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[54] **SUBSURFACE CURRENT UTILIZING BUOY SYSTEM**

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[73] Assignee: **Sanders Associates, Inc.**, Nashua, N.H.

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[52] **U.S. Cl.** ..... **9/8 R**, 114/16 E

[51] **Int. Cl.** **B63b 21/52**

[58] **Field of Search** ..... 9/8; 114/16 E, 235 B; 244/33; 102/13, 14

[56] **References Cited**

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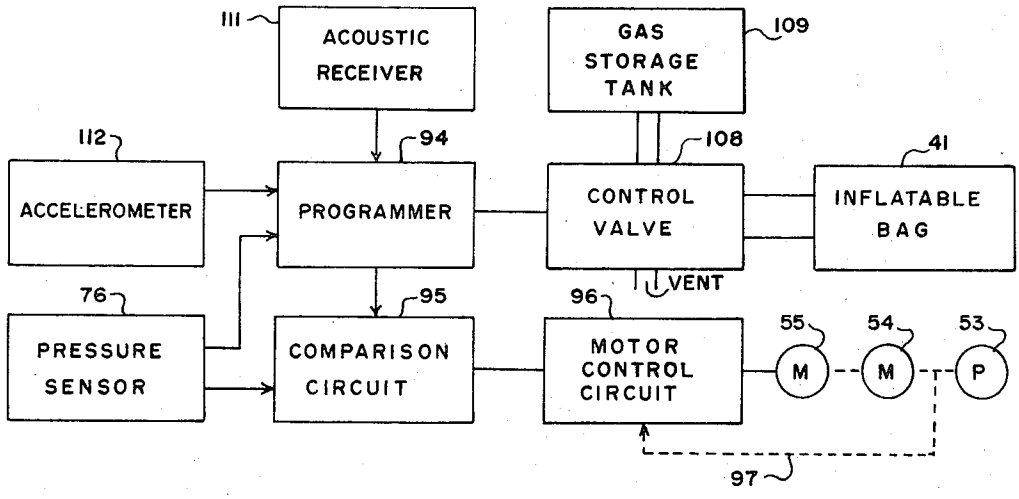
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Attorney, Agent, or Firm—Louis Etlinger; William L. Hunter

[57] **ABSTRACT**

A sonobuoy system is described in which the buoy proper is anchored by a slack cable from which an array of hydrophones is suspended. The sonobuoy is deployed beneath the surface and its depth is controlled by varying the attitude of the buoy so that ocean currents, which are present virtually everywhere in the sea, act on the buoy to generate positive or negative lift thereby increasing or decreasing the depth in accordance with a predetermined program or on command. Vanes attached to the buoy augment the lift of the body of the buoy. Attitude is changed by pumping water between fore and aft tanks. Provision is made for bringing the buoy to the surface from time to time to abstract the information which has been gathered.

24 Claims, 11 Drawing Figures



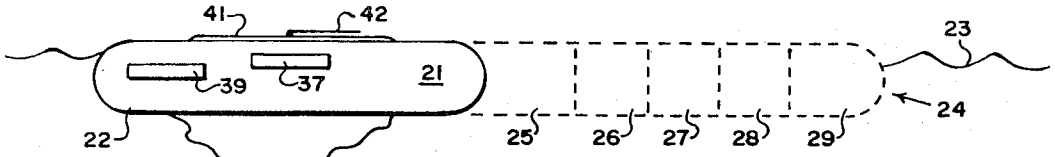
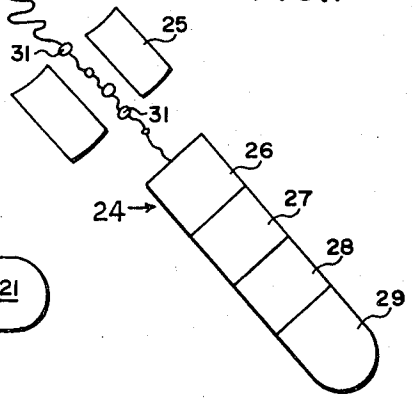


