ENERGY RELEASE BUOYANT ACTUATOR

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ABSTRACT

A buoyant actuator (10) is used in apparatus (11) for harnessing wave energy in a body of water such as the ocean. The buoyant actuator (10) is deployed within the body of water (12) and is responsive to wave motion in the body of water. The buoyant actuator (10) includes a body (101) incorporating a flow path along which water can flow, and a gate means (115) for controlling flow along the flow path. The gate (115) includes closure elements configured as flaps (221) providing a barrier (222) across the flow path through the body (101). Each flap (221) is moveable into and out of a condition in which it cooperates with the other flaps (221) to provide the barrier (222). A latch mechanism (231) is provided for releasably retaining each flap (221) in the condition providing the barrier (222). The latch mechanism (231) has a magnetic coupling.
ENERGY RELEASE BUOYANT ACTUATOR

FIELD OF THE INVENTION

[0001] This invention relates to an energy release buoyant actuator responsive to wave motion, and more particularly to such a buoyant actuator for coupling wave motion to a device operable in response to wave motion. The invention also relates to a wave energy conversion system.

[0002] The invention has been devised particularly, although not necessarily solely, as a buoyant actuator for harnessing wave energy and for converting the harnessed energy to linear motion for driving an energy conversion device such as a fluid pump or a linear electric generator. In such an arrangement, the buoyant actuator may be operably connected to the energy conversion device, the actuator being buoyantly suspended within the body of water, but typically below the water surface. The buoyant actuator is in effect a submerged float which moves in response to wave action within the body of water.

BACKGROUND ART

[0003] The following discussion of the background art is intended to facilitate an understanding of the present invention only. The discussion is not an acknowledgement or admission that any of the material referred to is or was part of the common general knowledge as at the priority date of the application.

[0004] It is known to couple wave motion to a device operable in response to wave motion, one example of which is use of a float to translate wave motion into a reciprocating pump action. Typically such floats are of solid construction and comprise buoyant material such as foam.

[0005] When exposed to an aggressive sea state, typically adverse weather conditions (such as in storm conditions), floats can be subject to extreme forces. Known floats can be prone to damage, collapse or detachment when exposed to such conditions. Further, tethers to which the floats are connected can be damaged or ruptured in such conditions. Also, it may be desired to control the movement of the buoyant actuator so as to limit the pump strokes and the loading on the attached equipment.

[0006] It is against this background and the problems and difficulties associated therewith that the present invention has been developed. Accordingly, it is an object of the present invention to address at least one of the problems or difficulties of previously known floats, or at least provide a useful choice as an alternative.

BRIEF DESCRIPTION OF THE INVENTION

[0007] According to a first aspect of the invention there is provided a buoyant actuator responsive to wave motion comprising a body defining an interior volume comprising gate means to vary the response of the buoyant actuator to the wave motion.

[0008] Preferably, the gate means is confined within the interior volume.

[0009] Preferably, the gate means is adapted to permit water to flow through the body of the buoyant actuator.

[0010] Preferably, the gates is means is responsive to a particular sea state.

[0011] In one arrangement, the particular sea state is an aggressive sea state in adverse weather conditions (such as storm conditions). This is for the purpose of maintaining the integrity of the buoyant actuator when exposed to such conditions, and also any mechanism to which the buoyant actuator is coupled.

[0012] Preferably, the gate means may comprise at least one closure element movable between a closed condition which it normally occupies and which impedes water flow through the body, and an open condition in which it permits water flow through the body.

[0013] Preferably, a releasable coupling is provided for releasably maintaining the closure element in the closed condition.

[0014] Preferably, the releasable coupling is adapted to actuate to release the closure element to allow, it to move from the closed condition to the open condition to establish the opening. The release may be actuated by the sea state or by remote control.

[0015] Preferably, the releasable coupling comprises a magnetic coupling. The magnetic coupling may utilise a magnetic attractive force to maintain the closure element in the closed condition. The magnetic coupling may comprise a plurality of magnets provided on the respective closure element and/or at corresponding locations along a part of the body against which the closure element locates when in the closed condition. In this way, the closure elements will remain in closed conditions until the force against them is sufficient to overcome the magnetic attraction, thus forcing the flaps to release and swing away from the closed condition to establish the opening.

[0016] Preferably the closure element comprises a flap.

[0017] Preferably, the flap is pivotally movable between a closed condition which it normally occupies and which impedes water flow through the body, and an open condition in which it swings outwardly to permit water flow through the body.

[0018] The magnetic attractive force may be configured to a particular wave motion by varying any or more of the following: the number of magnets, the strength of the magnets and the gap which the magnetic field traverses to provide the attractive force.

[0019] The magnetic attractive force may be adjustable

[0020] The magnetic attachment means are adjustable from a remote location.

[0021] Preferably, the magnetic attachment means are electromagnetic.

[0022] The magnetic coupling may comprise a magnet means on the closure element adjacent the inner end thereof and a mating part to which the magnet means is magnetically attracted. The mating part may comprise a striker plate. The magnetic coupling is operable to retain the respective closure element in the closed condition until the force against the closure element is sufficient to overcome the magnetic attraction, thus forcing the magnetic coupling to release the closure element and swing away from the closed condition to establish an opening to allow the water flow though the body.

[0023] The magnet means may comprise an array of permanent magnets accommodated within a housing. The housing is adapted to isolate the magnets from the water environment in which the buoyant actuator is intended to operate.

[0024] The housing may comprise non-magnetic, non-porous material (such as a plastic polymer) in which the permanent magnets are encased. Preferably, the plastic polymer material would have some resilient properties to offer some physical dampening. Typically, the permanent magnets would be molded into the housing. Such an arrangement is
advantageous as it also confines the permanent magnets and retains them in position within the housing and also in position relative to each other.

[0025] The housing may present a contact face to confront the mating part of the magnetic coupling. The permanent magnets may be recessed with respect to the contact face to provide the housing with a cushioning portion between the contact face and the permanent magnets. The contact face may also function as a wear surface, protecting the recessed permanent magnets from the effects of wear upon contact between the magnet means and the mating part.

[0026] Typically, the housing is removable and replaceable, as necessary.

[0027] The cushioning portion is preferably integral with the housing. In another arrangement, the cushioning may be provided by a layer of cushioning material applied to the housing for contact with the mating part of the magnetic coupling.

[0028] Preferably, at least one closure element closes by its own weight. However, in another arrangement, at least one closure element may be biased towards its closed condition. This may be achieved by use of a biasing mechanism, such as incorporation of a spring in the hinge for the closure element.

[0029] In a further arrangement, the hinged closure element may be biased in the closed condition via a rubber spring mechanism attached to a free end of the at least one flap.

[0030] Typically, the gate means comprises a plurality of closure elements. This is advantageous as it renders the buoyant actuator fault tolerant to closure element failure. If one closure element were to fail open in, normal operation there would still not be sufficient flow passage established for water to enter and then leave the hollow interior of the buoyant actuator to an extent which would adversely affect its operation. For there to be flow that might adversely affect operation of the buoyant actuator there would need to be at least two closure elements open, and the probability of two closure elements failing open is considerably less than the probability of just one closure element failing.

[0031] Preferably, the closure elements are configured to cooperate with each other to provide a barrier across the flow path through the body, each closure element being moveable into and out of a condition in which it cooperates with the other closure elements to, provide the barrier. The barrier need not necessarily block flow entirely through the body but rather simply impede that flow to the necessary extent.

[0032] In one arrangement, the barrier provided by the closure elements extends across the flow path to be substantially normal to the direction of flow of water through the body.

[0033] In another arrangement, the barrier is of raked construction such that each closure element when in the closed condition is inclined to the direction of flow of water through the body. Specifically, each closure element may be inclined in the direction towards the open upper end of the body; that is, the inner end of each closure element is closer to the open upper end of the body than the outer end when in the closed condition, but still within the confines of the body. In this way, the range of movement of the closure elements between the fully closed and fully open conditions is reduced. With this arrangement, the closure elements when in the closed condition provided the barrier with the raked and somewhat conical configuration.

[0034] Preferably, the releasable couplings of each closure element may be actuated by the same sea conditions.

[0035] In one arrangement, the body may be configured to have a longitudinal extent and to provide a flow path along which the water can flow though the body parallel to the longitudinal axis of the body.

