Aug. 7, 1962 R. E. FRANÇOIS 3,048,814

UNDERWATER TARGET SIMULATOR

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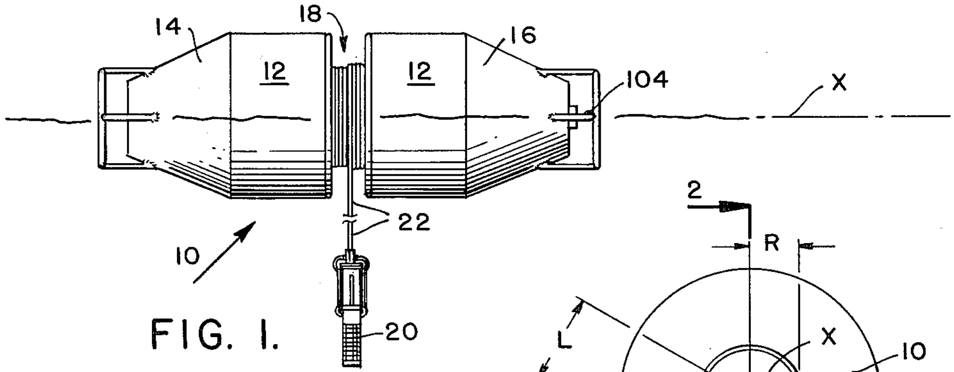

FIG. 1.

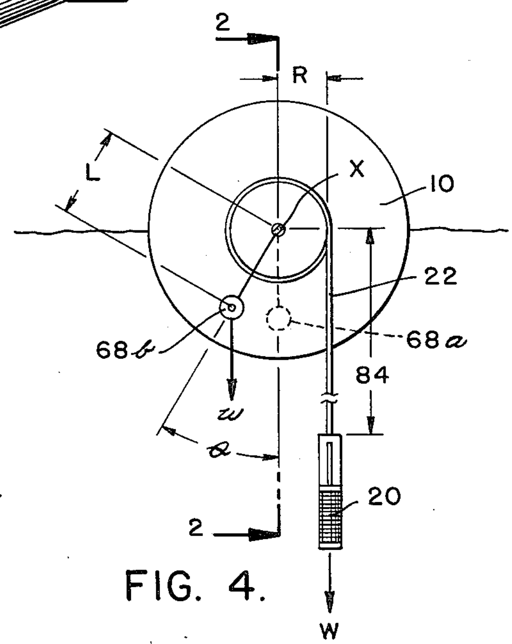

FIG. 4.

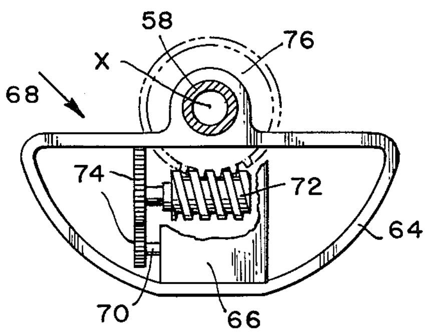

FIG. 3.

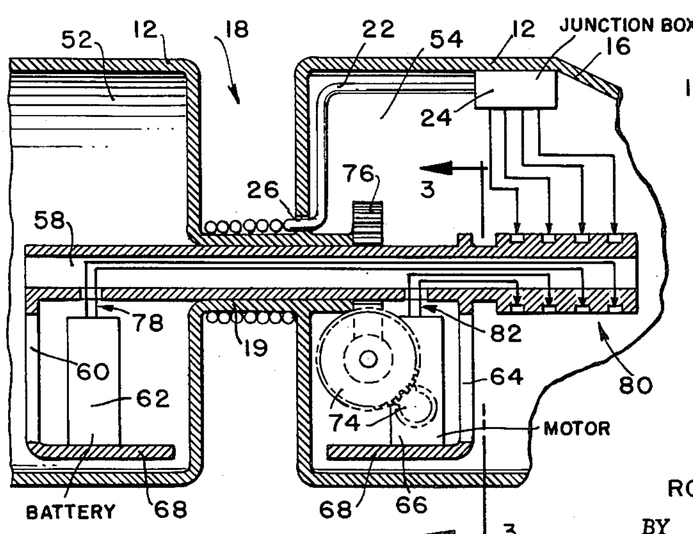

FIG. 2.