FIG. 1



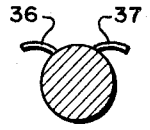
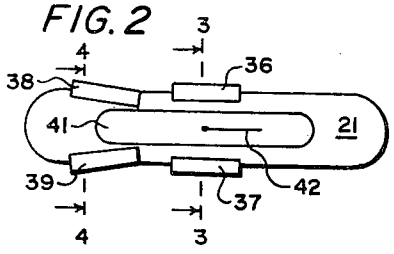


FIG. 3

FIG. 2



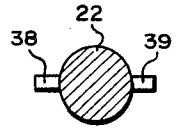


FIG. 4

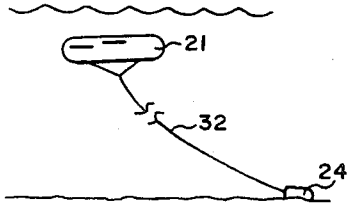


FIG. 5

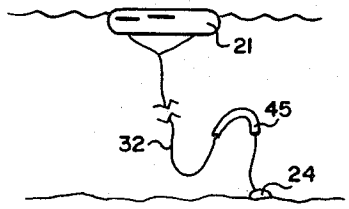


FIG. 7

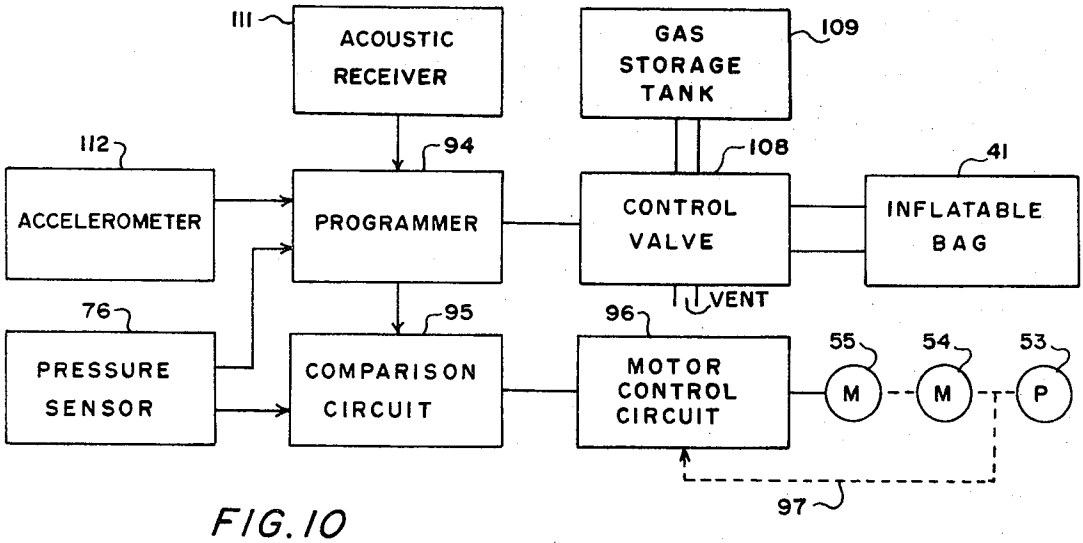
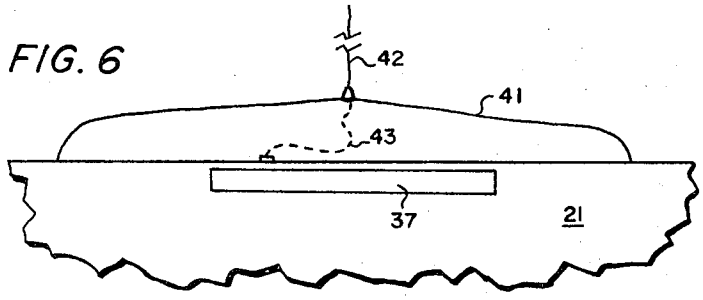