[0036] In another arrangement, the body may be of frustoconical configuration having an upper end, lower end and side extending between the two ends. With this arrangement, the side is of convex shape and preferably bulging at the middle.

[0037] Preferably the body is of modular construction.

[0038] Preferably the body comprises an inner structure supporting a shell which defines an upper end, a lower end and the side.

[0039] The shell may comprise a plurality of sections configured as panels adapted to be connected together. The panels may be arranged in at least two rows comprising an upper row and a lower row. The upper row defines an upper edge at the upper end of the body and the lower row defines a lower edge at the lower end. The upper edge bounds the upper portal and the lower edge bounds the lower portal.

[0040] Preferably, there are two rows, being the upper row and the lower row, and the panels are each of the same configuration so that any panel can be located at any position within either row. This, is advantageous as it facilitates cost-effective manufacture of the panels and ready assembly of the panels into the shell.

[0041] Preferably, each panel is of generally rectangular construction.

[0042] Preferably, the connections between adjacent panels comprise half lap joints.

[0043] The body may be provided with one or more anchoring points to facilitate movement of the buoyant actuator once deployed in water.

[0044] Under certain combinations of hydrodynamic conditions and motion of the buoyant actuator in the moving body of water, it is possible for the flaps to close with excessive force, in effect being slammed shut rather than closing gently. With a view to mitigating this problem, some form of physical damper may be provided between the contacting surfaces. This damper may take the form of shaped pieces of elastomeric material with appropriate energy damping properties, attached to either or both contacting surfaces; for example, the elastomeric material can be attached to each flap or the mating part of the body.

[0045] Other dampering arrangements are, of course, possible; for example, the swinging motion of the flaps could be dampened hydraulically or by way of electrical (eddy current) damping control. Further, other elastomeric damping on contacting surfaces, and dampering of the swinging motion by hydraulic or electrical (eddy current) means may be provided.

[0046] A suitable hydraulic damper may comprise a dashpot in which the viscous fluid comprises water drawn from, and expelled into, the water environment in which the buoyant actuator is deployed. The piston of the dashpot may be fitted with a resilient bumper for contact with the respective flap, the arrangement being that resilient nature of the bumper affords some initial cushioning to the closing action of the flap.

[0047] According to a second aspect of the invention there is provided a buoyant actuator responsive to wave motion comprising a body incorporating a flow path along which water can flow, and a gate means for controlling flow along the flow path, the gate means comprising a plurality of closure
elements configured to cooperate with each other to provide a barrier across the flow path through the body, each closure element being moveable into and out of a condition in which it cooperates with the other closure elements to provide the barrier. The barrier need not necessarily block flow entirely through the body but rather simply impede that flow to the necessary extent.

[0048] When one or more closure elements have moved out of the condition in which they cooperate with the other closure elements to provide the barrier, the barrier opens to permit fluid flow therethrough. In effect, the closure elements are configured as hatches which can open and close, and when in the closed condition provide the barrier. When in the open condition the hatches each provide an opening within the barrier through which water can flow.

[0049] Preferably, the barrier is so configured and positioned to be within the confines of the body. Further the closure elements which constitute the barrier preferably remain within the confines of the body even when in the fully open condition.

[0050] In one arrangement, the barrier provided by the closure elements extends across the flow path to be substantially normal to the direction of flow of water through the body.

[0051] In another arrangement, the barrier is of raked construction such that each closure element when in the closed condition is inclined to the direction of flow of water through the body. Specifically, each closure element may be inclined in the direction towards the open upper end of the body; that is, the inner end of each closure element is closer to the open upper end of the body than the outer end when in the closed condition. In this way, the range of movement of the closure elements between the fully closed and fully open conditions is reduced. With this arrangement, the closure elements when in the closed condition provided the barrier with the raked and somewhat conical configuration.

[0052] According to a third aspect of the invention there is provided a buoyant actuator responsive to wave motion comprising a body having a support structure adapted to receive a plurality of sections defining a chamber for interrupting water flow through the body, wherein the support structure and plurality of sections are adapted to be transported and assembled in situ.

[0053] The body may be of any appropriate shape such as, for example, cylindrical, spherical, frusto-spherical, or frusto-conical. The shape of the body may be configured by provision of closure elements thereon. The profiled elements may be of buoyant construction; typically being, formed of buoyant material with a low specific gravity, such as foam material.

[0054] Preferably, each section comprises a frame having two ends, one end adapted to receive a wall portion and the other end adapted for connection to the support structure.

[0055] Preferably, the plurality of sections is adapted to couple to one another to define the chamber for interrupting water flow through the body.

[0056] In one arrangement, a hydrodynamic property of the buoyant actuator may be selectively varied. This may allow the performance characteristics of the buoyant actuator to be calibrated according to the environment in which the buoyant actuator is operating at any particular time (including, for example, the likely sea state).

[0057] The variation to the hydrodynamic property may comprise a variation to the buoyancy (either positively or negatively) or a variation to the response area (such as the volume or configuration) of the body, as well as a combination thereof.

[0058] Where the hydrodynamic property being varied is the buoyancy of the buoyant actuator, the variation may be achieved by addition or removal of buoyant material in the buoyant actuator. For example, the variation to the buoyant material may comprise addition of buoyant material to, or extraction of buoyant material from, the support structure. This may be achieved in an automatic mode by addition or removal of a fluid (liquid or gas). The variation to the response area may entail a variation of the configuration of the body. The configuration of the body may be varied by use of profiled elements, as alluded to earlier. By way of example, the outer shape of the buoyant actuator may be varied by attaching, for example, buoyant material to the exterior surface of the buoyant actuator.

[0059] According to a fourth aspect of the invention there is provided a buoyant actuator for immersion in a body of water, the buoyant actuator comprising a body defining a hollow interior adapted to receive a volume of water from the surrounding water body, the body having flow control means for controlling flow through the hollow interior, the flow control means having a first condition for blocking or at least impeding fluid flow through the body and a second condition permitting fluid flow through the hollow interior.

[0060] Preferably, the flow control means are confined within the interior volume.

[0061] Preferably, the flow control means are adjustable.

[0062] In an arrangement, the flow control means may be remotely adjustable.

[0063] According to a fifth aspect of the invention there is provided a kit for assembling a buoyant actuator, the kit comprising a support structure and a plurality of sections adapted for connection to the support structure to assemble the buoyant actuator.

[0064] According to a sixth aspect of the invention there is provided a buoyant actuator responsive to wave motion comprising a body defining an interior volume, the body comprising an inner structure supporting a shell which defines the inner volume, the shell comprising a plurality of sections configured as panels adapted to be connected together.

[0065] According to a seventh aspect of the invention there is provided a buoyant actuator responsive to wave motion comprising a body defining an interior volume, the body being of frusto-conical configuration having an open upper end, an open lower end and a side extending between the two ends. With this arrangement, the side is of convex shape and preferably bulging at the middle.

[0066] According to an eighth aspect of the invention there is provided a buoyant actuator responsive to wave motion comprising a body incorporating a flow path along which water can flow, and a gate means for controlling flow along the flow path, the gate means comprising a plurality of closure elements providing a barrier across the flow path through the body, the closure elements being moveable into and out of a condition in which it cooperates with the other closure elements to provide the barrier, and latch means for releasably retaining each closure element in said condition, the latch means comprising a magnetic coupling.

[0067] According to a ninth aspect of the invention there is provided a wave energy conversion system comprising at least one buoyant actuator according to any one of the preceding aspects of the inventions as set forth above.
Preferably, the buoyant actuator is operably connected to an energy conversion device (such as a fluid pump or a linear electric generator) to translate wave action thereto.