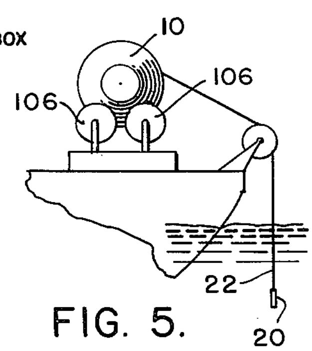

FIG. 5.

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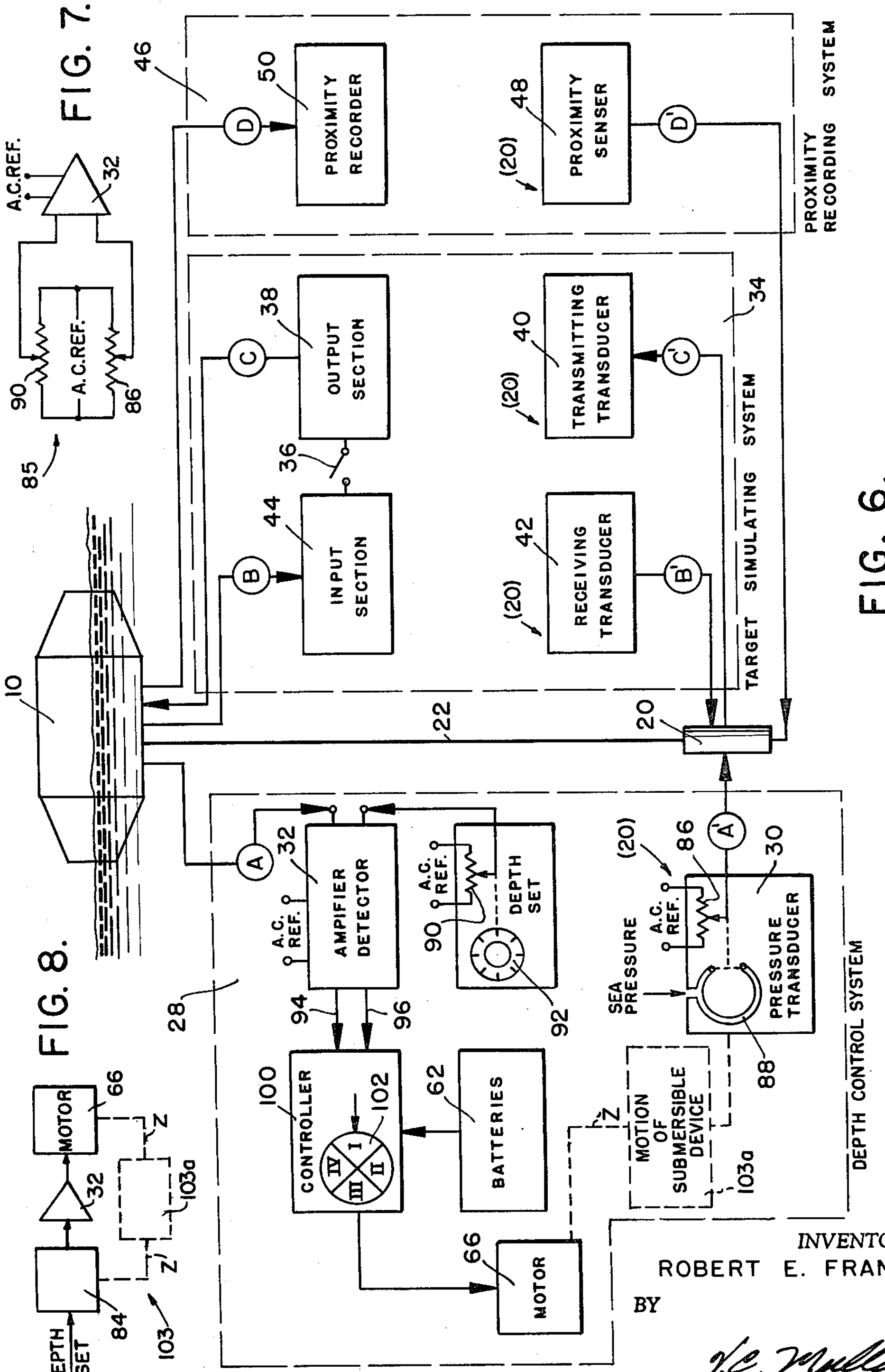

