March 24, 1964 R. J. ANDERSON 3,125,980

AZIMUTH CONTROL SYSTEM FOR TOWED SUBMERSIBLE BODIES

Filed March 8, 1957 2 Sheets-Sheet 1

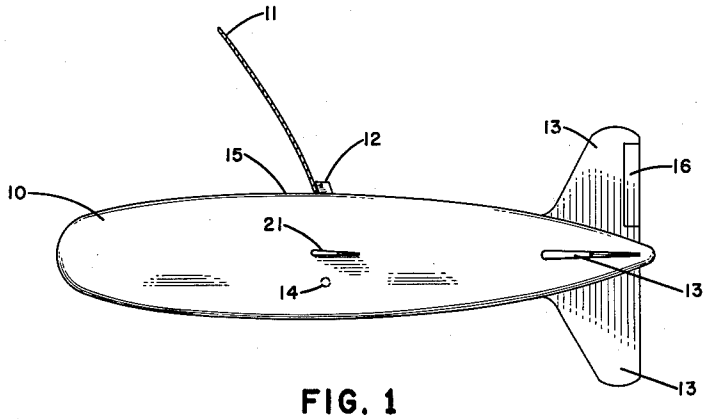


FIG. 1

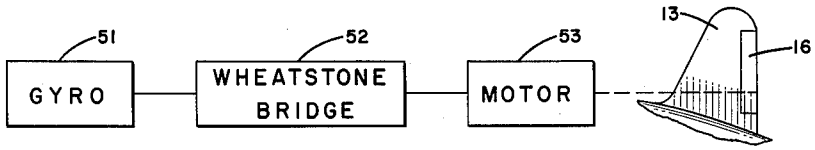


FIG. 4

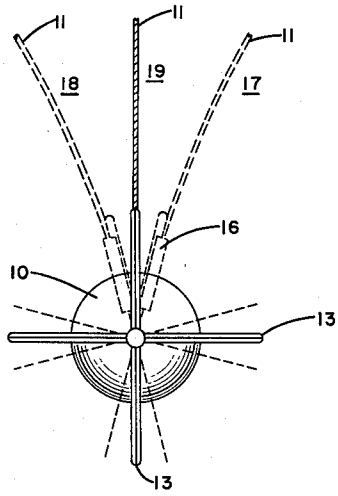


FIG. 2

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AZIMUTH CONTROL SYSTEM FOR TOWED SUBMERSIBLE BODIES

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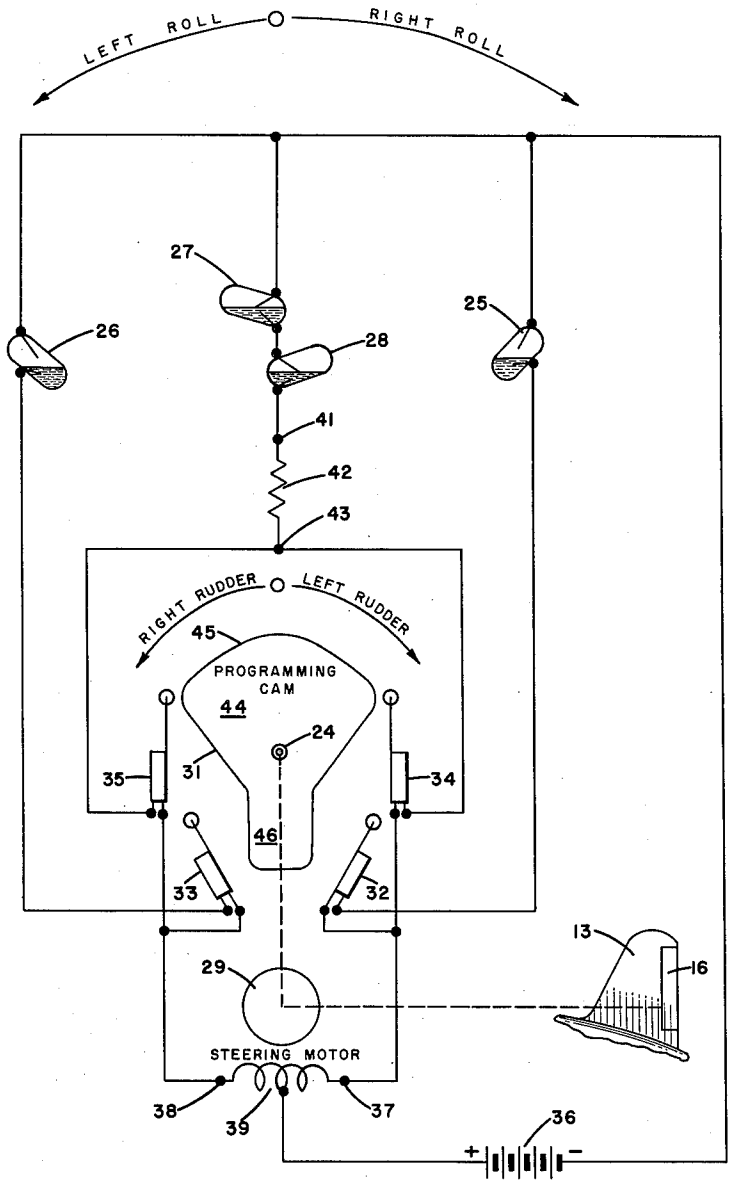