According to a tenth aspect of the invention there is provided a method of harnessing wave energy in a body of water, the method comprising deployment of a buoyant actuator according to any one of the preceding aspects of the invention in the body of water.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be better understood by reference to the following description of several specific embodiments thereof as shown in the accompanying drawings in which:

FIG. 1 is a perspective view of a buoyant actuator according to a first embodiment forming part of apparatus for harnessing ocean wave energy;

FIG. 2 is a schematic perspective view of the buoyant actuator;

FIG. 3 is a plan view of the buoyant actuator,

FIG. 4 is a schematic perspective view of a section of the buoyant actuator shown in FIG. 1;

FIG. 5 is a side view of the section of the buoyant actuator shown in FIG. 4;

FIG. 6 is a plan view of FIG. 4, illustrating in particular the gate means of the buoyant actuator;

FIG. 7 is a plan view of the gate means of the buoyant actuator illustrating the open condition thereof;

FIG. 8 is a schematic perspective view of the section of the buoyant actuator with the gate means in the open condition thereof;

FIG. 9 is a side view of the section of the buoyant actuator as shown in FIG. 8;

FIG. 10 is a side view of the interior of the support structure;

FIG. 11 is a schematic perspective view of the support structure;

FIG. 12 is a plan view of the support structure;

FIG. 13 is a schematic perspective view of the apparatus being assembled;

FIG. 14 is a sectional view of the buoyant actuator shown in FIG. 2;

FIG. 15 is a perspective view of a buoyant actuator according to a second embodiment forming part of apparatus for harnessing ocean wave energy;

FIG. 16 is a schematic side view of the arrangement shown in FIG. 15;

FIG. 17 is an underside plan view of the buoyant actuator according to the second embodiment;

FIG. 18 is side view of the buoyant actuator.

FIG. 19 is a view similar to FIG. 18 but in section to reveal the internal structure of the buoyant actuator;

FIG. 20 is a perspective view of the buoyant actuator from the underside thereof;

FIG. 21 is further side view of the buoyant actuator;

FIG. 22 is a further underside plan view of the buoyant actuator;

FIG. 23 is a fragmentary perspective view of the buoyant actuator, depicting the upper row of panels forming the shell of the buoyant actuator;

FIG. 24 is a side view of the arrangement shown in FIG. 23;

FIG. 25 is an exploded view of panels in the upper row;

FIG. 26 is a cross-section of panels in the upper row;

FIG. 27 is a fragmentary perspective view of the buoyant actuator, depicting the lower row of panels forming the shell;

FIG. 28 is a side view of the arrangement shown in FIG. 27;

FIG. 29 is a side view of four interconnected panels in the shell;

FIG. 30 is a cross-sectional view of the interconnected panels depicted in FIG. 29;

FIG. 31 is a schematic sectional view of two panels, illustrating in particular the joint therebetween;

FIG. 32 is a further sectional view of two panels, illustrating in particular the joint therebetween;

FIG. 33 is an elevational view of one of the panels from the inner side thereof;

FIG. 34 is a view similar to FIG. 33 but from the outer side thereof;

FIG. 35 is perspective view of the panel viewed from above;

FIG. 36 is a perspective view of the internal structure of the buoyant actuator viewed from the underside thereof;

FIG. 37 is a plan view of the internal structure;

FIG. 38 is a side view of the internal structure;

FIG. 39 is a fragmentary perspective view of the internal structure;

FIG. 40 is a plan view of the arrangement as shown in FIG. 39;

FIG. 41 is a side view of the arrangement as shown in FIG. 39;

FIG. 42 is a perspective view of a flap forming part of the buoyant actuator;

FIG. 43 is a plan view of the flap;

FIG. 44 is a side view of the flap;

FIG. 45 is an exploded perspective view of a magnet means used as part of a magnetic coupling for each flap of the buoyant actuator;

FIG. 46 is a schematic plan view of a variation of the magnetic means;

FIG. 47 is a schematic side view of the arrangement shown in FIG. 46;

FIG. 48 is a side view of a buoyant actuator according to a third embodiment;

FIG. 49 is a side view of part of the internal structure of the buoyant actuator of FIG. 48;

FIG. 50 is a schematic side view of a head portion of the internal structure shown in FIG. 49;

FIG. 51 is a schematic side view of a buoyant actuator according to a fourth embodiment with the flaps shown in an open condition;

FIG. 52 is a view similar to FIG. 51, except that the flaps are shown in a closed condition to establish a barrier;

FIG. 53 is a fragmentary view of a buoyant actuator according to a fifth embodiment, illustrating in particular a flap in a closed condition and in engagement with a dampener means for dampening the closing action of the flap;

FIG. 54 is a view similar to FIG. 53, except that the flap is shown in a condition in which it has swung away from the dampening means;

FIG. 55 is also a view similar to FIG. 53, except that the flap is shown in its return path and commencing contact with the dampener means; and
FIG. 56 is a schematic plan view of a wave energy conversion system incorporating buoyant actuators according to any of the previous embodiments.

BEST MODE(S) FOR CARRYING OUT THE INVENTION

The embodiments shown in the drawings are each directed to an energy release buoyant actuator 10 for use in apparatus 11 for harnessing ocean wave energy.

Referring to FIG. 1, the apparatus 11 is installed and operating in a body of seawater 12 having a water surface 13 and a seabed 14. The apparatus 11 includes a pump mechanism 15 anchored with respect to the seabed 14. The buoyant actuator 10 is operably connected to the pump mechanism 15 and is buoyantly suspended within the body of seawater 12 above the pump mechanism 15 but below the water surface 13 at a depth such that its upper surface is typically a few metres below the neutral water line. Moreover, the combination of buoyant actuator 10 and the pump mechanism 15 to which it is operably connected preferably defines a total length which in its minimum condition (when the buoyant actuator is at the lowest point of its excursion) is appropriate for deployment in water depths preferably no less than ten metres and no greater than one hundred metres. The buoyant actuator 10 is operatively connected to the pump mechanism 15 by way of a coupling 16 which includes a tether 17.

Referring now to FIGS. 2 to 6, the buoyant actuator 10 according to the first embodiment comprises a body 21 having a support structure 23 and a plurality of sections 25. Sections 25 surround the support structure 23 defining a chamber 24 of generally annular configuration having an outer chamber wall 26 and an inner chamber wall 28. The ends of the buoyant actuator 10 are open allowing entrance of water into the chamber 24.

As shown in FIG. 4, each section 25 comprises a frame 27 having an outer end adapted for supporting a wall portion 29 and an inner end adapted for attachment to the support structure 23. The sides of each frame 27 are adapted to couple to each other as shown in FIG. 13. The sections 25 define the chamber 24 surrounding the structure 23. Each section 25 is traversed by gate means 31. The gate means 31 are adapted to be confined within the buoyant actuator in the open and closed conditions. The purpose of which will become apparent later.

The frame 27 is a structure comprising steel struts. The wall portions 29 are metal sheets. Alternatively, frame 27 and wall portions 29 may be constructed from other materials suitable to sustain the marine conditions.

Water flow through chamber 24 between the open ends thereof may be controlled via the gate means 31 actuated in response to a predetermined fluid pressure differential imposed thereon between the hollow interior and the surrounding body of water in which the buoyant actuator 10 is immersed. The predetermined fluid pressure differential arises from heaving motion imparted to the buoyant actuator when it is subjected to an aggressive sea state. In other arrangements, the movement of the buoyant actuator may be controlled by selective operation of the gate means 31 so as to stay within specific ranges of movement.

The gate means 31 comprise a closure element configured as a flap 33 pivotally connected to a side of the frame 27 via hinges 35 (see FIG. 6). Hinges 35 are attached to one side of flap 33. At an opposite side (the free end) of flap 33, a latch mechanism 37 releasably maintains the flap 33 in the closed condition. This impedes water flow through the chamber 24. The latch mechanism 37 comprises a releasable coupling 39 which in the illustrated arrangement comprises magnetic couplings 41 and a plate 43. The plate 43 is located at the opposite side of frame 27. The magnetic couplings 41 are attracted to plate 43 so as to maintain the flap 33 in the closed condition (see FIGS. 4 and 5). The magnetic coupling 41 may comprise a plurality of magnets (see FIGS. 8 and 9) provided at a location along the free edge of the respective flap 33 and/or at corresponding locations along a corresponding edge of frame 27. In this way, the flaps 33 will remain in closed conditions until the force against them is sufficient to overcome the magnetic attraction, thus forcing the flaps 33 to release and swing away from the closed condition to establish the opening (see FIGS. 7 to 8) and to allow the water flow through the body.

In this embodiment, the releasable coupling 39 is adapted to actuate to release the flap to allow it to move from the closed condition to the open condition to establish the opening in response to the adverse weather conditions.

The magnetic attractive force may be adjustable. The magnetic attractive force may be adjusted to a particular wave motion varying any of: the number and strength of the magnets, and the separation of the magnets and the struts.

In another arrangement, the magnetic attractive force is adjusted from a remote location. In this case the magnetic attachment means may be, for example, electromagnets with variable magnetic attractive force.