FIG. 6.

FIG. 7.

FIG. 8.

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UNDERWATER TARGET SIMULATOR

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5 Claims. (Cl. 340—4)

This invention relates to underwater target simulators and more particularly to improvements in the floatation, reeling and depth control apparatus for such devices.

Underwater target simulators are used to provide targets for acoustic homing underwater missiles in fleet or proofing exercises. Such simulators include submersible sound transmitting equipment, which is lowered beneath the surface of the sea to a depth whereat a submarine, the intended target for such missile may operate. When employed in conjunction with a missile having a passive acoustic homing system of the type that homes toward submarine operating noises, the device transmits underwater sounds simulating such operating noises. When employed in conjunction with a missile having an active acoustic homing system, of the type that homes toward objects which reflect sound impulses sent out by the attacking missile, the device transmits sound simulating such reflected sound impulses. Also, although such devices are stationary, they may simulate a moving target by employing the Doppler principle. It has been the practice to operate such devices from an independent floating structure, as for example, from the deck of a warship, or from semi-permanent rafts in inland waters, and to employ conventional windlass equipment to lower and raise the submersible equipment, such windlass equipment being of the type which only permits control of the amount of cable payed out. Operating the simulator from such independent floating structures has been, at times, inconvenient and costly. For example, when operated from ships, at least two ships are required to schedule target exercises, one being used solely as a target tending ship, and when operated from a semi-permanent raft the cost of installing and maintaining such raft structure is high. Also, where windlass equipment of the type mentioned is employed to lower and raise the submersible equipment, at times it has been found difficult to accurately control the depth at which the submersible equipment operates, by reason of ocean currents which may cause the cable and submersible equipment to stream rather than hang vertically, and which may cause the depth of the equipment to vary after being initially lowered.

It is an object of the present invention to provide a device of the type referred to, which may be set afloat as a compact self-contained unit, including floatation, reeling and depth control apparatus.

It is a further object to provide depth control apparatus for such a device to accurately control the depth of the submersible equipment, when operated in areas having interfering currents.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. 1 is a side elevation of an underwater target simulator utilizing the present invention, shown floating upon water;

FIG. 2 is an enlarged partial central longitudinal section taken on line 2—2, FIG. 4;

FIG. 3 is a section taken on line 3—3 of FIG. 2 with an electric motor partially broken away to show details of the gear train;

FIG. 4 is a diagram of forces acting on the buoy when afloat, illustrating the mechanics of reeling;

FIG. 5 is an end view of the device, shown on the deck of a ship supported by rollers, illustrating an alternative mode of operation;

FIG. 6 shows the device floating on water, with a block diagram showing components of the operating and control system;

FIG. 7 shows a detail of the control system of FIG. 6; and

FIG. 8 is a servo loop diagram of the control system of FIG. 6.

Referring to the drawing, buoy **10** comprises a watertight shell **12**, circular in cross section, having frusto-conical end portions **14** and **16** forming an annular space **18** disposed centrally between its ends, the buoy being adapted to float about half submerged in water and rotatable about a generally horizontal axis X. Submersible device **20** is suspended from buoy **10** by means of a cable **22**, which contains electric wires. As best shown in FIGS. 1 and 2, cable **22** extends from a junction box **24** within buoy **10**, sealingly through a port **26** in shell **12** and thence is wound around a hub **19** forming an inner wall of annular space **18**, its free portion being suspended beneath buoy **10** and terminating at the submersible device **20**.

