, pairs of one mass flow valve 7 and one supply valves 9 may be parts of respective bottle heads 8-1, similar to wing W1, as indicated by the dotted square.

[0074] Several operational scenarios of the wings are now explained in an exemplary manner referring to wing W1 of Fig.3. However, the other wings W2 and W3 may be operated in a similar manner.

Scenario 1

[0075] Scenario 1 relates to filling the storage tanks 1 with equal mass flow rates through both refilling ports 11-1 and 11-2. To achieve this, the mass flow valves 7 of the first tank ports 8-1 and the second tank ports 8-2 are open (e.g., maximally), and the refilling ports 11-1 and 11-2 are open and connected to respective filling guns 16. Furthermore, the inter-network valve 12 is open, and the connection valves 13 may be closed.

[0076] For (re)filling, pressurized gas, in particular hydrogen, is introduced into the distribution networks 10-1 and 10-2, respectively, through the filling guns 16 and connected refilling ports 11-1 and 11-2. Because of the inter-network valve 12, pressure between the first and second distribution networks 10-1, 10-2 equalizes such that basically the same fluid pressure is applied to the

first and second tank ports 8-1, 8-2 of the respective storage tanks 1. Thus, hydrogen should flow into the storage tanks 1 simultaneously from both tank ports 8-1 and 8-2, creating a mixing zone 9 in the middle of the storage compartment 2, as depicted schematically in Fig.2.

[0077] When the storage tanks 1 are full, the first and second tank ports 8-1, 8-2 are being closed, and fluid remaining in the distribution networks 10-1 and 10-2 may be released.

Scenario 2

[0078] Scenario 2 relates to the case that the storage tanks 1 are not being filled with equal mass flow rates through both end even if the pressure at the refilling ports 11-1 and 11-2 is the same. This might happen if, e.g., the measured pressure has a significant measurement error, the valves do not behave equally, etc.

[0079] Scenario 2 also relates to the case that levels of the pressure and/or mass flow rate of the first and second distribution networks 10-1 and 10-2, and thus at the first and second tank ports 8-1 and 8-2, respectively, may be specifically set to different values, e.g., to shift the position of the mixing zone in the storage compartment 2.

[0080] In both cases, the pressure and/or mass flow rate of the first and second distribution networks 10-1 and 10-2 may be specifically set to different levels. To be able to do so, the inter-network valve 12 should be closed.

[0081] If the fluid distribution system is equipped with connection valves 13 and/or supply valves 19, these valves may stay closed during (re)filling.

Scenario 3

[0082] In one scenario for operation of the aircraft A (e.g., a flight), only the first distribution network 10-1 is used to supply the ECCs 15 with fluid F under normal conditions, i.e., without faulty components. The fluid F from the storage tanks 1 is released through the first tank ports 8-1 into the first distribution network 10-1. From there, the fluid F flows through the connection valves 13 into the third distribution network 14, and from there to the ECCs 15, through the supply valves 19, if present. The second distribution network 10-2 is not used which is achieved by the second tank ports 8-2 and inter-network valve 12 being closed.

[0083] Alternatively, the second distribution network 10-2 may be used during normal operation, in which case the second tank ports 8-2 and inter-network valve 12 are open.

Scenario 4

[0084] This scenario covers failure of one or more ECCs 15. When this happens, the fluid F from all storage tanks 1 is still used to supply the remaining ECCs 15.

This is particularly advantageous when compared to a design in which the ECCs 15 are only connected to respective storage tanks 1 without first and/or third distribution networks 10-1, 14. Fluid supply to a faulty ECC 15 may be shut off by closing a respective supply valve 19, if present.

Scenario 5

[0085] This scenario covers failure of one or more mass flow valves 7 of first tank ports 8-1 or any other fault in which the fluid connection between one or more storage tanks 1 and the first distribution network 10-1 is blocked or disrupted. In this case, the mass flow valves 7 of the second tank ports 8-2 of the faulty storage tanks 1 are opened, as well as the inter-network valve 12. Thus, fluid F of a storage tank 1 having a blocked passage to the first distribution network 10-2 is released into the second distribution network 10-2 and flows from there through the inter-network valve 12 to the first distribution network 10-1. The storage tanks 1 having tank ports 8-1, 8-2 at both ends thus advantageously enable using their fluid storage to supply ECCs 15 even in case that one of the tank ports 8-1, 8-2 is blocked. This, in turn, greatly improves flight safety, in particular for aircraft having electric propulsion.