FIG. 10

FIG. 6



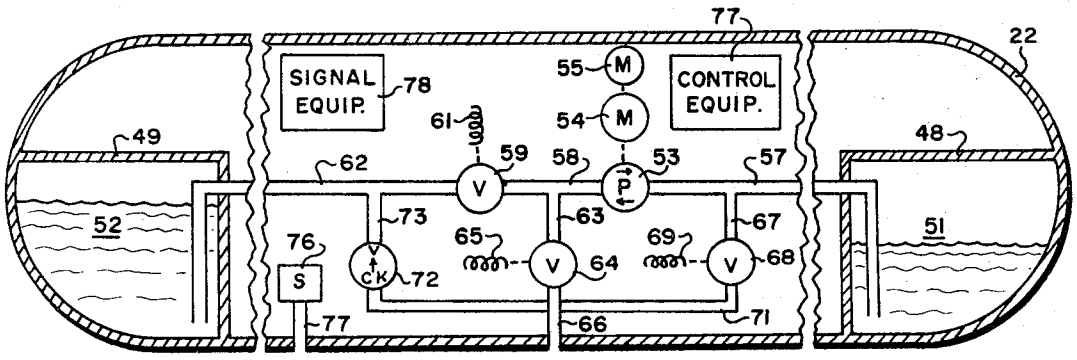


FIG. 8

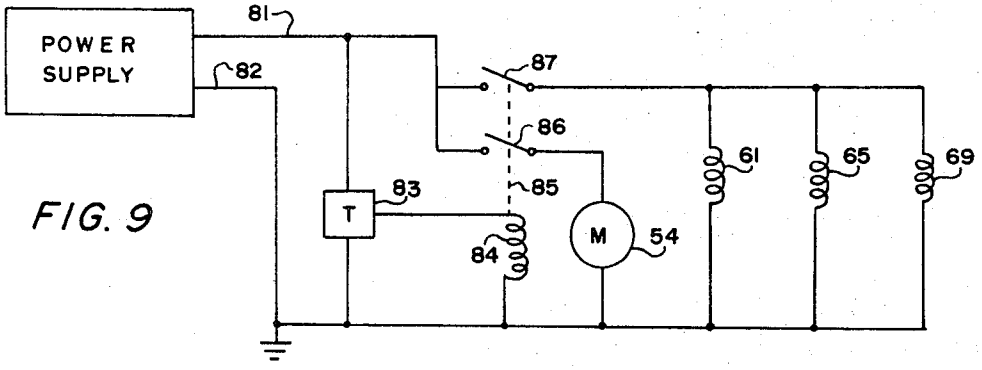


FIG. 9

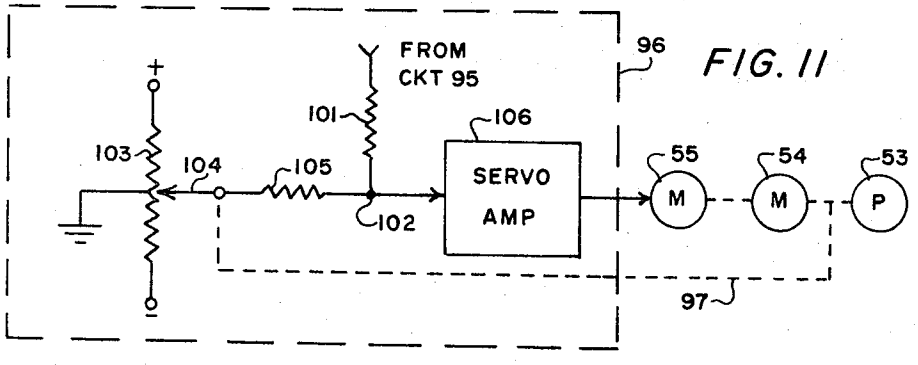


FIG. 11

SUBSURFACE CURRENT UTILIZING BUOY SYSTEM

FIELD OF THE INVENTION

This invention relates generally to buoys which are deployed in the ocean and which contain or to which are attached equipment for detecting various phenomena and particularly to sonobuoys equipped to detect underwater sounds.

BACKGROUND OF THE INVENTION

Typically a sonobuoy is deployed at a known position in the ocean and is held there, at or near the surface, by a long cable connected to an anchor resting on the bottom. One or more sound sensitive devices are supported, either on the anchor cable or by a separate support, to generate signals in response to incident acoustic energy. Instead of being transmitted continuously, such signals are usually stored by a suitable recorder in the sonobuoy and transmitted from time to time to a surface vessel or to a hovering aircraft. Transmission is usually by means of a radio link and accordingly it is necessary that the sonobuoy, or at least part of it, be above the surface of the sea during transmission.