As shown in FIG. 6, submersible device **20** contains components of the various operating and control systems. Within the depth control system **28**, pressure transducer **30**, located in the submersible device, senses the depth of submersible device **20** beneath the surface of the water and relays this information to amplifier detector **32**, in the buoy, through electric circuit A, A′ of cable **22**. The target simulating system **34** has two modes of operation, a first mode for operation with missiles having passive acoustic homing systems and a second mode for operation with missiles having active acoustic systems. When operated in the first mode, switch **36** is in the open position and electrical impulses to simulate target operating noises are generated in output section **38**, in the buoy, and then fed through electric circuit C, C′ to transmitting transducer **40**, in the submersible device, where they are transformed to sound impulses in the water. When operated in the second mode, switch **36** is moved to the closed position and receiving transducer **42**, in the submersible device, receives sound impulses from the attacking torpedo, relaying such pulses to input section **44** in the buoy, through electric circuit B, B′, and input section **44** controls output section **38** causing it to produce electric impulses of proper magnitude and timing to simulate sound echoes, which are relayed to transmitting transducer **40** through circuit C, C′. Such target simulating system is old in the art and per se forms no part of the present invention. Within the proximity recording system **46**, proximity senser **48**, in the submersible device, senses the distance between the submersible device **20** and the path of a torpedo fired thereat, sometimes referred to as miss distance, and relays this information to promixity recorder **50**, in the buoy, through circuit D, D′, such proximity recording system also being old in the art and per se forming no part of the invention. It is to be understood that submersible device **20** is rarely hit by an attacking torpedo due to the relatively small size of the device and to the fact that the steering systems employed by the attacking missiles do not steer a straight collision course, instead hunting back and forth to either side of such a course. It should also be understood that in FIG. 6 all components of the depth control, target simulating and proximity recording systems that are physically located in submersible device **20** are so indicated in the drawing by an arrow applying a parenthetically enclosed reference numeral "20" thereto and the remaining components are physically located in the buoy.

Annular space **18** divides the buoy into two axially aligned compartments **52**, **54** joined by a hollow hub **19** in which is journaled a hollow shaft **58**, the ends of which extend into the two compartments. Within compartment **52**, shaft **58** rigidly carries frame **60** which in turn rigidly carries electric batteries **62**, and in like manner within compartment **54**, shaft **58** carries frame **64** and electric motor **66**. The respective centers of mass of frame **60**, batteries **62**, frame **64**, and motor **66** are in angular alignment with one another about axis X to form a rigid pendulum **68** suspended from shaft **58**. Motor **66** may be operated to rotate motor shaft **70** in either of opposite directions of rotation, driving worm gear **72** through reduction gears **74**. Worm gear **72**, in turn engages worm wheel **76** which is fixed to the buoy shell **12**, the worm and worm wheel being of the irreversible type. Since worm wheel **76** is rigidly secured to the shell **12**, motor **66** acting through the gear train may generate relative rotation between pendulum **68** and shell **12** in either of opposite directions of rotation, depending upon the direction in which motor shaft **70** is rotated. Also, since the gear train transmits motion only when worm gear **72** is rotated, the worm effects a self locking action which prevents relative rotation between pendulum **68** and shell **12** about an axis X when motor **66** is stopped. Batteries **62** provide the power for motor **66** through the depth control system **28** located in junction box **24**, the batteries communicating with the junction box through cables **78**, which pass through hollow shaft **58**, and slip ring and brush assembly **80**, and the motor communicating with junction box **24** through cables **82** and slip ring and brush assembly **80**.