Scenario 6

[0086] This scenario covers that one or more storage tanks 1 runs empty prematurely. Then, its / their tank ports 8-1 and 8-2 may be simply shut off / closed without affecting the operation of the ECCs 15.

[0087] As indicated above, the described scenarios can be adapted in analogy to the other fluid distribution designs using two-port storage tanks 1, e.g., as described for wings W2 and W3.

[0088] Of course, the invention is not restricted to the described embodiments.

[0089] For example, the supply valves 19 may also be present in the wings W1 and W2.

List of Reference Signs

[0090]

1	gas bottle
2	storage compartment
3	liner
4-1	first connection tube
4-2	second connection tube
6-1	first bottle head
6-2	second bottle head
7	mass flow valve
8-1	first tank port
8-2	second tank port
9	mixing zone
10-1	first fluid distribution network

10-2	second fluid distribution network
11-1	first refilling port
11-2	second refilling port
12	inter-network valve
5 13	connection valve
14	third fluid distribution network
15	electrochemical converter
16	refilling gun
17	refilling nozzle
10 18	fluid supply line
19	supply valve
102	storage compartment
103	liner
104	connection tube
15 105	reducer
106	bottle head
107	mass flow valve
A	aircraft
F	fluid
20 W1	wing of the aircraft
W2	wing of the aircraft
W3	wing of the aircraft

25 Claims

1. A fluid storage tank (1), comprising an elongated rigid storage compartment (2) for storing fluid (F), having a first tank port (8-1) at a first end and a second tank port (8-2) at a second end.
2. The fluid storage tank (1) according to claim 1, wherein the storage compartment (2) is equipped with a first temperature sensor positioned in the vicinity of a first end section of the storage compartment (2) and a second temperature sensor positioned in the vicinity of a second end section of the storage compartment (2).
3. The fluid storage tank according to any of the preceding claims, wherein each of the tank ports (8-1, 8-2) comprises a remotely controllable valve (7), particularly mass flow valve.
4. A method for filling a fluid storage tank (1) according to any of the preceding claims, wherein the fluid storage tank (1) is simultaneously filled with fluid (F) through both tank ports (8-1, 8-2).
5. The method according to claim 4, wherein the fluid (F) is filled through both tank ports (8-1, 8-2) at an equal mass flow rate.
6. An aircraft (A), comprising multiple fluid storage tanks (1) according to any of the claims 1 to 3, wherein
 - their first tank ports (8-1) are interconnected

- by a first fluid distribution network (10-1) and their second tank ports (8-2) are interconnected by a second fluid distribution network (10-2),
 - each distribution network (10-1, 10-2) comprises at least one refilling port (11-1, 11-2) for the fluid (F), and
 - the first and second distribution networks (10-1, 10-2) are interconnected via at least one remotely controllable inter-network valve (12). 5
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7. The aircraft (A) according to claim 6, wherein the first distribution network (10-1) is connected to a third fluid distribution network (14) via at least one remotely controllable connection valve (13), and at least one electro-chemical converter (15) is connected to the third distribution network (14). 15
8. The aircraft (A) according to claim 7, wherein
- the first distribution network (10-1) is connected to the third fluid distribution network (14) via multiple connection valves (13) and
 - each of the first tank ports (8-1) comprises its mass flow valve (7) and one of the connection valves (13). 20 25
9. The aircraft (A) according to any of the claims 6 to 8, wherein the at least one electro-chemical converter (15) is adapted to provide electric energy to power at least one electric propulsion motor when supplied with the fluid (F). 30
10. The aircraft (A) according to any of the claims 6 to 9, wherein the fluid storage tanks (1) are individually removable from the aircraft (A). 35
11. The aircraft (A) according to any of the claims 6 to 10, wherein the first distribution network (10-1) comprises a first refilling port (11-1) and the second distribution network (10-2) comprises a second refilling port (11-2). 40
12. The aircraft (A) according to claim 11, wherein at least one of the refilling ports (11-1, 11-2) comprises multiple refilling valves. 45