The flaps 33 may each be adapted to close under the influence of its own weight at specific water flow levels. Alternatively, each flap may be biased towards its closed condition. This may be achieved by use of a spring mechanism, such as incorporation of a spring in the hinge for the flap.

In a further arrangement, the hinged flap is biased in the closed condition via a rubber spring mechanism attached to a free end of the at leak one flap.

The spring force needs to be relatively weak in the sense that it will facilitate closure only after the sea conditions have subsided and the flap is just luffing. However, it may not be necessary to have provision for spring loading on the flaps as the flaps may self-close merely with the gentle motion of the buoyant actuator 10.

As previously explained, the opening of flaps 33 allows water to pass through the chamber 24 so that there is minimal resistance to the moving water that impinges on the buoyant actuator. This removes much of the potential energy as the buoyant actuator 10 is not being heaved up as much by the waves and it is lighter, and it also reduces the kinetic energy at the same time because the mass is reduced (water is no longer trapped) and the velocity is reduced (because the buoyant actuator is no longer providing such reaction to the wave forces that would cause it to accelerate). It is not possible to make the buoyant actuator 10 appear completely transparent to the water as there will always be some coupling between the two but it is expected that the storm loads on the pumps 15 and couplings 21 can be attenuated to acceptable levels using the gate means 31 so there is not the need to engineer very massive (and expensive) structures to resist these large forces.

It is a feature of the buoyant actuator 10 that it is fault-tolerant to flap failure. If one flap 33 were to fail open in normal operation (due for example, to a failure in the magnetic latch, or a broken hinge) there would still not be enough
of a flow passage established for water to enter and then leave the hollow interior of the buoyant actuator 10 to an extent which would adversely affect its operation. For there to be flow that might adversely affect operation of the buoyant actuator 10 there would need to be at least two flaps open, and the probability of two flaps failing open is considerably less than the probability of just one flap failing.

[0142] In this respect, the confining of the gate means 31 within the buoyant actuator is particularly advantageous. The gate means 31 are protected from the external sea environment and are not exposed to be vulnerable to damage in the event of the buoyant actuator 10 being involved in a collision. This arrangement permits the use of mesh material to close the open ends of the buoyant actuator 10 to prevent ingress of marine material into chamber 24. Also, methods for inhibiting growth of marine organisms may be employed. For example, coatings may be applied to the surfaces of the gate means 31 to discourage formation of colonies of marine organisms.

[0143] The sections 25 described above form together with the support structure 23 the buoyant actuator shown in Figs. 2 and 3.

[0144] Referring to FIG. 10, the support structure 23 comprises a central core 49 and a frame 47 surrounding the central core 23. The frame 47 comprises three groups of struts 51. First and second group of struts 51 extend outwardly at an angle from the core 40 defining each a conical space within the structure 23. The first group of struts 51 extends from a first end of the core 49 to the middle section of the core 49; the second group extends from the middle of the central core 49 to the second end section of the core. The third group of struts (not visible) extend radially outwardly from the first end of the core 49. In this arrangement the struts define a pentagonal prism. Alternatively, other shapes may be suitably. In the arrangement shown in FIG. 10, there are 10, struts 51 per group of struts, a pair corresponding to each side 54 of structure 23. Lugs 59 and 61 extend longitudinally from each end of central core 49. Lugs 59, 61 may serve as lifting and support means during operation, transport and assembly of the buoyant actuator 10.

[0145] Furthermore, frame 47 comprises a series of vertically aligned struts 45 extending along the periphery of frame 47 (see FIGS. 10 to 12). Between the series of struts 45 are located side panels 53. Side panels 53 define the facets of the support structure and also the inner chamber wall 26. End panels 55, 57 are located at ends of the frame 47. This arrangement defines a closed internal volume within structure 23 shown in FIG. 12. The struts 45 extend above side panels 53 so as to receive sections 25.

[0146] The arrangement described defines a void within the structure 23. Due to the substantially hollow nature of the buoyant actuator 10, it is lightweight compared to known prior art floats. The void is filled with buoyant material to provide overall net buoyancy to the buoyant actuator 10. The buoyant material may be, for example, air, bladders containing air, low density materials such as foams, among others. The foam may be a closed cell poured urethane foam, although other suitable materials could be used.

[0147] The buoyancy provides additional uplift during the pumping stroke. A wave exerts almost as much upwards force as it does downwards force on the buoyant actuator 10. As each pump 15 only acts in one direction the buoyancy inside the buoyant actuator 10 acts as a potential energy storage during the down stroke so that the buoyancy and uplift force both work on the pump during the upwards stroke direction. [0148] The hydrodynamic properties of the buoyant actuator may be varied by selectively varying the buoyancy within the structure 23. The variation to the buoyancy may comprise addition of buoyant material to, or extraction of buoyant material from, the structure 23. Also, in other arrangements the type of buoyant material may be varied.

[0149] In other arrangements, the hydrodynamic properties of the buoyant actuator may be varied by selectively varying the outer shape of the buoyant actuator. This may be accomplished by attaching, for example, buoyant material to the outer surface of wall portions 29.

[0150] Suitable shapes may include spheres, frusto-spheres, squat inverted-cones, frusto-cones or squat cylinders for the buoyant actuator with a single tether. Other shapes may, of course, also be suitable.

[0151] A spherical shape may be optimal because, owing to its symmetry, there is no rotational coupling between the wave disturbance and the buoyant actuator, thereby providing optimal conversion of heaving force to linear tension on the tether.

[0152] The differences in energy gathering performance between a sphere, a squat cylinder and a squat inverted cone are not so great as to exclude these shapes in favour of spheres when other factors such as manufacturability and robustness are also taken into consideration. Hence there is a range of shapes that have acceptable energy gathering performance and acceptable ratings in terms of robustness.

[0153] Because of its modular construction, the buoyant actuator is capable of being transported as separate elements and assembled near its final destination. The arrangement is, in effect, a kit comprising the previously described support structure 23 and the ten sections 25. As shown in FIG. 13, the buoyant actuator 10 is formed by fastening sections 25 to strubs 45 of support structure 23 and coupling neighbouring sections 25 with respect to each other. This operation may be performed while the support structure 23 is suspended vertically from lug 61 with help of, for example, a crane.

[0154] The assembled buoyant actuator 10 (see FIG. 2) may be lifted via lug 61 for deployment into the body of water. As previously explained, in operation the buoyant actuator 10 is operatively connected to a pump mechanism 15 by way of a coupling 16 which includes a tether 17. The tether 17 is fastened to lug 59 of the buoyant actuator (see FIG. 10).

[0155] The pump 15 is anchored within the body of water 12 and adapted to be activated by wave energy via buoyant actuator 10. Pump 15 is operably connected to a buoyant actuator 10 according to the embodiment buoyantly suspended within the body of seawater 12 above the pump but below the water surface 13 at a depth such that it is typically a few metres below the neutral water line. With this arrangement, pump 15 is activated by movement of the buoyant actuator 10 in response to wave motion. The pump 15 may provide high pressure working fluid (for example, water) to a closed loop system in which energy in the form of the high pressure fluid is exploited.

[0156] In operation, a wave impinging on the apparatus 10 causes uplift of the buoyant actuator 10. This uplift is transmitted through the tethers 17 to the pump 15 causing it to perform a pumping stroke. Once the wave has passed, the uplift force applied to the buoyant actuator 10 diminishes and the buoyant actuator descends under the weight of the various components connected thereto, including the pumping
mechanism of pump 15, thereby causing the pump 15 to perform an intake stroke. As the piston mechanism descends, it plunges into water which has entered the intake chamber. As the piston mechanism descends, water within the intake chamber flows into the piston chamber and the progressively expanding pumping chamber. An intake check valve allows entry of the water. This charges the piston chamber and the discharge chamber in readiness for the next pumping stroke which is performed upon uplift of the buoyant actuator 10 in response to the next wave disturbance.