The mechanics of reeling the cable is best understood by reference to FIG. 4. Since buoy **10** is cylindrical, it is rotatable about axis X when afloat, in response to torque exerted thereon. Cable **22** exerts a clockwise torque on shell **12** by reason of the force of gravity represented by arrow W, acting upon the mass of submersible device **20** and upon the mass of the portion of cable suspended beneath the housing **84**. Such torque is equal to force W, multiplied by radius R, the moment arm of force W about axis X. When the motor is stopped, pendulum **68** will also exert a torque on shell **12** if it is displaced from the vertical broken line position **68***a* by a displacement angle not in excess of 90 degrees, because as heretofore explained relative motion between the pendulum and shell is prevented when the motor is stopped. For example, in full line position **68***b*, wherein the pendulum is displaced from the broken line position by a displacement angle θ, the pendulum exerts a counterclockwise torque equal to the force of gravity, represented by arrow w, acting on the pendulous mass, multiplied by the moment arm of force W, such moment arm being equal to the product of pendulum length L and the sine function of displacement angle θ. It is to be understood that the masses of frame **60**, batteries **62**, frame **64** and motor **66**, are in aggregate of sufficient magnitude to permit the pendulum to counterbalance the maximum torque exertable by the cable. Therefore, in accordance with the well known principle that an object will be in equilibrium about an axis when the resultant torque acting about such axis is zero, the buoy will float with the pendulum displaced from the vertical broken line position **68***a*, by an angle of displacement θ whereby the torque exerted by the pendulum counterbalances the torque exerted by the cable, or expressed mathematically, where $WR=wL \sin \theta$. It is also apparent that if the equilibrium is upset by relative rotation between pendulum **68** and shell **12**, one or the other of the counterbalancing torques will restore equilibrium by rotating the housing. For purposes of illustrating the aforesaid phenomenon it is to be assumed that the buoy shown in FIG. 4 is in equilibrium with the pendulum in solid line position **68***b*, displaced from the vertical broken line position **68***a* by a displacement angle θ. If displacement angle θ is somehow increased by a small angular increment, the moment arm of force W will increase in proportion to the sine function of the angular increment, causing the torque exerted by the pendulum to exceed the torque exerted by the cable. The torque exerted by the pendulum will cause the buoy to rotate clockwise to restore equilibrium, and in doing so will raise submersible device **20** a small increment of distance. Conversely, if displacement angle θ is decreased by a small angular increment, the torque exerted by the pendulum will decrease, and the torque exerted by the cable will rotate shell **12** clockwise, restoring equilibrium, and lowering submersible device **20** a small increment of distance. It is to be understood that incremental changes in force of gravity W, due to changes in the portion of cable suspended beneath the housing **34**, and that incremental changes in radius R, due to change in the number of layers wrapped around the buoy may be neglected, since in every instance the incremental change in torque exerted by the pendulum will be greater than the corresponding incremental change in torque exerted by the cable.

In the present invention, the aforesaid phenomenon whereby the housing rotates to restore equilibrium if the displacement angle θ between the pendulum and the vertical broken line position **62***a* is changed, is utilized to generate rotation by means of the motor. As heretofore explained, motor **66** may generate relative rotation between pendulum **68** and shell **12** in either of opposite directions of rotation. Accordingly, if it is desired to raise submersible device **20**, motor **66** is operated in a direction of rotation to cause displacement angle θ to increase, and in the same manner as heretofore illustrated in terms of incremental changes, the shell will rotate in a counterclockwise direction, raising the submersible device. Conversely, if it is desired to lower the submersible device **20**, motor **66** is operated in a direction of rotation to cause displacement angle θ to decrease.