Various sonobuoy mooring systems have been proposed. In one arrangement, the entire sonobuoy floats on the surface at all times, held by a long slack cable fastened to an anchor. This arrangement requires that the sonobuoy package and the cable be sturdy enough to withstand the constant buffeting by surface waves, winds and currents. Additionally, the buoy, being on the surface is subject to ready detection by hostile forces.

In another arrangement, the sonobuoy is held well below the surface by a taut anchor cable. A small surface float, carrying an antenna and perhaps other equipment, is tethered to the main buoy by a slack cable. This arrangement requires substantial positive buoyancy, a strong cable, and a heavy anchor. Although the surface float may be smaller than the sonobuoy, nevertheless it is on the surface and subject to damage and/or detection.

It is a general object of the present invention to provide an improved sonobuoy system.

Another object is to provide a sonobuoy which remains entirely below the surface except during periods of data transmission.

Another object is to provide a sonobuoy which is never exposed to excessively rough sea surfaces.

Another object is to provide a sonobuoy which will seek and maintain any commanded depth beneath the surface.

Another object is to provide an arrangement by which the depth of the sonobuoy can be varied from time to time or continuously by a predetermined program or by command.

A more specific object is to provide a sonobuoy the depth of which can be varied by utilizing the power contained in ocean currents.

SUMMARY OF THE INVENTION

In a recent examination of ocean current distribution, it was found that virtually nowhere in the first 1,000 feet of ocean surface water does the current drop below 0.05 knots, except during tide switching in shelf waters which is only for half an hour or so. The present invention is based on the principle of utilizing, rather than resisting, such currents. In a preferred embodiment, the buoy is tethered by a slack moor. Its depth beneath the surface is measured by a suitable sensor such as a pressure sensitive device which controls a mechanism for adjusting the attitude of the buoy itself and/or vanes attached thereto thereby varying the lifting forces exerted and the depth of the buoy. The depth may be maintained at a predetermined fixed level, or varied in accordance with a program, or varied in response to a command.

BRIEF DESCRIPTION OF THE DRAWING

For a clearer understanding of the invention, reference may be made to the following detailed description and the accompanying drawing, in which:

FIG. **1** is a schematic elevation view of the buoy just after it has been deployed;

FIG. **2** is a schematic plan view of the buoy;

FIG. **3** is a schematic cross section view taken on the line **3—3** of FIG. **2**;

FIG. **4** is a schematic cross section view taken on the line **4—4** of FIG. **2**;

FIG. **5** is a schematic elevation view showing how the buoy is held by the slack moor in the presense of ocean currents;

FIG. **6** is a fragmentary schematic elevation view showing the buoy on the surface during transmission with an antenna on top of an inflated bag;

FIG. **7** is a schematic elevation view showing how the cable may be kept off the ocean floor in the absence of ocean currents;

FIG. **8** is a partial cross section view of the buoy showing the buoyancy and attitude adjusting equipment;

FIG. **9** is a schematic diagram of the initial buoyancy control circuit;

FIG. **10** is a schematic block diagram of the depth control equipment; and

FIG. **11** is a schematic block diagram of a portion of the equipment shown in FIG. **10.**

DESCRIPTION OF PREFERRED EMBODIMENT

Referring first to FIG. **1** a sonobuoy incorporating the invention is indicated generally by the reference character **21** and includes a housing **22.** This figure is not drawn to scale and the invention may be used with many of the standard sonobuoy packages, one of which is about 60 inches long and 7 inches in diameter. The buoy **21** is shown a short time after depolyment by a ship or by an aircraft. Since it initially has a large positive buoyancy, it is, at this time, at or near the surface **23** of the sea. Before being deployed, it had attached thereto an appendage indicated generally by the reference character **24** and shown in dotted lines in the position as occupied before deployment. More specifically, the appendage **24** includes a sensor package **25,** a cable metering and lock up package **26,** a cable storage package **27,** a floatation package **28** and a combined power supply and anchor package **29.**