In the event of an aggressive sea state, typically adverse weather conditions (such as in storm conditions), the buoyancy actuator 10 can be subject to extreme forces which impart a heaving motion to the buoyant actuator 10. In such conditions there is a need to preserve the buoyant actuator 10 against damage and limit the heaving loads that it transmits to other components of the apparatus 11. This is achieved by releasing the energy of the buoyant actuator 10 effectively rendering it inoperative, or at least limit the heaving forces imposed on it, by allowing water to flow through the buoyant actuator. This has the effect of rendering the buoyant actuator 10 transparent to the body of water in which it is immersed; that is, the buoyant actuator 10 responds less to the heaving motion of the water than it otherwise would. This outcome is achieved by opening of the gate means 31. The gate means 31 opens in response to a predetermined fluid pressure differential imposed thereon, thereby permitting water flow upwardly through the buoyant actuator 10. The predetermined fluid pressure differential arises from upward heaving motion imparted to the buoyant actuator 10 when it is subjected to an aggressive sea state.

In other arrangements, the movement of the buoyant actuator may be controlled by selective operation of the gate means 31 so as to stay within specific ranges of movement.

Referring now to FIGS. 15 to 45, there is shown a buoyant actuator 10 according to a second embodiment. As depicted in FIGS. 15 and 16, the buoyant actuator 10 according to the second embodiment forms part of apparatus 11 installed and operating in a body of seawater 12 having a water surface and a seabed 14. The apparatus 11 includes a pump mechanism 15 and a pump mechanism 15 and is operably connected with the pump mechanism 15 by way of a coupling 16 which includes a tether 17. The buoyant actuator 10 is operatively connected to the pump mechanism 15 by way of a coupling 16 which includes a tether 17.

The body 101 of the buoyant actuator comprises a body 101 of frusto-conical configuration having an upper end 103, a lower end 105 and a side 107 extending between the two ends. With this arrangement, the side 107 is of convex shape and bulging at the middle.

The body 101 is hollow, and the upper end 103 and the lower end 105 each open onto the hollow interior 109 within the body. The hollow interior 109 defines a chamber 110 which incorporates a controlled flow path along which, when open, water can flow through the body between the open upper end 103 and the open lower end 105. The upper end 103 defines an upper portal 104 opening into the chamber 110 and the lower end 105 defines a lower portal 106 opening into the chamber 110.

The body 101 comprises an inner structure 111 supporting a shell 113 which defines the upper end 103, the lower end 105 and the side 107 of the body.

The inner structure 111 is configured for attachment of the tether 17 thereto.

The buoyant actuator 10 is configured such that the centre of mass is below the centre of buoyancy. This provides some stability to the buoyant actuator when operating in adverse sea conditions. In this embodiment, the relative positioning and construction of the inner structure 111 and the shell 113 achieves this relationship between the centre of mass and the centre of buoyancy.

The inner structure 111 incorporates gate means 115 for controlling flow through the body 101 between the upper portal 104 at the open upper end 103 and the lower portal 106 at the open lower end 105, as will be described in more detail later. The gate means 115 is operable in response to a predetermined fluid pressure differential imposed thereon, as was the case with the first embodiment, thereby permitting water flow upwardly through the buoyant actuator 10. The predetermined fluid pressure differential arises from upward heaving motion imparted to the buoyant actuator 10 when it is subjected to an aggressive sea state.

The embodiment seeks to provide an arrangement which can achieve the largest possible cross-sectional flow area through the upper and lower portals 104, 106 of the body 101 for a given trapped water volume within the body, and the frusto-conical configuration of the body is conducive to such an arrangement.

The shell 113 is of modular construction, comprising a plurality of sections 121 configured as panels 123 adapted to be connected together. In the arrangement shown, the panels 123 are arranged in two rows, being an upper row 125 and a lower row 127. The upper row 125 defines an upper edge 128 at the upper end 103 of the body 101 and the lower row 127 defines a lower edge 129 at the lower end 107. The upper and lower edges 128, 129 are rounded in cross-sectional profile.

The upper edge 128 bounds the upper portal 104 and the lower edge 129 bounds the lower portal 106.

The panels 123 are each of the same configuration so that any panel can be located at any position within either row 125, 127. This is advantageous as it facilitates cost-effective manufacture of the panels 123 and ready assembly of the panels 123 into the shell 113.

Each panel 123 is of generally rectangular construction, comprising a panel body 131 having an outer face 133, an inner face 135 and four edges 137. The four edges 137 comprise an outer edge 139, an inner edge 141 and two opposed side edges 143, 145.

When a respective panel 123 is installed in the assembled shell 113, the outer edge 139 of the panel defines either part of the upper edge 128 of the shell 113 or lower edge 129 of the shell 113, according to whether the panel 123 is located in the upper row 125 or lower row 127 of the assembled shell 113. The outer edge 139 is rounded to conform to the rounded profile of the upper and lower edges 128, 129 of the shell 113.

The two opposed side edges 143, 145 of each respective panel 123 are configured for connection to the adjacent edges of neighboring panels 123 in the same row of panels within the assembled shell 113. This can be seen with reference to FIG. 18 in which panel 123a is shown, together with its neighboring panels 123b and 123c. FIG. 29 also
shows the arrangement, but without panel 123. Panel 123a has opposed side edges 143a and 145a, with side edge 143a connected to side edge 145b of panel 123b and side edge 145a connected to side edge 143c of panel 123c.

More particularly, the side edges 143, 145 of each respective panel 123 are configured for mating engagement with the corresponding side edges of adjacent panels. In the arrangement shown, the side edges 143, 145 are configured to provide half lap joints 147 between the panels 123. With this arrangement, the side edge 143 of one panel and the corresponding side edge 145 of a neighbouring panel can mate in overlapping relation. The mating side edges 143, 145 can be secured together in any appropriate way, such as by mechanical fixing, chemical bonding or welding. In the arrangement shown, the connection is mechanical fixing using fasteners 149 such as bolts or rivets. Connection by way of mechanical fixing using removable fasteners can be advantageous as it facilitates disassembly of the shell 113 should that be required later for repair or maintenance purposes.

The half lap joints 147 are formed by a rebate 151 along each side edge 143, 145 to define a flange 153 and an adjacent recess 155. The flange 153 and recess 155 are configured for mating engagement. With such an arrangement, in the lap joint 147 between two panels, the flange 153 on side edge 143 of the first panel 123 locates in the corresponding recess 155 on side edge 145 of the second panel, and the flange 153 on side edge 145 of the second panel 123 locates in the corresponding recess 155 on side edge 143 of the first panel.

The inner edge 141 of each respective panel 123 is configured for connection to the inner edge of neighboring panel 123 in the adjacent row of panels within the assembled shell 113. This can be seen with reference to FIGS. 18 and 29 in which panel 123a in the upper row 125 is panel 123d in the lower row 127 are shown, with their respective inner edges 141a and 141d being adjacent to each other.

More particularly, the inner edge 141 of each respective panel 123 is configured for mating and interlocking engagement with the inner edge 141 of the neighboring panel 123 in the adjacent row of panels within the assembled shell 113. In the arrangement shown, the inner edge 141 is configured to provide a plurality of half lap joints 161. In this embodiment, there are two half lap joints provided by each inner edge 141, but more may also be possible.

The two half lap joints 161 are formed by first and second rebates 163, 165 along the inner edge 141 on opposite sides thereof. The first rebate 163 defines an outer flange 167 and an adjacent inner recess 169. Similarly, the second rebate 165 defines an inner flange 171 and an adjacent outer recess 173. The outer flange 167 and the outer recess 173 are contiguous, and the inner recess 169 and the inner flange 171 are also contiguous.

The outer flange 167 and the inner recess 169 are configured for mating engagement, and the inner flange 171 and the outer recess 173 are also configured for mating engagement. With such an arrangement, in the lap joint 147 between two panels, the flange 153 on side edge 143 of the first panel 123 locates in the corresponding recess 155 on side edge 145 of the second panel, and the flange 153 on side edge 145 of the second panel 123 locates in the corresponding recess 155 on side edge 143 of the first panel.

In this embodiment, the mating engagement between the respective flanges 167, 171 and recesses 169, 173 which constitute the half lap joints 161 is a friction fit engagement, thereby providing a snap fit connection between the panels 123 at their inner edges 141.

With this arrangement, the inner edge 141 of one panel and the corresponding inner edge 141 of neighboring panel can mate in overlapping relation. The mating inner edges 141 can be secured together in any appropriate way, such as by mechanical fixing, chemical bonding or welding. In the arrangement shown, the connection is mechanical fixing using fasteners 175 such as bolts or rivets. Connection by way of mechanical fixing using removable fasteners can be advantageous as it facilitates disassembly of the shell 113 should that be required later for repair or maintenance purposes.