By means of depth control system **28**, shown in FIG. 6, the submersible device **20** may be accurately lowered to a preselected depth and thereafter maintained at such depth despite fluctuations in currents. Basically, the depth control system is a servo loop with the error signal generated by a conventional A.C. Wheatstone bridge **86**, best shown in FIG. 7. Potentiometer **86** which is operatively connected to a conventional pressure sensing Bourdon tube **88** within the submersible device constitutes one leg of the bridge, and depth set potentiometer **90**, which is operatively connected to manual depth set control **92** constitutes the other leg, the slide arm of each potentiometer being the balance point of each respective leg. The circuit component values and mechanical ratios are selected whereby the bridge is in balance when the submersible device is at the preselected desired depth, the arm of potentiometer **90** being moved by depth set control **92** to set the desired depth of operation into the bridge and the slide arm of potentiometer **86** being moved in response to pressure changes at submersible device **20**. An A.C. reference voltage, is applied across the legs of the bridge. In accordance with the well known principle of the A.C. Wheatstone bridge, if the submersible device **20** is not at the preselected depth wherein the bridge is in balance, an A.C. error signal is generated between the balance points, the error voltage being in alternatively (1) of the "in phase" or "zero phase" condition, or (2) of the "opposed phase" or "180° phase" condition, relative to the A.C. reference signal applied across the legs of the bridge depending upon whether the submersible device is above or below the desired depth, the signal having a magnitude determined by the difference between the actual depth and the preselected depth. The A.C. error voltage is then fed to amplifier detector 32, the slide arm of potentiometer 86 being electrically connected to input terminal through circuit A, A' within cable 22, and the slide arm of potentiometer 86 being electrically connected to the other input terminal. Amplifier detector 32 has the A.C. reference potential applied thereto and contains conventional phase detection circuitry to determine the phase polarity of the error signal relative to the reference signal and relay circuitry to produce either of two D.C. control signals, when an A.C. signal in excess of a predetermined threshold magnitude is fed thereto. When an A.C. signal having phase polarity corresponding to the condition wherein the submersible device is above the preselected depth and having a magnitude corresponding to a depth difference of 10 feet or more, is fed thereto, amplifier detector 32 puts out a down D.C. signal 94. Conversely, when an A.C. signal of a phase polarity corresponding to the submersible device being below the preselected depth by 10 or more feet is fed thereto, the amplifier detector puts out an up D.C. signal 96. It is apparent that when the submersible device is within 10 feet above and 10 feet below the desired depth, the detector amplifier will provide no output whatsoever. Signals 94, 96 are fed into motor controller 100, which is controlled by a four position rotary switch 102 wherein: positions I and III are "stop" positions wherein the depth control system is disengaged and motor 66 is not permitted to operate; position II is the "automatic" position wherein the depth control system is engaged and motor 66 is operated in response to up or down signals 96, 98; and position IV is an "up" position wherein the motor is operated to raise submersible device 20 to the surface, there being the provision of conventional ceiling limit circuitry (not shown) actuated by Bourdon tube 88 to stop the motor when submersible device 20 is within a few feet of the surface to prevent striking the buoy. It is apparent that when switch 102 is in position II, the automatic position, the depth control system forms a closed loop servo system 103, FIG. 8 comprising error detector bridge 84, amplifier 32, and motor 66 with the loop closed by movement of submersible device 20 relative to the surface of the water symbolically indicated by broken line block 103*a* and broken line Z. For example, if switch 102 is moved to position II, when the submersible device 20 is at or near the surface of the water and depth set potentiometer 90 is set for a depth substantially below the surface, the bridge will generate an A.C. error signal of such phase polarity and magnitude to cause amplifier detector 32 to produce a down D.C. signal 94, which is fed into motor controller 100, causing the motor to operate with a direction of rotation whereby submersible device reaches the preselected depth set into depth set potentiometer 90, whereupon the bridge is balanced and the error signal disappears. Also, after initially lowering the submersible device to the preselected depth, the depth control system continues to function, and if the submersible device rises or drops sufficiently to produce an A.C. error signal of sufficient magnitude to cause amplifier detector 32 to put out a D.C. signal, the motor will be operated in a direction of rotation to return the submersible device to the preselected depth.

