Abstract: A buoyancy control system for a machine (10) which is submerged during normal operation, the system comprising an attachment (25) for releasably attaching the machine (10) to a fixed structure (24) below the surface of a body of water in use. The machine is provided with a rigid vessel (30) is arranged to maintain gas under pressure and a further vessel (32) of variable internal volume. A valve arrangement (38, 40) controls fluid communication between the rigid vessel (30) and the further vessel (32), the valve arrangement being selectively operable at a depth below the surface of the water to allow fluid communication between the rigid and the further vessel such that the volume of the further vessel is variable under the action of the surrounding water pressure.

Declarations under Rule 4.17:
— as to the identity of the inventor (Rule 4.17(i))
— as to applicant’s entitlement to apply for and be granted a patent (Rule 4.17(H))

Published:
— without international search report and to be republished upon receipt of that report (Rule 48.2(g))
Machine Buoyancy Control

This invention relates to buoyancy control apparatus for submersible machinery and more particularly, although not exclusively, to turbines for use in tidal power generation applications.

A broad variety of underwater machinery comprises one or more rotors mounted to a support structure. Control of buoyancy is important in many such applications to ensure a desired operation depth can be reliably achieved.

Conventional buoyancy control systems require active regulation or control of gas pressure within one or more vessels. Within submarines, for example, air and water are typically pumped between ballast tanks to control buoyancy and stability. In addition, it is well known to regulate applied pressure to inflate and/or deflate rigid or flexible chambers of buoyancy control devices with variations depth in order to maintain neutral buoyancy.

A majority of such applications have in common that the buoyancy of the machinery is actively regulated in order to allow controlled motion of a vessel or other equipment underwater. Underwater turbines or pumps typically differ from such applications in that they are often fixed or anchored to a fixed location such that they are substantially stationary during normal operation so as to provide for movement of fluid relative thereto. However it is necessary to raise such fixtures to the surface of a body of water intermittently for maintenance, inspection or other reasons.

UK Patent Application Publication GB 2 431 628 discloses a tidal turbine having a positively buoyant nacelle. In order to deploy the turbine underwater, the turbine is first tethered to a fixed underwater structure and then winched down to the structure, to which it is secured for operation. When maintenance is required, the turbine is released from the fixed structure and it floats to the surface under the positive buoyancy of the nacelle.

The buoyancy required to maintain the turbine at a suitable ride height at the water surface for maintenance is significant. Such a turbine structure provides a relatively strong upward force due to the nacelle buoyancy even when mounted to the fixed structure. This upward force causes a risk of detachment during normal operation of the turbine and so safeguards must be put in place to mitigate
this risk. It is generally undesirable that a buoyancy mechanism which is only intermittently required causes an ongoing operational risk.

Furthermore, upon release, the constant buoyancy force caused by the nacelle can lead to a significant upward acceleration of the turbine structure, which is controlled using the tether. The loading of the system in this manner causes strain on the turbine and fixed submerged structure and presents a significant safety risk in the event that the tether were to become detached. Steps are thus required to mitigate such risks by providing safety features and/or by strengthening the turbine, fixed structure and tethering system, all of which add cost and weight to the system.

The acceleration which is made possible by the nacelle buoyancy can cause significant hydrodynamic loading which can jeopardise the operational integrity of components such as the casings and seals. In addition, the stability of the structure when buoyant may be difficult to control.

For the above reasons, it may be desirable to reduce the buoyancy force caused by the nacelle. However such measures would result in a reduced ride height of the structure when buoyant and may thus reduce the accessibility of the turbine for maintenance. The practical considerations for such a system thus result in a trade-off between structural safety, including complexity and weight of the structure, and accessibility for maintenance, the outcome of which is less than ideal.

It is an aim of the present invention to provide a machine buoyancy control system for which the above problems are mitigated or avoided.