The shell 113 is of buoyant construction. For this purpose, each shell panel 123 is buoyant. This may be accomplished in any appropriate way, such as by forming one or more voids within the panel or encapsulating buoyant material such as foam within the panel. In this embodiment, the body 131 of each panel 123 is of hollow construction comprising a skin 181 having an outer skin section 183 defining the outer face 133 and an inner skin section 185 defining the inner face 135. The outer and inner skin sections 183, 185 are in spaced apart relation to define a closed space 187 therebetween. An array of bridging elements 189 are formed integrally with the outer and inner skin sections 183, 185 and extend therebetween across the space 187 to provide reinforcement for the two skin sections. In this embodiment, the space contains air but may contain any appropriate buoyant matter including other gases or foam material.

One or more anchoring points 190 are provided on the exterior of the shell 113 to facilitate movement of the buoyant actuator 10 once deployed in water. Typically, such movement would be performed as a towing action. The anchoring points 190 are connected to the inner structure 111 to provide a robust arrangement.

The inner structure 111 provides a central core 201 supporting the shell 113. The inner structure 111 comprises a central column 203 and a frame 205 mounted on the central column 203. Typically, the central column 203 and the frame 205 are constructed primarily of metal, which assists in ensuring that the centre of mass of the buoyant actuator 10 is below the centre of buoyancy.

The central column 203 comprises an upper section 206 and a lower section 207. The upper section 206 comprises a central plate 208 surrounding the column 203 and mounting brackets 209 below the central plate 208.

The frame 205 comprises arms 210 extending radially from the upper section 206 of the central column 203 and struts 211 extending between the lower section 207 of the central column 203 and the radially outer ends of the arms 210. Each arm 210 comprises a frame element 213 mounted at its radially inner end on one of the mounting brackets 209. The radially outer end of each frame element 213 is supported by a respective one of the struts 211.

The frame 205 includes mounts 215 to which the shell 213 can be attached. In the arrangement illustrated, the mounts 215 comprise mounting brackets 217 at the outer ends of the frame elements 213 onto which the shell 213 can be bolted.

The frame 205 also includes radial frame elements 218 extending between the lower section of the central column 203 and the shell 213 to brace the shell in position on the inner structure 111, as best seen in FIG. 20.
The radial arrangement of the arms 210 defines spaces 219 between the arms which form part of the flow path through the body along which, when open, water can flow through the body between the upper portal 104 and the lower portal 106. The spaces 219 are of generally triangular configuration, with the apex radially innermost.

The gate means 115 is operable to regulate flow of water through the body 101 between the upper portal 104 and the lower portal 106.

The gate means 115 comprises a plurality of closure elements configured as flaps 221 adapted to cooperate with each other to provide a barrier 222 across the flow path through the body 101 between the upper portal 104 and the lower portal 106. The barrier 222 need not necessarily block flow entirely through the body 101 but rather simply impede that flow.

Each flap 221 is moveable into and out of a condition in which it cooperates with the other flaps to provide the barrier 222. When one or more flaps 221 have moved out of that condition, the barrier 222 opens to permit fluid flow therethrough. In effect, the flaps 221 are configured as hatches which can open and close, and when in the closed condition provide the barrier 222. When in the open condition the hatches each provide an opening within the barrier through which water can flow.

In the arrangement shown, the flaps 221 are each associated with a respective one of the spaces 219 for opening and closing the space with respect to flow.

The flaps 221 are configured to conform to the shape of the spaces 219. In the arrangement shown, each flap 221 comprises an inner end 223, an outer end 225 and two opposed sides 227. The configuration of the flap 221 is best seen in FIGS. 42, 43 and 44. The sides 227 comprise an inner side section 227a and an outer side section 227b. The sides 227 are configured such that inner side sections 227a of adjacent flaps 221 locate closely adjacent each other, as can be seen in FIG. 40 when the flaps are in the closed condition. This facilitates attainment of an effective barrier 222.

The flaps 221 are pivotally mounted on the frame 205 for swinging movement between open and closed conditions in relation to the respective spaces 219. In the closed condition, the flaps 221 extend across the spaces 219 to thereby establish the barrier 222 and obstruct flow. Because of its pivotal mounting, each flap 221 can swing away from its respective space 219 to expose the space and thereby open the barrier 222 to flow therethrough. The flaps 221 are shown in the closed condition in FIGS. 36, 37 and 39. FIG. 19 shows the flaps 221 partly swung away from the closed condition.

In the arrangement shown, each flap 221 is pivotally mounted on the frame 205 adjacent the outer end 225 thereof by means of hinges 229. When the flap 221 is in the closed condition, the inner end 223 is supported on the central plate 208.

The barrier 222 is so configured and positioned to be within the confines of the shell 113. Further, the flaps 221 which constitute the barrier 222 remain within the confines of the shell 113 even when in the fully open condition.

A latch mechanism 231 is associated with each flap 221 to retain the flap in the closed condition to impede water flow through the body 101. The latch mechanism 231 comprises a releasable coupling 238 which in this embodiment comprises magnetic coupling 239. The magnetic coupling 239 provides an attractive force between the inner end 223 of each flap 221 and an adjacent part of the central core 201. In the illustrated arrangement, the magnetic coupling 239 comprises a magnet means 241 on the flap 221 adjacent the inner end 223 thereof and a striker plate 243 on the central column 203. The striker plate 243 is of material (such as steel or other ferromagnetic material) to which the magnet means 241 is magnetically attracted and, in the arrangement illustrated, is defined by the central plate 208 of the central column 203.

The magnetic coupling 239 is operable to retain the respective flap 221 in the closed condition until the force against the flap is sufficient to overcome the magnetic attraction, thus forcing the magnetic coupling to release the flap and swing away from the closed condition to establish an opening to allow the water flow through the body 101.

The magnet means 241 in this embodiment comprises an array of permanent magnets 245 accommodated within a housing 247. The permanent magnets 245 may be of any appropriate type. Permanent magnets having good aging characteristics are desirable. Neodymium magnets (also known as NdFeB magnets) are believed to be particularly suitable.

The housing 247 is adapted to isolate the magnets 245 from the water environment in which the buoyant actuator is intended to operate.

Under certain combinations of hydrodynamic conditions and motion of the buoyant actuator 10 in the moving body of water, it is possible for the flaps 221 to close with excessive force, in effect being slammed shut rather than closing gently. If this condition is not mitigated it can lead to excessive wear of, and damage to, the flaps 221 themselves, as well as to the latch mechanisms 231 and other parts of the inner structure 111. In order to mitigate this problem some form of physical dampener may be provided between the contacting surfaces. This dampener may take the form of shaped pieces of elastomeric material with appropriate energy damping properties, attached to either or both contacting surfaces; for example, the elastomeric material can be attached to each flap 221 or the mating part of the inner structure 11 such as the striker plate 243, or both.

Other dampening arrangements are, of course, possible; for example, the swinging motion of the flaps 221 could be dampened hydraulically or by way of electrical (eddy current) damping control. Indeed, it may be advantageous to provide both elastomeric damping on contacting surfaces, and damping of the swinging motion by hydraulic or electrical (eddy current) means.

In FIGS. 46 and 47 of the drawings there is shown a variation of the magnet means 241 devised to provide protection for the permanent magnets 245 and also afford some physical dampening when contacting the striker plate 243. In this variation, the housing 247 comprises non-magnetic, non-porous material (such as a plastic polymer) in which the permanent magnets 245 are encased. Preferably, the plastic polymer material would have some resilient properties to offer some physical dampening. It is believed that polyurethane, acrylic and polymer HiPE would be particularly suitable plastic polymers for the housing 247.

Typically, the permanent magnets 245 would be molded into the housing 247. Such an arrangement is advantageous as it also confines the permanent magnets 245 and retains them in position within the housing and also in position relative to each other.

The housing 247 presents a contact face 251 to confront the striker plate 253. In the arrangement shown, the permanent magnets 245 are recessed with respect to the con-
tact face 251 to provide the housing with a cushioning portion 253 between the contact face 251 and the permanent magnets 245. The contact face 251 also functions as a wear surface, protecting the recessed permanent magnets 245 from the effects of wear upon contact between the magnet means 241 and the striker plate 253.

[0206] Typically, the housing 247 is removable and replaceable, as necessary.