It is now to be assumed that a simulator assembly including buoy 10, submersible device 20 and cable 22 is to be operated. The simulator may be transported to the operating area by any ship or boat having suitable hoist and boom equipment to launch and retrieve the simulator. It is to be understood that the reeling apparatus is inoperative until a conventional shorting plug (not shown) is installed, and that for safety purposes such plug is not installed until the target simulator is afloat. The desired depth beneath the surface whereat submersible device 20 is to operate may be set into the

depth control system, either before or after launching, by means of depth set control 92 which is mounted on the outside of shell 12 in some accessible location. The simulator is then launched, to freely float, or it may be restrained against movement by water currents by means of sea anchors, if desired. Rotary switch 102 is controlled by a conventional rotary solenoid (not shown) which in turn is actuated by toggle switch 104 mounted on end portion 16 of shell 12, which location permits convenient operation of the toggle with the help of a boat hook. Every time toggle switch 104 is struck it actuates the rotary solenoid to advance rotary switch 102 one position in its sequence of positions. Accordingly, assuming switch 102 is initially in position I, upon striking the toggle once, rotary switch 102 will advance to position II, the automatic position, wherein motor 66 is operated in response to the depth control system, causing motor 66 to operate, unreeling the cable until the submersible device reaches the preselected depth. It becomes apparent that in contradistinction to prior art devices, the depth control system will cause the submersible device to be lowered to the preselected depth, even if currents are present which cause the cable and submersible device to stream rather than hang vertically, since the control system operates in response to the pressure transducer 30 carried by the submersible device, rather than in response to the amount of cable payed out in unreeling. The target simulator may then be left to float unattended while acoustic underwater missiles are fired thereat, and the target simulating system 34 and proximity recording system 46 will perform as hereinbefore described, simulating an underwater target, and recording the miss distance. As long as switch 102 is left in position II, the automatic position, the depth control system will continue to operate maintaining submersible device 20 at the preselected depth despite any changes in water currents which would otherwise cause the depth of same to vary. At the conclusion of exercises, switch 102 is moved to "position IV," the up position, by striking toggle switch 104 twice, and as heretofore explained motor 66 is operated, raising the submersible device to within a few feet of the surface where it automatically stops.

FIG. 5 illustrates the invention adapted for use from the deck of a ship by means of a roller bed comprising four freely rotating conical rollers 106, of which two are shown, such rollers being adapted to engage the frustoconical end portions 14, 16 of the shell 12, whereby the buoy, when resting on the roller bed, is freely rotatable about axis X, while being otherwise constrained against axial and radial movement. It is apparent that the motor, in conjunction with the pendulum, will reel the buoy while resting on the roller bed in the same manner as when afloat, thereby permitting use from the deck of a ship.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. Underwater target simulator apparatus comprising; a floating buoy having a generally horizontal axis about which it may rotate on the water and a cable reel forming part of said buoy and rotatable therewith, a submersible device adapted to be suspended a desired distance below the surface of the water and above the bottom of the body of water and adapted to simulate a target and sense the miss distance of a missile directed thereat, a cable wound about said reel having one end affixed to the buoy and its other end affixed to said submersible device, pendulous means within the buoy rotatable relative thereto and about said axis including motor means carried thereby for applying torque to the buoy in either of opposite directions of rotation, whereby said submersible device may be raised or lowered in the water.

2. The apparatus of claim 1 including means carried by said device for sensing its depth below the surface of the water, and electrical circuit means extending through said cable between said device and motor, said circuit means including means responsive to difference between the actual depth of the submersible device and the desired depth to rotate the motor in either of opposite directions of rotation to thereby raise or lower said device to maintain same at the desired depth.

3. The apparatus of claim 1 wherein the buoy comprises a generally circular drum forming axially spaced compartments and wherein said cable reel comprises a central hub joining said compartments, said hub and confronting end walls of said compartments forming an annular space for receiving said cable.

4. The apparatus of claim 3 wherein said hub is hollow, a hollow shaft journaled within said hub and extending between said compartments, an electric motor suspended from the shaft within one of the said compartments, an electric battery suspended from the shaft within

the other of said compartments, and circuit means extending between said battery and motor and through said hollow shaft for operating said motor by said battery, the motor, battery and hollow shaft being rigidly connected to form a pendulum.

5. The apparatus of claim 4 having gearing means comprising a worm wheel fixed to the buoy and a self locking worm gear operatively connected to the motor and meshing with the worm wheel.

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