According to the present invention there is provided a buoyancy control system for a machine which is submerged during normal operation, the system comprising: an attachment for releasably attaching the machine to a fixed structure below the surface of a body of water in use; a rigid vessel arranged to maintain gas under pressure; a deformable vessel arranged to allow selective inflation thereof; and, a valve arrangement controlling fluid communication between the rigid and deformable vessels, the valve arrangement being selectively operable at a depth below the surface of the water to allow controlled fluid communication between the rigid and deformable vessels under the action of the surrounding water pressure.
The present invention is applicable to any machinery which is intended to operate underwater during normal operation but which may intermittently or periodically need to be raised to the surface, for example, for maintenance work or the like. The present invention is particularly suited to machinery which is intended to operate for extended periods of time underwater in a fixed location or generally constrained area, such as power generation turbines. However the present invention may nominally be applied to any machinery which is intended to operate underwater in a primary mode of operation, in which the machinery is driven by - or drives - the water and wherein the buoyancy control according to the present invention is intended to be deployed when the primary mode of operation is disabled or otherwise inoperative.

The volume of the deformable vessel is typically minimal at greatest depth or else at an operational depth of the machine. Thus the deformable vessel may advantageously be unobtrusive at an operational depth below the water surface and may have negligible impact on the hydrodynamics of the machine.

The system may be considered to operate in a passive manner, such that the flow of gas between the rigid and inflatable vessels is regulated by the surrounding or external fluid pressure and the degree to which the valve arrangement is open. Such a system may negate the need for additional pressurising equipment for actively controlling gas pressure onboard the machine.

The rigid and one or more deformable vessels may define an internal pressurised system which is sealed from external fluid during use. Any or any combination of the rigid vessel, the deformable vessel and/or internal system is typically maintained at a pressure greater than the ambient pressure in the vicinity of the machine.

The shape and/or volume change of the deformable vessel may be driven by external fluid pressure. This may be achieved in combination with the internal pressure applied thereto by control of the open or closed condition of the valve arrangement.

In one embodiment, the valve arrangement comprises a first valve which is selectively operable between open and closed positions. The degree to which the first valve is open may be selectable. In one embodiment, the first valve has a plurality of open conditions representing so as to provide for a variable flow
restriction between the rigid and deformable vessels. The first valve may comprise actuation means arranged to actuate the valve between open and closed positions. The actuation means is preferably driven and may be powered by an power source such as an electrical energy store, which may be located on the machine.

According to one embodiment the valve arrangement comprises a second valve, which may take for form of a one-way or non-return valve. The second valve may be operable to open at a predetermined threshold pressure difference between the rigid and inflatable vessels. The second valve may allow for flow of gas from the inflatable vessel to the rigid vessel. The second valve may allow for flow into the rigid vessel upon submerging of the machine due to increasing external pressure with depth underwater.

The system may comprise a plurality of deformable vessels. Each deformable vessel may be independently in selective fluid communication with the rigid vessel via an associated valve arrangement. The plurality of deformable vessels may be arranged in a plurality of sets. A first - or first set - of the deformable vessels may be arranged for fluid communication with the rigid vessel via a first valve arrangement and a second - or second set - of the deformable vessels may be arranged for fluid communication with the rigid vessel via a second valve arrangement. The first and second valve arrangements may be independently operable. The first valve arrangement may be selectively openable prior to the second valve arrangement upon raising of the machine from its operational depth in order to control the orientation of the machine during ascent. Each valve arrangement may comprise a non-return valve. The non-return valve of the first valve arrangement may be set to open at a predetermined pressure differential which is different from that of the non-return valve of the second valve arrangement. This may assist in controlling the orientation of the machine during descent.

The inflatable vessels could communicate with none, any or all of the other volumes in the tidal turbine structure.

The attachment may comprise a releasable mechanical coupling, clamping means or the like.
Practicable embodiments of the present invention are described in further detail by way of example with reference to the accompanying drawings of which:

Figure 1 shows the main components of a tidal turbine arrangement according to the present invention;

Figure 2 shows a schematic section view through a buoyancy control arrangement according to the present invention;

Figures 3A and 3B show a schematic plan and end views through respective longitudinal and cross sections of a buoyancy control arrangement for a tidal turbine according to the present invention in a deployed condition;

Figure 4 shows a schematic plot of changes in pressure with depth; and,

Figure 5 shows a schematic plot of changes in internal volume during submerging and surfacing operations.

The invention provides for a passive buoyancy control system for machinery having an operational regime that involves changes in immersion depth, such as a tidal turbine.

Figure 1 illustrates the main components of one such tidal turbine. The machine of figure 1 generally comprises a turbine rotor assembly 12 having a plurality of rotor blades 14. The turbine rotor assembly 12 is mounted on a shaft 16 for communicating torque to a generator 18, which generally comprises rotor and stator portions (not shown) for generation of electricity in a conventional manner, as will be understood by a person skilled in the art.