When the sonobuoy is first dropped into the water, it will, in all probability, sink beneath the surface momentarily but since it has substantial positive buoyancy it will soon rise to the surface. The appendage disconnects itself and starts falling to the bottom. The sensor package **25** falls away exposing a plurality of acoustic sensing devices such as the hydrophones **31** fastened to

or suspended from a cable **32.** This cable includes conductors for carrying power and signal currents and is fastened to the housing **22** by means of a bridle **33** which, in turn, is fastened near opposite ends of the sonobuoy **21.** Since the buoy is floating, the descent of the appendage **24** causes the cable **32** to pay out until the appendage reaches the bottom. Then the drifting of the buoy **21** pulls additional cable from the storage package **27** and through the lock up package **26.** It is preferred that the total length of the cable be about 30 percent greater than the depth of the water at the point of deployment. This can be accomplished simply by predetermining the length of the cable or by adjusting the metering and lock up package **24** for a length of cable appropriate to the depth at which the buoy is to be deployed. Alternatively, a more complex arrangement by which an additional 30 percent of cable is payed out after the package hits the bottom may be used but such apparatus has not been shown because it is within the skill of those familiar with the art and is not part of the present invention. The important thing for present purposes is that there be sufficient cable to constitute a slack moor, that is, that the cable extending from the anchor to the buoy **21** have a substantial horizontal component as shown in FIG. **5.**

As shown in FIGS. **1, 2,** and **3,** the buoy **21** is provided with vanes **36** and **37** fastened about amidships of the housing **22** near the top as shown. These vanes are to provide a lift in addition to that provided by the surface of the housing **22.** Preferably they are curved in shape so that, before deployment, they fold flush against the cylindrical surface of the housing **22** but are extended as shown after deployment. Such extension may be done manually or automatically. The important thing is that they be so extended after the buoy is deployed.

As shown in FIGS. **1, 2,** and **4,** an additional pair of vanes **38** and **39** is disposed on the housing **22** near the stern and positioned as shown to prevent alternate vortex shedding, thereby eliminating oscillations in the horizontal plane as the water currents pass over the buoy **21.** These vanes are also preferably curved to conform to housing **22** to simplify storage and handling before deployment.

On the top of the buoy **21** at about the central portion there is a conforming rubber skin or bag **41** in the middle of which is mounted an antenna **42.** When the buoy is beneath the surface, the bag **41** lies close against the surface of the housing **22** and the antenna **42** is disposed horizontally as nearly flush as may be with the top surface of the housing **22.** When the buoy is brought to the surface for the transmission of data, as will be more fully discussed, the bag **41** is inflated thereby erecting the antenna **42,** as shown in FIG. **6.** A conductor **43** connects the antenna with the interior of the sonobuoy **21.**

If the buoy **21** is to be deployed in regions where slack water is likely to occur, some precautions should be taken to keep the cable off the bottom of the ocean so that it does not become tangled with anything should the buoy drift to a position nearly above the anchor. As shown in FIG. **7,** this may be done by making a portion of the cable **45** which is near the anchor of a buoyant material or by attaching floats to such a portion. This end may be accomplished either by making the cable buoyant in the first place or by storing floats in the package **28** and attaching them to the cable as the last portion is payed out.

Referring to FIG. **8,** there are shown schematicaaly two walls **48** and **49** which form, along with the housing **22,** fore and aft tanks **51** and **52,** respectively. A bidirectional positive displacement pump **53** is mechanically connected to two electric motors **54** and **55.** The motor **54** is used to establish initial buoyancy conditions while the motor **55** is used to vary the attitude of the buoy. It would of course be possible to use a single motor for both purposes but it is preferred, at present, to use two motors, as shown.

One side of the pump **53** is connected by means of a conduit **57** directly to the interior of the tank **51** while the opposite side is connected by means of a conduit **58** to one side of a valve **59,** operated by a solenoid **61.** The other side of the valve **59** is connected by means of a conduit **62** to the interior of the tank **52.** The conduit **58** communicates with a conduit **63** which in turn communicates with one side of a valve **64,** operated by a solenoid **65.** The other side of the valve **64** is connected to a conduit **66** which passes through the housing **22** and communicates with the open sea. The conduit **57** communicates with a conduit **67** which is connected to one side of a valve **68,** operated by a solenoid **69.** The other side of the valve **68** is connected by means of a conduit **71** to the inlet side of a check valve **72,** the outlet side of which is connected by means of a conduit **73** to the conduit **62.** The check valve **72** will pass fluid only in the direction shown, that is from the conduit **71** to the conduit **73** but not in the other direction. The valve **59** is open while the valves **64** and **68** are closed in the absence of energization of their respective solenoids. Energization of the solenoids closes valve **59** and opens valves **64** and **68.**