FIG. 3

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AZIMUTH CONTROL SYSTEM FOR TOWED SUBMERSIBLE BODIES

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6 Claims. (Cl. 114—235)

This invention relates to towed submersible bodies and more specifically to azimuth control systems for towed submersible bodies.

In the development of towed sonar to detect submarines and the like it has been found in practice that it is necessary that the towing vehicle, such as for example, a lighter than air airship or surface vessel be able to maneuver quickly when the target takes evasive action. Under such circumstances it is essential that the towed sonar faithfully fully follow the towing vehicle regardless of any towing maneuver in azimuth to allow tracking of the target and to prevent undesirable stresses in the towing cables or its connection as a result of such maneuvers.

In the case of airtowed sonar contemplated by the present invention the sonar is suitably mounted in a housing of suitable design that is preferably both aerodynamically and hydrodynamically stable to insure optimum conditions for water entry, water exit and towing at the desired depth. Furthermore, it has been found in practice that such a body must be towed from a point intermediate its ends and for the case of an airtowed housing or body the fixed stabilizer surfaces should be of sufficient size as to provide aerodynamic stability, which size will be generally greater than that required for hydrodynamic stability alone. The fixed stabilizer surfaces may be located on the rear portion of the body as is the conventional practice and as is not the conventional practice, provided with a single vertical rudder, hereinafter referred to as a control surface, for horizontal steering of the body.

An object of the invention is to provide a submersible body which can be successfully towed by means of a tow line secured to a self-propelled vehicle that will faithfully follow the towing vehicle regardless of any towing maneuver in azimuth of the towing vehicle.

Another object of the invention is to provide a means for a towed submersible body whereby azimuth variations in the direction of travel of the towing vehicle will cause the towed submerged body to faithfully follow the towed vehicle.

Still another object of the invention is to provide a simple and improved azimuth control system for towed submersible bodies.

A further object of the invention is to provide a means of towing a submersible body beneath and behind a self-propelled vehicle by means of a tow line in such a manner that variations in the azimuth heading of the towing vehicle will cause the towed body to follow substantially directly astern of the towing vehicle.

These and other objects and features of the invention, together with their incident advantages, will be more readily understood and appreciated from the following detailed description of the preferred embodiment thereof selected for purposes of illustration and shown in the accompanying drawings, in which:

FIGURE 1 generally illustrates to towed submersible housing or body in which the invention is employed for detecting and tracking submerged objects.

FIGURE 2 is a rear view of the body shown in FIGURE 1 showing in solid lines the normal or straight tow position of the body and in phantom roll positions of the body due to a change in heading or azimuth of the towing vehicle.

FIGURE 3 is a schematic diagram, party diagrammatic

of an "on-off" azimuth control system for the submersible body shown in FIGURE 1.

FIGURE 4 is a block diagram of a "proportional" azimuth control system for the submersible body shown in FIGURE 1.

Referring now to the drawings and more particularly to FIGURE 1 thereof, there is shown therein a body designated generally by the numeral 10 of conventional hydrodynamic design having a tow line or cable 11 affixed intermediate the forward and rearward portions of the body to a suitable connection or tow point 12 by any conventional means. Fixed stabilizer surfaces 13 are provided on the rear portion of the body to render the body substantially stable when being towed and outwardly extending short wing stubs 21 are provided at substantially the center middle portion of the body 10 to maintain the body at the desired depth. Dynamic and/or static stability of the body 10 both in air and in water, depending on the manner and the means by which it is being towed may be secured by proper location of the center of gravity 14 and the tow point 12.

In order to obtain optimum towing conditions and maximum sensitivity for the present invention a tow point 12 is provided in the middle portion of the body directly above the longitudinal axis and above the center of gravity 14 such that a lever arm exists either in fact or in theory between the center of gravity 14 and the tow point 12. The connection or tow point may be provided at the end of a tow staff (not shown) pivotally mounted about the center of gravity for limited longitudinal movement or it may be rigidly affixed to or near the upper surface 15 of the body as previously described such that any offside tending of the tow line or cable 11 will cause the body 10 to rotate about its longitudinal axis. A single control surface 16 is pivotally provided in the upper stabilizer surface 13 for horizontal steering and to oppose any tendency of the body to continue rotation about its longitudinal axis while in a turn.