The rotor shaft 16 is connected to the generator rotor by a gearing arrangement in the form of a gearbox 20. The gearbox 20 allows the rotational output of the turbine rotor 12 to be modified to rotational speeds which favour suitable generation of a potential difference in the generator. The gearbox may comprise a variable ration gearing to accommodate a range of rotor 12 operational speeds.

The rotor assembly 12 is mounted relative to a nacelle 22 such that the rotor 12 and nacelle form a common assembly structure. The gearbox 20 and generator 18 are mounted within the nacelle 22, which serves as a housing therefore.

The nacelle 22 has one or more attachment formations allowing attachment to a rigid support structure 24 when the turbine is deployed for use. The nacelle
22 and support 24 typically comprise corresponding attachment formations in the form of a releasable coupling, which is shown generally as a clamp formation 25 in figure 1. Any such coupling which allows semi-permanent latching of the turbine nacelle to the support for an extended duration of usage, whilst providing for subsequent release and re-attachment may be suitable for this purpose. Typically a mechanical latching or locking mechanism. In other embodiments, the turbine structure may be tethered to one or more supports 24 using suitable tethering lines, which are releasably attached there-between. In such embodiments, the turbine structure may have a limited or constrained freedom of movement in use relative to the or each support structure.

The support structure is seated on the bed 26 of the body of water, which - in this embodiment - comprises the sea bed. A base structure may be provided for the support 24 in a conventional manner to ensure it remains reliably embedded in, or fixed to, the sea bed.

Turning now to figure 2, there is shown a schematic of a vessel structure 28 used in the control of the buoyancy of the turbine-and-nacelle assembly. The arrangement of figure 2 generally comprises a rigid tank 30 and a flexible membrane 32 appended thereto. The flexible membrane forms a further vessel of varying size, dependent on the balance between internal and external pressure. The rigid tank and flexible membrane are connected in a gas-tight sealed arrangement so as to form a combined gas-containing structure.

The internal volume of the rigid tank 30 is defined by a rigid wall structure 34 and is filled with gas. In this embodiment, the rigid tank is formed within the nacelle and may comprise an internal cavity of the nacelle. The shape of the rigid tank 30 may be dependent on the available space within the nacelle and need not take any particular geometric configuration other than to meet such space requirements. It is possible that the nacelle wall defines the outer wall of the rigid tank 30 such that the nacelle itself may comprise the tank. Whilst this embodiment is specific to a nacelle structure, it is to be noted that the passive buoyancy control vessel structure described herein may be appended to, or formed within, any alternative form of housing or mounting structure according to the machinery to which it is applied. The principles described herein are equally...
applicable to any other parts of a tidal turbine suitable to sustain the resulting buoyancy forces.

A portion 36 of wall structure 34 separates the internal volume of the rigid tank 30 from that of the flexible membrane 32. First 38 and second 40 valves are arranged between the internal volumes of the rigid 30 and flexible 32 vessels, in this example within the dividing wall portion 36. The first valve 38 is selectively actuable between one or more open conditions and a closed condition by an actuator 42 in order to control flow of gas from the rigid tank 30 to the flexible vessel 32.

The actuator may be controlled to open or close the valve based upon a data signal or other instructions received thereby. Such a signal may be provided from a transmitter operated by a user and would typically require the actuator to be in communication with a receiver located on or within the nacelle 22. A control signal of this type may be transmitted using a wired connection to the user transmitter or else using suitable wireless signal transmission equipment for transmission through water, based for example of radio, acoustic or electromagnetic signals. Alternatively, one or more pressure sensors may provide readings of external and/or internal pressures which may trigger opening or closing of the valve 38 for predetermined pressure scenarios. In one embodiment, the pressure reading may be used to determine the depth of the nacelle and the valve 38 may be actuated according to depth.

Preferably, the system is passive in that valve actuation occurs dependent entirely upon relative pressures in each of the chambers rather than additional actuation means.

The valve 40 comprises a non-return valve which is arranged to open at a predetermined pressure gradient there-across. In this regard the valve closure may be sprung or otherwise biased towards a closed position. The valve 40 is arranged to allow flow from the flexible vessel 32 to the rigid tank 30 only. This allows for deflation of the flexible vessel as will be described below.