[0207] In this embodiment, the cushioning portion 253 is integral with the housing 247. In another arrangement, the cushioning may be provided by a layer of cushioning material applied to the housing 247 for contact with the striker plate 253.

[0208] Although not shown, cushioning can also be provided in relation to the striker plate 243. By way of example, the striker plate 243 may be supported on a shock-absorbing mounting arrangement. The shock-absorbing mounting arrangement may comprise rubber mounts on which the striker plate 243 is elastically supported.

[0209] In this second embodiment, the barrier 222 provided by the flaps 221 extends across the chamber 110 to be substantially normal to the direction of flow of water through the body 101 between the upper portal 104 and the lower portal 106. Typically, the flaps 221 can swing through an arcc of movement of about 90 degrees in moving between the fully closed and fully open conditions. With such a range of movement, the flaps may be susceptible to closing with excessive force under certain combinations of hydrodynamic conditions and motion of the buoyant actuator 10 in the moving body of water. As alluded to above, the provision of dampening seeks to alleviate this potential problem.

[0210] Another approach to alleviating the problem of closing of the flaps 221 with excessive force is to reduce the range of movement of the flaps between the fully closed and fully open conditions and thereby reduce the extent to which the flaps are susceptible to combinations of hydrodynamic conditions and motion of the buoyant actuator 10 in the moving body of water when they are out of the closed condition.

[0211] The buoyant actuator 10 according to the third embodiment, which is shown in FIGS. 48, 49 and 50, adopts such an approach.

[0212] The buoyant actuator 10 according to the third embodiment is similar in many respects to the buoyant actuator 10 according to the third embodiment and similar reference numerals are used to identify similar parts.

[0213] In the buoyant actuator 10 according to the third embodiment, the barrier 222 is of raked construction such that each flap 221 when in the closed condition is inclined to the direction of flow of water through the body 101 between the upper portal 104 and the lower portal 106. Specifically, each flap 221 is inclined in the direction towards the upper portal 104; that is, the inner end 223 of each flap 221 is closer to the upper portal 104 than the outer end 225 when in the closed condition, as shown in FIG. 48. In this way, the range of movement of the flaps between the fully closed and fully open conditions is reduced.

[0214] With this arrangement, the flaps 221 when in the closed condition provide the barrier 222 with the raked and somewhat conical configuration.

[0215] The inner structure 111 comprising the central column 203 and the frame 205 is modified to accommodate this arrangement. In particular, the arms 210 which define the spaces 219 therebetween are raked. Additionally, the central column 203 incorporates a head portion 261 which supports the inner ends 223 of the flaps 221 when in the closed condition and also provides the striker plates 243 for the magnetic couplings 239 which function as the latch mechanisms 231. Specifically, the head portion 261 comprises a plurality of segments 263 each of which defines a respective one of the striker plates 243.

[0216] The frame 205 comprises a spider structure 271 comprising raked upper frame elements 273 and raked lower frame elements 275 which converge at their outer ends to mounting plates 277 onto which the shell 113 can be mounted. With this arrangement, the upper frame elements 273 define the arms 210 and the spaces 219 therebetween.

[0217] Referring now to FIGS. 51 and 52 there is shown schematically a buoyant actuator 10 according to a fourth embodiment. The buoyant actuator comprises a body 301 which is hollow and which has, an upper end 303 and the lower end 305 each opening onto the hollow interior 307 within the body. The hollow interior 307 defines a chamber 309 which incorporates a controlled flow path along which, when open, water can flow through the body between the open upper end 303 and the open lower end 305. A gate means 311 is provided for controlling flow through the body 301 between the open upper end 303 and the open lower end 305. As with earlier embodiments, the gate means 311 is operable in response to a predetermined fluid pressure differential imposed thereon. The predetermined fluid pressure differential arises from heaving motion imparted to the buoyant actuator 10 when it is subjected to an aggressive sea state.

[0218] The gate means 311 comprises a plurality of flaps 313 configured to cooperate with each other to provide a barrier 315 across the flow path through the body 301 between the open upper end 303 and the open lower end 305. The barrier 315 need not necessarily block flow entirely through the body 301 but rather simply impede that flow.

[0219] Each flap 313 is moveable into and out of a condition in which it cooperates with the other flaps to provide the barrier 315. When one or more flaps 313 have moved out of that condition, the barrier 315 opens to permit fluid flow therethrough. As with earlier embodiments, the flaps 313 are configured as hatches which can open and close, and when in the closed condition provide the barrier 315. When in the open condition the hatches each provide an opening within the barrier 315 through which water can flow.

[0220] In this embodiment, the flaps 313 are pivotally mounted for swinging movement between the open and closed conditions. In the arrangement illustrated the flaps 313 are pivotally mounted on pivots 317 defined by hinges 319 mounted on the body 310. The flaps 313 are operably connected to buoyant devices 321 which bias the flaps 313 into the closed condition. The buoyant devices 321 are disposed exteriorly of the body 301 in the arrangement illustrated. A stop 323 is associated with each buoyant device 321 to limit upward movement of the device under the influence of buoyancy. Upon upward swinging movement of the flaps 313 from the closed condition (as shown in FIG. 52) to the open condition (as shown in FIG. 51) in response to a differential pressure imposed thereon, the buoyant devices 321 move downwardly away from the stops 323 against the influence of buoyant forces imposed on them. When the differential pressure on the flaps 313 reduces to a sufficient extent, the buoyant forces imposed on the buoyant device 321 return the latter into engagement with the stops 323, thereby returning the flaps 313 to the closed condition.
In this embodiment the flaps 313 are supported within the chamber 309 in a cantilever fashion; that is, the flaps 313 extend in an unsupported manner into the chamber 309 from the hinges 319. With this arrangement, the flaps 313 can be constructed to incorporate some inherent flexibility, thereby allowing the flaps to deflect a limited extent when in the closed condition in response to downward hydrodynamic forces (as depicted in broken lines in FIG. 52). This may be advantageous as flexing of the flaps 313 can provide some cushioning in the closing action of the flaps.

As mentioned above in relation to several embodiments of the buoyant actuator 10, there is a possibility under certain combinations of hydrodynamic conditions and motion of the buoyant actuator 10 for the flaps which constitute the barrier to close with excessive force, in effect being slammed shut rather than closing gently. Several dampening arrangements have been disclosed, including reference to dampening by hydraulic means.

Referring now to FIGS. 53, 54 and 55, there is shown schematically a portion of a buoyant actuator 10 according to a fifth embodiment. The buoyant actuator 10 according to this embodiment comprises a gate means 351 comprising a plurality of flaps 353 (only one of which is shown) configured to cooperate with each other to provide a barrier across the flow path, as was the case with earlier embodiments.

The buoyant actuator 10 according to this embodiment further comprises a hydraulic damper 355 adapted to facilitate closure of each flap 353 in a cushioned manner. The hydraulic damper 355 comprises a dashpot 357 having a cylinder 359 and a piston 361. The piston 361 comprises a piston head 363 and a piston shaft 365. The piston head 363 is accommodated in the cylinder 359 to divide the cylinder into two chambers 367, 369. Chamber 367 is opposed to the piston shaft 365 and includes a spring 371 adapted to bias the piston 361 into an extended condition. The chamber 367 also includes porting 373 for controlled intake and expulsion of fluid, which in this embodiment is typically water from the surrounding seawater environment. The free end of the piston shaft 365 is fitted with a resilient bumper 375 for contact with the respective flap 353.

When the flap 353 is in the closed condition (as depicted in FIG. 53), the bumper 375 is in contact with the flap 353, the piston 361 is in the retracted condition within the cylinder 359 and the spring 371 is compressed. Upon movement of the flap 353 out of the closed condition (as depicted in FIG. 54), the flap 353 separates from the bumper 375, allowing the piston 361 to extend under the influence of the compressed spring 371. Extension of the piston causes progressive expansion of the chamber 367 which in turn causes water to be drawn into the chamber 367 through the porting 373. Upon return movement of the flap 353 (as depicted in FIG. 55), the flap 353 first engages the bumper 375 which affords some initial cushioning by virtue of its resilient nature. Continued return movement of the flap 353 applies force to the piston 361, causing it to retract. Retraction of the piston 361 causes progressive contraction of the chamber 367 which in turn causes expulsion of water from the chamber 367 through the porting 373. The porting 373 is sized to regulate the rate of expulsion of the water from the chamber 367 and thereby provides a viscous damping effect. Accordingly, the flap 353 completes its closing action in a controlled manner and without excessive force.