The operation and disposition of the body in a straight tow and in a right or left turn is best shown in FIGURE 2. As previously pointed out by proper design the body may be made statically and hydrodynamically stable. For this reason when the body is being towed on a straight course the center of gravity 14, tow point 12 and cable 11 will lie in a substantially vertical plane containing the longitudinal axis of the body and the longitudinal axis of the body will be substantially horizontal, which is to say that the body will travel in a substantially straight line with little or no variations in pitch. When the towing vehicle, such as for example, an airship or surface vessel changes course the towed body will no longer lie directly astern and hence the tow line 11 will assume a new position 17—18 to the right or left of its normal or vertical position 19 dependent upon the direction and amount of course change. Due to the dynamic and static stability of the towed body and the location of the tow points 12, the towed body 10 will be rotated about is longitudinal axis during a change in course of the towing vehicle and the tow point 12 will be thereby simultaneously rotated through an angle dependent upon the new position of the tow line which is determined by the towing factors, such as for example, depth, towing speed, rate of turn of the towing vehicle and the like.

In practice it has been found preferable to provide stabilizer surfaces 13 of conventional design on the rear portion of the body, to dispose the stabilizer surfaces at right angles with each other, two lying in a vertical plane and two lying in a horizontal plane, as is conventional practice in the art and additionally provide a single control surface 16 pivotally mounted in the vertical or upstanding stabilizer surface 13 for horizontal steering. A

single control surface 16 for horizontal steering disposed and located as previously described performs the dual function of providing horizontal steering of the body and prevents excessive roll or heel of the body in the direction of turn by providing a force or moment opposite in direction to that created by the tow line.

Sensing and actuating means for the control surface 16 is shown in FIGURE 3 for "on-off" steering or control. As used herein "on-off" steering is distinguished from "proportional" steering and is of the type wherein the control surface 16 is thrown from its normal or unactivated longitudinally disposed position to full right or full left and vice versa upon a sufficient deviation in course of the towing vehicle.

With reference now particularly to FIGURE 3 there is shown two mercury roll switches 25—26, two return mercury switches 27—28, a reversible steering motor 29 mechanically connected to the control surface 16 in any convenient manner for pivotal operation thereof, a programming cam 31 rotatably operated by the steering motor 29, two mechanically actuated roll switches 32—33 and two mechanically actuated return switches 34—35 disposed in operative relationship with the programming cam 31 as will be more fully described hereinafter. For convenience of explanation it is assumed that the right roll and left roll as indicated in FIGURE 3 occurs when viewing the body from rearwardly of the stabilizer surfaces 13, i.e., the right roll is a rotation of the body 10 about its longitudinal axis in a clockwise direction and a left roll is a rotation of the body 10 about its longitudinal axis in a counter-clockwise direction.

The mercury switches 25, 26, 27, 28 are most conveniently mounted with their longitudinal axis lying in a plane perpendicular to the longitudinal axis of the body, such as for example, on a transverse perpendicular dividing wall or bulkhead and the steering motor 29 may be operably connected to the control surface 16 in any conventional manner, such as for example, by pusher rods and the like and the programming cam 31 may be fixedly mounted directly on the armature shaft of the steering motor as at 24 or operatively driven by the steering motor through a gear train or the like (not shown).

A field winding circuit is shown in FIGURE 3 comprised of a right roll mercury switch 25 and a left roll mercury switch 26 connected in series with one terminal of a source of electric current 36 such as a battery or the like and in series respectively with a normally closed right roll mechanical switch 32 and a normally closed left roll mechanical switch 33 which are each separably connected respectively to an end terminal 37—38 of the field winding 39 of the steering motor 29. Two return mercury switches 27—28 are connected in series with each other and the source of current 36 and terminal 41 of a motor damping resistor 42. The remaining terminal 43 of the damping resistor 42 is connected to two normally open mechanical switches 34—35 which are each connected respectively to the end terminals 37—38 of the field winding 39.

The mercury switches 25, 26, 27, 28 may be of conventional form wherein a change of position is necessary to open or close the switch and, if desired, may be additionally provided with suitable means or formed such that splashing of the mercury will be substantially prevented thereby reducing the possibility of undesirable operation of the steering motor during extreme operating or towing conditions.