Turning to figure 3, there is shown an embodiment in which the nacelle 22 is provided with a plurality of flexible membranes 32A-F depending there-from. This configuration provides one embodiment of the main passive buoyancy elements that could be provided on a tidal turbine in accordance with the
invention. Each flexible vessel may be individually connected to the rigid tank 30 by a dedicated valve arrangement as shown in figure 2. Alternatively, in the embodiment shown, the flexible vessels 32A-F are arranged in sets, each set having a dedicated valve arrangement for communication with the chamber. In a yet further embodiment, a plurality of rigid tanks 30 may be provided, each being connected to a dedicated flexible vessel or set thereof.

The turbine blades 14 are omitted from figure 3 for clarity, which may also have collapsible protective padding attached thereto.

A first set of flexible vessels comprises vessels 32A and 32B which may be considered to represent ascent or superstructure elements. These vessels are located towards the upper edge or surface 44 of the nacelle 22. A maintenance hatch 46 or other access closure is mounted in the upper surface 44. A second set of flexible vessels comprise vessels 32C and 32D which represent buoyancy aids. These are located towards a lower surface 48 or else beneath the nacelle 22. Further vessels 32E and 32F are provided towards the bow 50 and stern 52 of the nacelle 22 respectively and may provide a third set of vessels.

The operation of the buoyancy control system will now be described in relation to the deployment and retrieval of the turbine 10 with reference to figures 4 and 5.

The internal system may first pressurised with gas to a pressure sufficient to generate the buoyancy forces required at predetermined depths to be described below. The predetermined pressure is preferably sufficient to provide the turbine-and-nacelle structure with relatively small positive buoyancy at the desired operational depth. However in the embodiment shown in figure 4, it can be seen that the internal pressure is substantially that of atmospheric pressure. Accordingly the starting pressure may be determined by ambient conditions at the surface of the water prior to deployment.

During initial deployment and subsequent maintenance, the nacelle floats on the surface by virtue of the inflated flexible members 32, in particular the buoyancy members 32C and 32D shown in figure 3B, which are sufficient to maintain the nacelle 22 at an elevated position relative to the water surface 54. In this condition, at least the upper surface 44 and access hatch 46 are above the water surface 54.
The internal air pressure inside the tank 30 and inflated membrane 32 when at the surface 26 of the water is greater than the external ambient pressure (i.e. greater than atmospheric pressure). The internal pressure may be approximately equal to or slightly less than the external pressure at the desired operational depth. The slight difference would account for the positive buoyancy desired at the operational depth to allow subsequent retrieval of the turbine.

In order to deploy the turbine for use, the turbine structure 10 is first forced downwards towards the support structure 24. This may be achieved using winch system 56 shown in figure 3B which is mounted to the turbine 10 and connected to the support structure 24 by cable 28 or other suitable line. The operation of the winch tensions the cable, forcing the turbine to submerge against the positive buoyancy of the inflated vessels 32.

During descent the air in the inflatable vessels 32 is compressed to a smaller volume by external pressure, which increases with depth underwater. On winching below the surface, the sprung non return valves would 'crack' (that is, open against a bias towards a closed condition) at a predetermined pressure, for example after being submerged to a depth of 5-10 metres. The inflatable vessels 32 would thus deflate at a rate determined by the external water pressure acting on the flexible membranes 32 and the size of the valve 40 opening. The valve is thus sized to allow relatively rapid deflation, sufficient to remove the added buoyancy provided by the flexible vessels quickly and provide pressure balance between the external and internal pressure. To this end the pre-loaded non-return valves 40 may have a larger valve orifice than the valve 38.

The valve 40 may also serve to avoid excessive or unwanted deflation during impact with waves or floating objects.

The passive buoyancy control exhibited by the system relies on the expansion or compression of air within the sealed internal vessel structure due changes in depth, which is 1 bar (gauge) per 10m. Thus as the one or more membrane 32 collapses the internal pressure rises in line with the change in external pressure. Any parts of the nacelle that communicate with the internal air experience a pressure equal to that outside the nacelle. In this way, pressure loads on casing and across seals are balanced during descent.
The rigid tank 30 is rigid at least to the extent that it has a fixed volume regardless of depth above or underwater. That is to say that the tank retains its structural integrity for the entire range of operational pressure between the water surface and the operational depth underwater. Thus as the turbine nacelle is lowered to its operational depth for mounting on the support 24, the inflatable membrane 32 achieves a fully deflated condition such that substantially all the air therein has passed through the valve 40 into the rigid tank 30. This represents the minimum volume - and accordingly the maximum pressure - for the air within the buoyancy control system.