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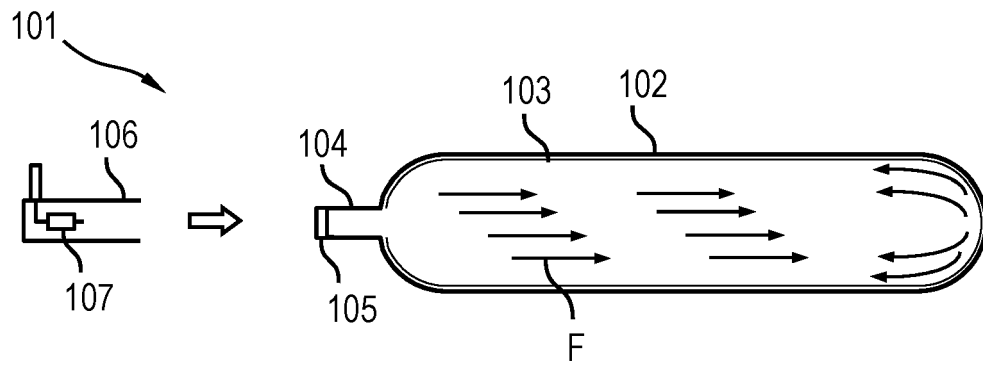


Fig.1

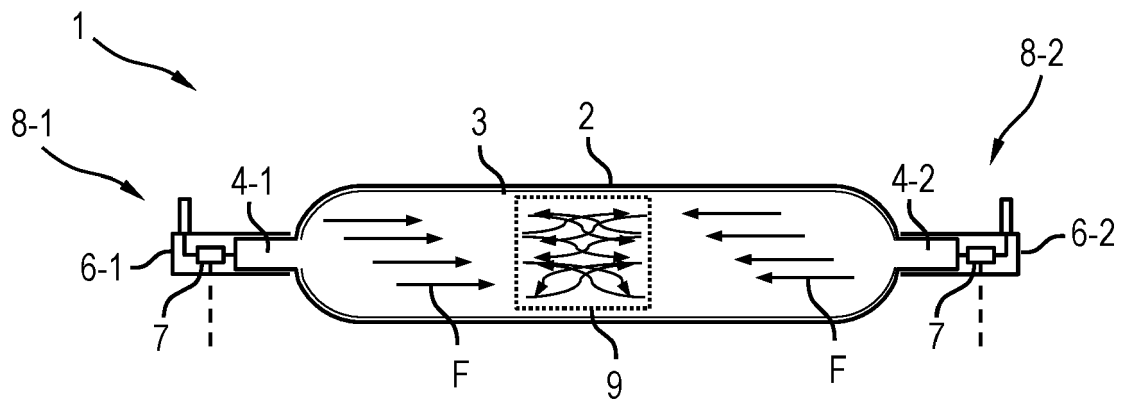


Fig.2

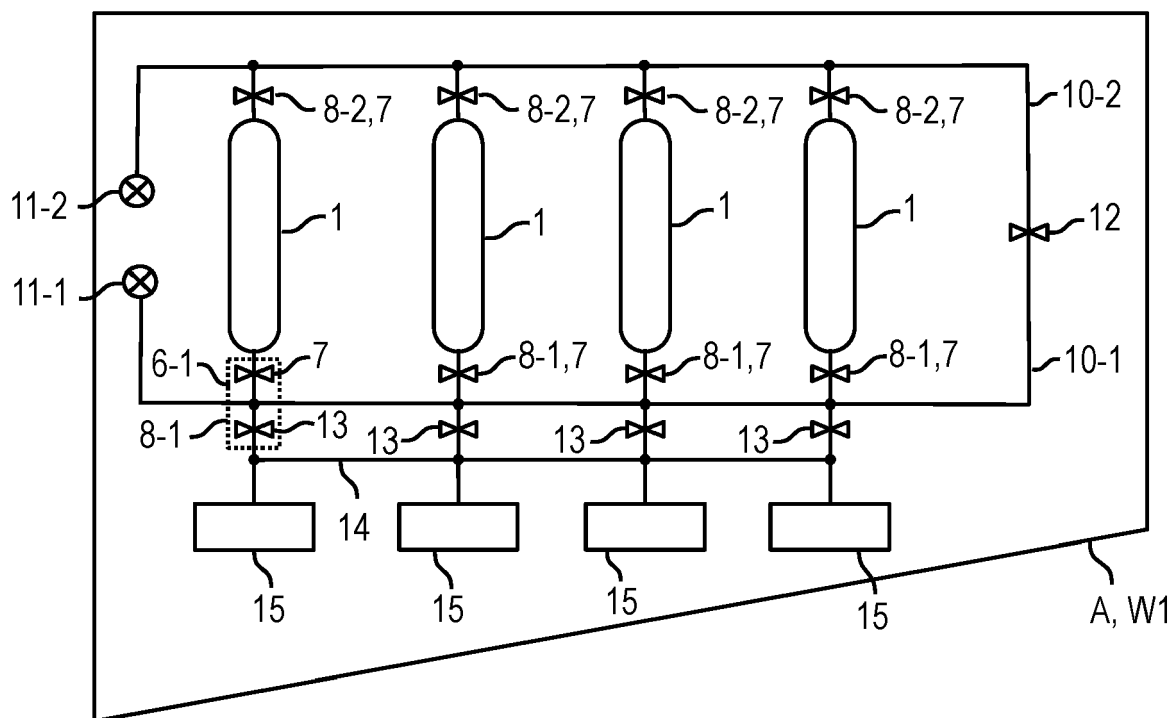


Fig.3

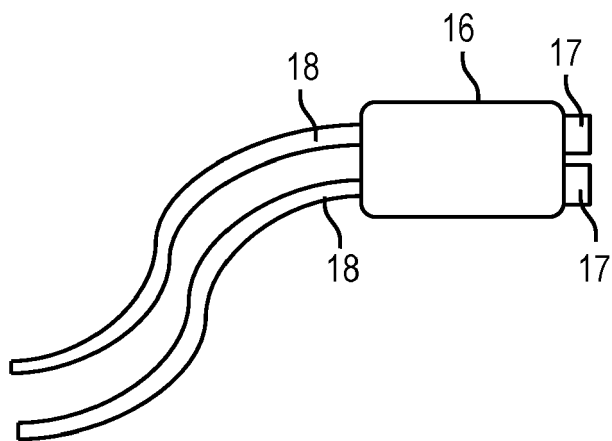