Also shown in FIG. **8** is a pressure sensor **76** which communicates with the open sea by means of a conduit **77** which extends through the housing **22.** The sensor **76** generates a signal, such as an electric voltage or current or a mechanical displacement, which is indicative of the pressure incident on the housing **22** which in turn is indicative of the depth of the buoy. Additional control equipment, to be more fully described, is shown in block diagram form at **77.** The equipment for processing and transmitting the signal from the hydrophone **31** is shown in block diagram form at **78.**

When the sonobuoy **21** is first deployed in the water, it has a very substantial positive buoyancy and floats on the surface. After all of the cable has been payed out, it is preferred that the buoyancy be substantially decreased so that it is just slightly buoyant during normal submerged operation. This is accomplished by means of the valving apparatus just described above in connection with FIG. **8** and in connection with the circuitry of FIG. **9.** Operation of this equipment starts after the sonobuoy section **24** reaches the bottom and all the extra cable is payed out. At that time, the power supply within the package **29** is activated. This power supply may be a radioisotope thermoelectric generator or a battery or other kind of power source and is preferably converted from a low voltage to a high voltage direct current for more efficient power transmission up the cable to the sonobuoy **21** where it is reconverted to a low voltage unidirectional current.

Referring now to FIG. **9,** prior to the time the power supply is made active there is no voltage in the circuit and the solenoids **61, 65** and **69** are de-energized with

the result that the corresponding valves 64 and 68 are closed while the valve 59 is open. When all of the cable is payed out, the power supply is made active and a voltage appears on conductors 81 and 82. A timing circuit 83 is connected to these conductors and operates, when energized, to put a voltage across a winding 84 for a predetermined time starting immediately. The winding 84 is the operating winding of a relay indicated generally by the reference character 85 and which includes switches 86 and 87. When the winding 84 is energized, the switch 87 closes, energizing solenoids 61, 65 and 69, thereby closing valve 59 and opening valves 64 and 68. One terminal of the motor 54 is permanently connected to the ground conductor 82 and closure of switch 87 energizes the motor to run in such a direction as to cause the pump 53 to pump fluid to the right as viewed in FIG. 8. Thus, fluid is drawn through the valve 64, the conduits 63 and 58, the pump and the conduit 57 to the tank 51 and also to the conduit 67, valve 68, valve 72 and conduit 62 to the tank 52. Since the pump is a positive displacement pump, operation for a predetermined time puts a predetermined quantity of fluid into the tanks 51 and 52 which is divided approximately equally between them. This quantity is so predetermined as to give the proper buoyancy to the buoy 21 which is a slight positive buoyancy sufficient to cause the buoy to tend to rise in the absence of water current drag exerted on the cable 32. At the end of the predetermined time, the winding 84 is de-energized, thereby shutting off the motor 54, and de-energizing the winding 61, 65 and 69 so as to close the valves 64 and 68 and open the valve 59. The result of this is that the pump 53 is now connected so that it can now pump fluid back and forth between the tanks 51 and 52.

Referring now to FIG. 10 there is shown in block diagram form the equipment which, in conjunction with that previously described, controls the depth of the sonobuoy 21. A programmer 94 includes a clock and generates signal voltages indicative of the desired depth of the sonobuoy at various times in accordance with a predetermined time schedule. For example, it may be desired that it stay below the surface at a certain depth for 23 hours of the day and then rise for 1 hour. The voltage from the programmer 94 is compared with that of the depth sensor 76 in a comparison circuit 95 which generates an error signal which is passed to a motor control circuit 96 which controls the motor 55 to actuate the pump 53 so as to pump fluid between the tanks 51 and 52 in the proper direction to change the weight distribution of the buoy and consequently its attitude and the angle of attack of the ocean currents thereby causing the buoy to rise or descend as directed by the error signal. It is preferred that the magnitude of the change in attitude be correlated with the magnitude of the error signal so that a command to change depth by small amount causes less change in attitude than a command to change depth by a large amount. To accomplish this, a signal indicative of the number of revolutions of the pump 53 is fed back to the circuit 96 where it is compared with the error signal from the comparison circuit 95. Such feedback could, of course, be electrical but at present is is preferred to use a simple mechanical converter including appropriate gearing, all as shown schematically by the dotted line 97. Any of various comparison and balancing circuits may be used, that preferred at present being shown schematically in FIG. 11.