If the turbine structure is lowered to a depth greater than that at which complete deflation has occurred, the gas trapped within the rigid tank will provide a positive buoyancy effect. In this manner the internal volume may reach its minimum condition at a depth which is slightly less than the operational depth for the structure. For example the minimum volume may be achieved between 0 and 10m depth above the operational depth. In an alternative embodiment this may represent a depth somewhere between 80 and 100% operational depth, and more typically at a depth between 90 and 100% operational depth. Thus a small positive buoyancy force can be retained to ease raising of the turbine structure, without placing excessive strain on the support 24 during normal turbine operation.

The turbine-and-nacelle structure is lowered into engagement with the support 24 such that it is clamped or otherwise attached thereto for operation as shown in figure 1.

When it is subsequently required to raise the turbine to the surface, the nacelle 22 is released from the support structure 24 by operation of a release mechanism. Upon release, for safety a rate of ascent of typically under 0.25m/s may be chosen. In 30m depth, this would give a total ascent time of around 2 minutes (depending on the height of the nacelle support).

Shortly after release, upon ascent of the turbine, the vessels 32A and 32B are allowed to inflate by opening of valve 38 by actuator 42. The rate of inflation is controlled by control of the degree to which the valve is opened. Ideally, inflation of the vessels 32A and 32B commences within the first 30 - 60 seconds.
of ascent or less to ensure the nacelle is maintained in an upright attitude during ascent.

Inflation of the buoyancy vessels 32C and 32D is retarded relative to the vessels 32A and 32B. This may be achieved by delaying onset of inflation of the buoyancy vessels or else by controlling one or more valves 42 to restrict flow of gas into the buoyancy vessels to a greater degree than into vessels 32A and 32B. For example the valves for the buoyancy vessels may be opened to a lesser degree than the valves associated with vessels 32A and 32B. The buoyancy vessels 32 may also provide streamlining and stability during ascent. A controlled ascent of this type may take up to 5 minutes or longer dependent on depth.

As the nacelle approaches the surface, the buoyancy vessels 32C and 32D achieve maximum volume so as to raise the upper portion 44 of the nacelle above the water surface 54 so as to allow access thereto. The degree to which the restriction valves 40 open may increase with proximity to the water surface to increase inflation thereof as required.

The flexible membrane 32 displays elastic properties and may comprise a flexible skin to the nacelle outer surface or else a bag or balloon-like arrangement which may be attached about surface 38 and 40. The flexible skin may provide a degree of corrosion protection for the nacelle and may follow a streamlined shape of the nacelle when deflated. A bag or balloon arrangement may be stowed within the nacelle during normal operation to avoid interference with the hydrodynamics of the nacelle.

Optionally electric power may be generated by small turbines located in the air streams passing through the valves between chambers, which could charge an energy store such as a battery or capacitor on board the turbine to provide a power source.

The embodiments described above can reduce the hydrodynamic load on the casings and seals, enhancing operational integrity and leakage prevention, when compared to the prior art. The upwards force on the nacelle and support structure can also be reduced, thereby decreasing the risk of detachment. The proposed buoyancy control system may also enhance any or any combination of buoyancy, stability, seaworthiness and/or streamlining. The inflated vessels may also provide cushioning protection (for personnel and equipment) to improve
safety and ease maintenance access. The passive nature of the buoyancy control system can reduce cost, weight and complexity compared to active pumped systems and reduces reliability problems, for example associated with 'dormant' failure of any little-used hardware or exposure to seawater.

In alternative embodiments, the combined volume of the rigid tank and collapsible vessels could be set at ambient, positive or negative gauge pressure when on the surface. An ambient internal pressure at the surface may provide a benefit in that it avoids any potential safety risks associated with a pressurised vessel. The collapsible members could be wholly or partly filled with resilient foam, to ensure a more precise or rigid shape when inflated, and / or to accelerate inflation. Various features could be incorporated to prescribe the collapsed shape of the flexible members, such as 'concertina' folds, more rigid formers or thin hoops for stiffening. The rigid parts of the system could additionally or alternatively be provided with pistons and springs to adjust rates of inflation or deflation.