Referring now to FIG. 56, a sixth embodiment of the invention relates to a wave energy conversion system 400 comprising a plurality of units 401 each being one of the apparatus according to the previous embodiments and each having a buoyant actuator 10. With such an arrangement, the respective buoyant actuators 10 are disposed in an array 403 of buoyant actuators. Any number of buoyant actuators 10 can be provided in the array.

The spacing between units 401 and the patterning of the array 403 are features that are optimised with respect to the actual wavelength of the dominant sea state and the directions of the waves.

The apparatus according to each embodiment may operate in conjunction with the closed loop system (not shown) in which energy in the form of the high pressure working fluid is exploited for use, for example, in power generation or a desalination plant.

From the foregoing, it is evident that each of the embodiments provides an energy release buoyant actuator which is relatively lightweight and which can be rendered effectively inoperative in adverse conditions for preservation.

Further, it should be appreciated that the scope of the invention is not limited to the scope of the embodiments disclosed.

While the embodiments described are each of modular construction, it should be understood that the buoyant actuator in accordance with the invention can be constructed as a single unit and transported to site in that condition.

Throughout the specification and claims, unless the context requires otherwise, the word “comprise” or variations such as “comprises” or “comprising”, will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

The claims defining the invention are as follows:

1. A buoyant actuator responsive to wave motion comprising a body defining an interior volume comprising at least one gate means to vary the response of the buoyant actuator to the wave motion.

2. The buoyant actuator according to claim 1 wherein the gate means is confined within the interior volume.

3. The buoyant actuator according to claim 1 or 2 wherein the gate means is adapted to permit water to flow through the body of the buoyant actuator.

4. The buoyant actuator according to claim 1, 2 or 3 wherein the gate means is responsive to a particular sea state.

5. A buoyant actuator according to any one of the preceding claims wherein the gate means comprises at least one closure element movable between a closed condition which it normally occupies and which impedes water flow through the body, and an open condition in which it permits water flow through the body.

6. The buoyant actuator according to claim 5 wherein a releasable coupling is provided for releasably maintaining the closure element in the closed condition, the releasable coupling being adapted to actuate to release the closure element to allow it to move from the closed condition to the open condition to establish the open condition.

7. The buoyant actuator according to claim 6 wherein the releasable coupling comprises a magnetic coupling.

8. The buoyant actuator according to any one of the preceding claims wherein the closure element comprises a flap.

9. The buoyant actuator according to claim 8 wherein the flap is pivotally movable between a closed condition which it
normally occupies and which impedes water flow through the body, and an open condition in which it swings outwardly to permit water flow through the body.

10. The buoyant actuator according to claim 7, 8 or 9 wherein the magnetic coupling comprises a magnet means on the closure means adjacent the inner end thereof and a mating part to which the magnet means is magnetically attracted.

11. The buoyant actuator according to claim 10 wherein the magnet means comprises an array of permanent magnets accommodated within a housing.

12. The buoyant actuator according to claim 11 wherein the housing presents a contact face to confront the mating part of the magnetic coupling, the permanent magnets being recessed with respect to the contact face.

13. The buoyant actuator according to claim 12 wherein the housing provides a cushioning portion between the contact face and the permanent magnets.

14. The buoyant actuator according to any one of the preceding claims wherein the gate means comprises a plurality of closure elements.

15. The buoyant actuator according to claim 14 wherein the closure elements are configured to cooperate with each other to provide a barrier across the flow path through the body, each closure element being moveable into and out of a condition in which it cooperates with the other closure elements to provide the barrier.

16. The buoyant actuator according to claim 15 wherein the barrier provided by the closure elements extends across the flow path to be substantially normal to the direction of flow of water through the body.

17. The buoyant actuator according to claim 14 wherein the barrier is of raked construction such that each closure element when in the closed condition is inclined to the direction of flow of water through the body.

18. The buoyant actuator according to claim 17 wherein each closure element is inclined in the direction towards the open upper end of the body.

19. The buoyant actuator according to any one of the preceding claims wherein the body is configured to have a longitudinal extent and to provide the flow path along which the water can flow through the body parallel to the longitudinal axis of the body.

20. The buoyant actuator according to any one of claims 1 to 18 wherein body is of frusto-conical configuration having an upper end, a lower end and a side extending between the two ends.

21. The buoyant actuator according to claim 20 wherein the side is of convex shape and bulging at the middle.

22. The buoyant actuator according to any one of the preceding claims wherein the body is of modular construction.

23. The buoyant actuator according to any one of the preceding claims wherein the body comprises an inner structure supporting a shell which defines an upper end, a lower end and the side.

24. The buoyant actuator according to claim 23 wherein the shell comprises a plurality of sections configured as panels adapted to be connected together.

25. The buoyant actuator according to claim 24 wherein each panel is of generally rectangular construction.

26. The buoyant actuator according to claim 25 wherein the connections between adjacent panels comprise half-lap joints.

27. The buoyant actuator according to any one of the preceding claims wherein the body is provided with one or more anchoring points to facilitate movement of the buoyant actuator once deployed in water.

28. The buoyant actuator according to any one of the preceding claims further comprising a damper means for damping movement of each closure element into the closed condition.

29. The buoyant actuator according to any one of claims 15 to 28 wherein the barrier provided by the closure elements extends across the flow path to be substantially normal to the direction of flow of water through the body.

30. The buoyant actuator according to any one of claims 15 to 28 wherein the barrier is of raked construction such that each closure element when in the closed condition is inclined to the direction of flow of water through the body.

31. A buoyant actuator responsive to wave motion comprising a body incorporating a flow path along which water can flow, and a gate means for controlling flow along the flow path, the gate means comprising a plurality of closure elements configured to cooperate with each other to provide a barrier across the flow path through the body, each closure element being moveable into and out of a condition in which it cooperates with the other closure elements to provide the barrier.

32. The buoyant actuator according to claim 31 wherein the barrier is so configured and positioned to be at the confines of the body and wherein the closure elements which remain within the confines of the body even when in the fully open condition.

33. The buoyant actuator according to claim 31 or 32 wherein the barrier provided by the closure elements extends across the flow path to be substantially normal to the direction of flow of water through the body.

34. The buoyant actuator according to claim 31 or 32 wherein the barrier is of raked construction such that each closure element when in the closed condition is inclined to the direction of flow of water through the body.

35. A buoyant actuator responsive to wave motion comprising a body having a support structure adapted to receive a plurality of sections defining a chamber for interrupting water flow through the body, wherein the support structure and plurality of sections are adapted to be transported and assembled in situ.

36. A buoyant actuator for immersion in a body of water, the buoyant actuator comprising a body defining a hollow interior adapted to receive a volume of water from the surrounding water body, the body having flow control means for controlling flow through the hollow interior, the flow control means having a first condition for blocking or at least impeding fluid flow through the body and a second condition permitting fluid flow through the hollow interior.

37. The buoyant actuator according to claim 36 wherein the flow control means are confined within the interior volume.

38. A buoyant actuator responsive to wave motion comprising a body defining an interior volume, the body comprising an inner structure supporting a shell which defines the interior volume, the shell comprising a plurality of sections configured as panels adapted to be connected together.

39. A buoyant actuator responsive to wave motion comprising a body defining an interior volume, the body being of frusto-conical configuration having an upper end, an open lower end and a side extending between the two ends.
40. A buoyant actuator responsive to wave motion comprising a body incorporating a flow path along which water can flow, and a gate means for controlling flow along the flow path, the gate means comprising a plurality of closure elements providing a barrier across the flow path through the body, the closure elements being moveable into and out of a condition in which it cooperates with the other closure elements to provide the barrier, and latch means for releasably retaining each closure element in said condition, the latch means comprising a magnetic coupling.

41. A kit for assembling a buoyant actuator according to any one of the preceding claims.

42. A kit for assembling a buoyant actuator, the kit comprising a support structure and a plurality of sections adapted for connection to the support structure to assemble the buoyant actuator.

43. A wave energy conversion system comprising at least one buoyant actuator according to any one of claims 1 to 40.

44. A method of harnessing wave energy in a body of water, the method comprising deployment of a buoyant actuator according to any one of claims 1 to 40 in the body of water.

45. A buoyant actuator substantially as herein described with reference to the accompanying drawings.

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