Referring now to FIG. 11, The error signal from the comparison circuit 95 is applied through a summing resistor 101 to a junction 102. A potentiometer 103 having a grounded center tap has its opposite extremities connected to voltage sources of opposite polarity. Its wiper 104 is positioned by the mechanical connection 97 and is electrically connected through a summing resistor 105 to the junction 102. The voltage of the junction 102 is the input to a servo amplifier of conventional construction, the output of which controls the motor 55.

The apparatus is designed so that when the buoy is at the desired depth, the error signal from circuit 95 is zero and the wiper 104 in the center position shown. If the buoy is then commanded to change depth, an error signal from circuit 95 places a voltage on junction 102 which, through amplifier 106 and motor 55 causes the pump 53 to rotate. The feedback path 97 adjusts the wiper 104 until the voltage balances the error signal, whereupon the voltage of junction 102 falls to zero and the pump stops. As the buoy approaches the desired depth, the error signal from circuit 95 decreases, placing a voltage on junction 102 which drives the pump in the opposite direction proportionally reducing buoy vertical travel velocity until the buoy reaches the commanded depth.

It is to be noted that operation of either motor 54 or motor 55 adjusts the wiper 104. Therefore, the apparatus is designed and the initial conditions established so that after the motor 54 has concluded its pumping operation to establish the initial buoyancy conditions, as previously explained, the wiper 104 is centrally located, as shown. Therefore, before deployment of the buoy, the wiper 104 is positioned away from the center by an amount indicative of the number of revolutions of the pump 53 necessary to pump the predetermined quantity of water into the tanks 51 and 52. Since the pump 53 is a constant displacement pump, the quantity of water pumped is directly related to number of revolutions which in turn is directly related to the time of operation. Accordingly, it is necessary to correlate, in the design, the parameters of the pump 53, motors 54 and 55, the timer 83 and the initial offset of the wiper 104.

Let us assume that the buoy 21 has been at its programmed depth gathering information for a programmed time, for example, 23 hours, and that it is to be brought to the surface so as to transmit the information. The programmer 94 generates a suitable signal which operates through the circuits and other equipment just described to increase the lift and cause the buoy 21 to ascend. As it reaches a predetermined depth, near the surface, as measured by the sensor 76, the programmer 94 operates a control valve 108 so as to open, for a predetermined time, a passage from a tank 109 containing a gas under pressure to the inflatable bag 41 which adds further buoyancy, erects the antenna 42, and holds the antenna above the waves after the buoy has surfaced. At the end of another predetermined time, the programmer 94 operates the valve 97 so as to vent the gas from the bag 41 to the atmosphere. The programmer than generates another signal commanding the buoy to descend to its previous depth, or, for that matter, to a different depth.

Also shown in FIG. 10 is an acoustic receiver 111 which may receive sonic signals and override the programmer 94 should it, at any time, be desired to bring

the sonobuoy to the surface. This receiver may, for example, by a part of a commercially available acoustic command system, one suitable kind being that marketed by AMF, Alexandria Division, Alexandria, Va, and designated model 200.

Waves at the surface of the sea cause an orbital circulation of the underlying water. Such motion, although greatest near the surface, extends a considerable distance below. As the waves increase in size, the actual motion and the accompanying accelerations likewise increase and extend further beneath the surface. This phenomenon is utilized to prevent a programmed surfacing of the buoy if the sea is so rough as to prevent reliable transmission of data and/or endanger the buoy. An accelerometer **112** is provided which senses the vertical acceleration of the orbital motion to which the buoy is subjected as it approaches the surface. If such acceleration exceeds a predetermined threshold, a signal is sent to the programmer **94** directing it to override the programmed surfacing and to command the buoy to descend.