Fig.4A

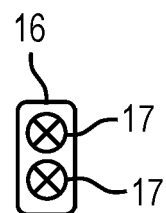


Fig.4B

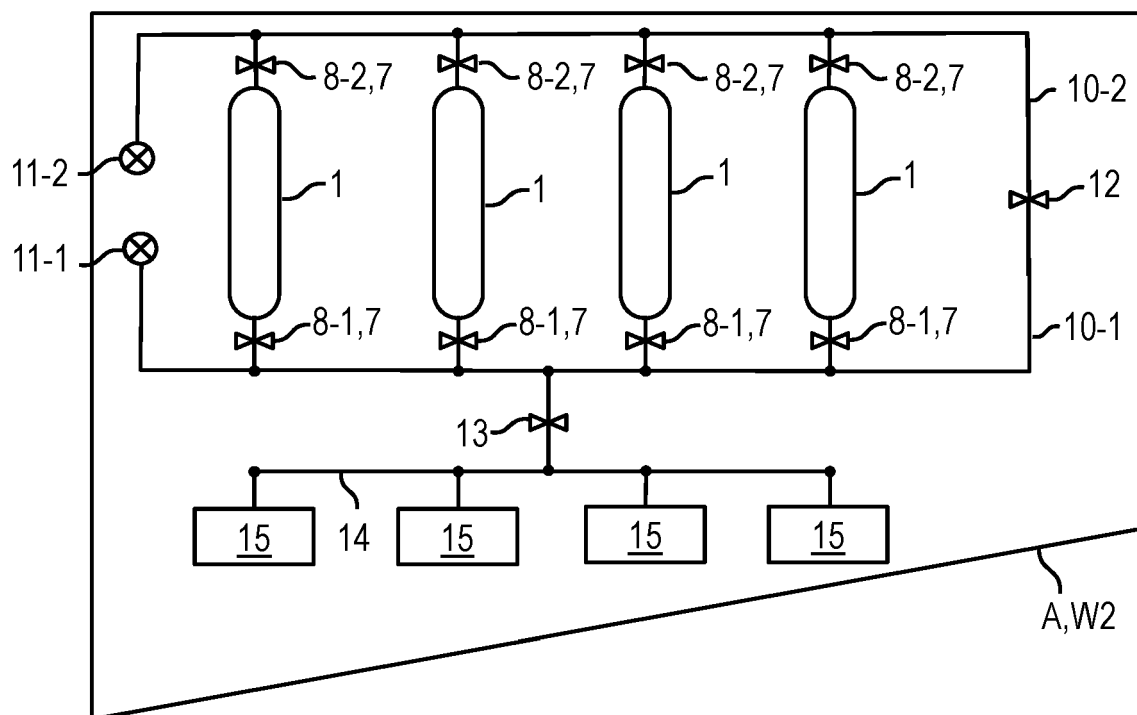


Fig.5

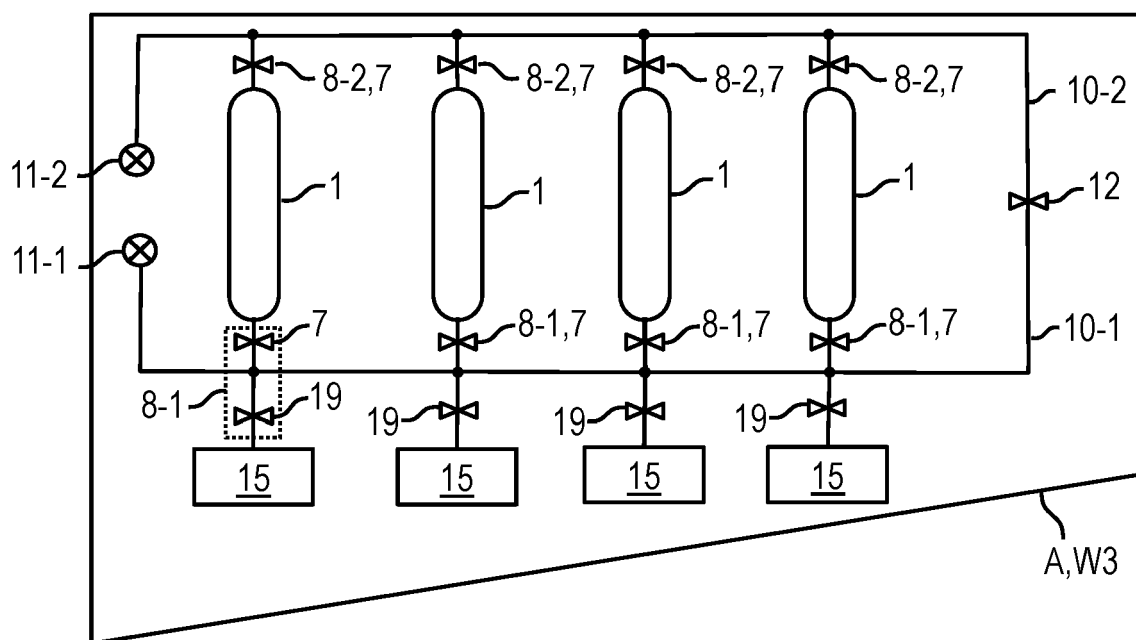


Fig.6



EUROPEAN SEARCH REPORT

Application Number
EP 21 16 7243

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Place of search Munich		Date of completion of the search 9 September 2021	Examiner Forsberg, Peter
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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