An alternative embodiment could use any fewer number of the passive variable buoyancy features described. These could be combined with other active features. The shapes of the chambers could be modified from those drawn.

In embodiments of the invention, the passive nature of the system makes use of the external pressure at varying depth to favourably control pressure differentiation between rigid and deformable chambers. Thus active or passive valve control schemes may equally be considered to fall within the scope of such a passive system.

In a further development, some or all flexible membranes may be removed in favour of a vessel which is open to the surrounding water. The volume of air is trapped inside such a vessel within the nacelle would accordingly undergo volume change according to the movable water surface by virtue of the pressure applied thereto. Accordingly the vessel itself would not change in shape but rather the volume of air therein and the degree to which the vessel is filled with water. At depth the air would be compressed to a smaller volume, reducing buoyancy as described above.

Whilst the invention is described as a buoyancy control system for machinery which is typically fixed underwater during normal operation, it may also
be applied to vehicles, including as submarines of all types, such as Remotely Operated Vehicles (ROVs). In particular the present invention may provide for a reserve or backup buoyancy control system in the event that the vehicle propulsion becomes disabled.
CLAIMS

1. A buoyancy control system for a machine which is submerged during normal operation, the system comprising:
   an attachment for releasably attaching the machine to a fixed structure below the surface of a body of water in use;
   a rigid vessel arranged to maintain gas under pressure;
   a further vessel of variable internal volume; and,
   a valve arrangement controlling fluid communication between the rigid vessel and the further vessel, the valve arrangement being selectively operable at a depth below the surface of the water to allow fluid communication between the rigid and the further vessel such that the volume of the further vessel is variable under the action of the surrounding water pressure.

2. A buoyancy control system according to claim 1, wherein the further vessel comprises a deformable vessel defined at least in part by a flexible membrane.

3. A buoyancy control system according to claim 1 or claim 2, which is devoid of pressurising or pumping equipment for actively controlling gas pressure distribution within the rigid and further vessels.

4. A buoyancy control system according to any preceding claim, wherein the rigid and further vessels define an internal pressurised system which is sealed from external fluid.

5. A buoyancy control system according to claim 4, wherein the internal system is pressurised to a level such that the volume of the further vessel in use is minimal at a depth substantially equal to or else slightly less than an operational depth underwater at which the machine operates.

6. A buoyancy control system according to any preceding claim, wherein the valve arrangement comprises a first valve which is selectively operable between open and closed positions under the control of an actuator or else a pressure differential between the rigid and further vessels.

7. A buoyancy control system according to claim 6, wherein the valve arrangement comprises a second valve being a non-return valve arranged to allow flow selectively from the further vessel into the rigid vessel.
8. A buoyancy control system according to claim 7, wherein the second valve is arranged to maintain a closed condition below a predetermined threshold pressure difference between the further and first vessels and to open upon application of a pressure differential above said threshold pressure difference.

9. A buoyancy control system according to any one of claims 6 to 8, wherein the first valve controls the rate of inflation of the further vessel during ascent of the machine.

10. A buoyancy control system according to any preceding claim, wherein the system comprises a plurality of further vessels, each further vessel having a corresponding valve arrangement to allow selective fluid communication with one or more rigid vessels.

11. A buoyancy control system according to claim 10, wherein the plurality of further vessels are arranged in a plurality of sets, each set being arranged for selective fluid communication with one or more rigid vessels via a corresponding valve arrangement independently of another set.

12. A buoyancy control system according to claim 10 or 11, wherein the plurality of further vessels or sets thereof are operable in a staggered fashion so as to maintain a desired orientation of the machine during ascent and/or descent.

13. A buoyancy control system according to any preceding claim, wherein the attachment comprises a releasable clamping mechanism.

14. A turbine or pump assembly comprising a buoyancy control system according to any one of claims 1 to 13.

15. A turbine assembly according to claim 14, comprising a nacelle wherein the rigid vessel is housed within a nacelle.

16. A buoyancy control system substantially as hereinbefore described with reference to the accompanying drawings.
FIG. 5

Surfacing Floats inflate slowly through restrictor

Submerging Floats deflate through 'cracked' non return valve