From the foregoing it will be apparent that applicant has provided a novel system which enables the sonobuoy to be disposed beneath the surface of the sea for the majority of the time where it is not subject to buffeting by waves and is not subject to ready detection by the enemy. The sonobuoy can be programmed to go to any desired depth by utilizing the free energy of ocean currents and to stay there for any desired length of time consuming negligible electric power. During this time the hydrophones can transmit their signals to the signal equipment **78** which, for example, may include a tape recorder and play back equipment as well as necessary radio transmitters all as is well known to those skilled in the art. When the sonobuoy comes to the surface, the recorder is played back and the information transmitted to a nearby surface ship or hovering aircraft. The details of the storage and transmission of the data from the hydrophones however, are not a part of Applicant's invention and are well knwon to those skilled in the art.

Although a specific example incorporating the Applicant's invention has been described in considerable detail for illustrative purposes, many modifications will occur to those skilled in the art. It is therefore desired that the protection afforded by Letters Patent be limited only by the true scope of the appended claims.

What is claimed is:

1. A buoy system for deployment in a body of flowing water, comprising,

a housing,

an anchor,

a slack cable interconnecting said housing and said anchor, and

means responsive to a signal for varying the lift produced by the flow of water over the surface of said housing.

2. A buoy system in accordance with claim **1** in which said means for varying includes means for varying the attitude of said housing.

3. A buoy system in accordance with claim **1** in which said signal is indicative of water pressure incident on said housing, whereby the depth may be controlled.

4. A buoy system in accordance with claim **1** in which said housing, its contents and the cable have an overall positive buoyancy.

5. A buoy system in accordance with claim **1** which includes vanes attached to the exterior of said housing to increase the lift.

6. A buoy system in accordance with claim **1** in which said signal is indicative of depth.

7. A buoy system in accordance with claim **1** in which said signal is an externally originating command.

8. A buoy system in accordance with claim **1** in which said signal is indicative of acceleration.

9. A buoy system in accordance with claim **1** in which said signal is indicative of vertical acceleration above a threshold level caused by surface waves.

10. A buoy system in accordance with claim **1** in which said signal is indicative of a predetermined program.

11. A buoy system in accordance with claim **10** in which said program includes a command to bring said housing to the surface.

12. A buoy system in accordance with claim **11** including means for detecting a rough condition of the sea surface upon ascent and means responsive to the detection of a roughness exceeding a predetermined threshold for overriding a command to bring said housing to the surface and for commanding said housing to descend.

13. A buoy system in accordance with claim **1** in which said cable is connected to said housing by means of a bridle fastened near opposite ends thereof.

14. A buoy system in accordance with claim **1** in which said cable includes conductors for the transmission of data and power.

15. A buoy system in accordance with claim **1** in which said means for varying includes means for maintaining said housing at a predetermined depth.

16. A buoy system in accordance with claim **1** which includes a plurality of hydrophones supported by said cable.

17. A buoy system in accordance with claim **16** having means including an antenna for transmitting the information received by said hydrophones.

18. A buoy system in accordance with claim **17** in which said means for varying includes means for bringing said housing to the surface of the water to transmit said information.

19. A buoy system in accordance with claim **18** which includes a gas tight bag, means for inflating said bag when said housing is on the surface and means for mounting said antenna on the upper portion of said bag.

20. A buoy system in accordance with claim **1** in which said means for varying includes means for varying the distribution of the weight within said housing.

21. A buoy system in accordance with claim **20** in which said means for varying includes fore and aft tanks partially filled with water and a positive displacement pump operatively connected to transfer water from one to the other of said tanks.

22. A buoy system in accordance with claim **1** including means for reducing the buoyancy of said housing after its deployment in the water.

23. A buoy system for deployment beneath the surface of a body of flowing water, comprising,

a buoy having positive buoyancy,

an anchor disposed on the bottom of the body of water, and

a flexible cable having a length substantially greater than the depth of said body of water interconnecting said buoy and said anchor,

said buoy including a pressure sensitive instrument for generating a signal indicative of the depth of said buoy beneath the surface,

said buoy also including means responsive to said signal for varying the weight distribution of said buoy, the attitude of said buoy, and lift due to the flow of water over the surface of said buoy, whereby the depth of said buoy is varied.

24. A buoy system in accordance with claim **23** in which said means for varying includes fore and aft tanks partially filled with water and a pump for transferring water between said tanks.

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