The mechanically operable roll switches 32—33 and the mechanically operable return switches 34—35 may be of the type commonly referred to and well known in the art as "microswitches" and are fixedly mounted in the same plane as the programming cam 31 and disposed in operable relationship therewith. The programming cam 31 is of the planar variety having an enlarged first portion 44 provided with a relatively long annular surface 45, a generally rectangular second portion 46 integral with portion 44 and of reduced size extending in a direction substantially opposite to the annular surface 45 and adapted for rotation about point 24, as by mounting the cam on the armature shaft of the steering motor. Mechanical switches 32—33 and 34—35 are fixedly disposed away from the programming cam 31 such that they will be unactivated when the programming cam is in its normally unactivated position but will be actuated in a predetermined manner upon rotation of the programming cam. Upon counter-clockwise rotation of the programming cam the annular surface 45 will be moved to a position to close switch 35 prior to the time portion 46 arrives at a position sufficient to open switch 32. Obviously, a clockwise rotation of the programming cam from its full counter-clockwise position will cause switch 32 to close prior to the time it will cause switch 35 to open. An initial rotation of the programming cam from its normally unactuated position in a clockwise direction will result in operation of switches 34—33 in substantially the same manner as previously described herein above for switches 32—35.

When the body is in its normal towing position the return mercury switches 27—28 are closed and the right roll mercury switch 25 and the left roll mercury switch 26 are open, but no current is fed to the field winding 39 of the steering motor 29 due to the fact that the return mechanical switches 34—35 are unactivated and in their normally open position. The four mercury switches 25, 26, 27, 28 are mounted as pointed out hereinbefore such that they will not be actuated until such a time as the body exceeds a critical degree of roll such as for example, three degrees. When the body assumes an angular position sufficiently to the right for example, the right roll mercury switch 25 will close and the return mercury switch 28 will open. Due to the fact that the right roll mechanical switch 32 is unactivated and in its normally closed position, current is allowed to flow through one half of the center tapped field winding 39, thereby energizing the steering motor for rotation in a predetermined direction. The direction of rotation of the armature shaft of the steering motor may be selected such as to cause the programming cam 31 to rotate in a counter-clockwise direction and since the steering motor is operated under full power, the programming cam 31 will be moved to its full counter-clockwise position and the control surface 16 will be moved to its full right position. Rotation of the programming cam 31 in a counter-clockwise direction causes the return mechanical switch 35 to be closed, and the right roll mechanical switch 32 to be opened, thus breaking the circuit to the field winding 39 of the steering motor and stopping the motor, the control surface 16 consequently remaining in its full right position. It may now be obvious that return mechanical switch 35 having been previously closed by the programming cam 31, when the right roll is relieved, the return mercury switches 27—28 will both be closed thereby allowing current to be applied only to the opposite portion of the field winding thereby causing the steering motor to rotate in a direction opposite to its previous direction and return the control surface 16 to its normal position. Due to the reversal of direction of rotation of the armature of the steering motor the programming cam 31 will be caused to now rotate in a clockwise direction thus allowing the right roll mechanical switch 32 to assume its normally closed position and simultaneously allowing the return mechanical switch 35 to assume its normally open position thus removing all current from the field winding 39 of the steering motor. Due to the inertia of the armature shaft of the motor, the programming cam will move past its center or normal position and close the return mechanical switch 34 thus causing the motor to again reverse its direction of rotation since the return mercury switches 27—28 are closed. Exact centering of the control surface 16 is accomplished

by the action of the programming cam **31** opening and closing the return mechanical switches **34—35**. In order to eliminate continuous oscillation of the control surface **16** due to inertia of the motor armature shaft, a damping resistor **42** is provided in series with each half of the field winding **39** of the steering motor. The function of the damping resistor **42** is to reduce the starting current to the steering motor thus dampening the oscillations of the armature shaft at the center or normal position and thereby causing the motor to come to rest in a very short time at the neutral position with the system de-energized.

Due to the symmetry of the field winding circuit it may now be obvious that the description given above is equally applicable for a left roll except that the operation of the right roll mercury switch **25**, the left roll mercury switch **26** and return mercury switches **27—28** are reversed, as is the direction of rotation of the programming cam **31**, i.e., for a left roll the programming cam **31** is rotated from its normal position in a clockwise direction and the control surface **16** is rotated to the left.

Sensing and actuating means for a "proportional" control system is shown in block form in FIGURE 4. As used herein, "proportional" control has reference to that type of control wherein the degree of control surface movement is proportional to the amount of actuating or error signal. For a proportional system as shown in FIGURE 4 a vertical gyroscope **51** adapted and disposed to sense roll errors may be provided to actuate a wheatstone bridge motor control circuit **52** for proportional operation of a steering motor **53** mechanically connected to the control surface **16** in any suitable manner as described previously hereinabove. A potentiometer (not shown) actuated by the gyro **51** may form the actuating arm of the wheatstone bridge motor control circuit similar to that shown and described in patent application Serial No. 587,180, now Patent No. 3,045,627, filed May 24, 1956, to which reference is hereby made.

It may now be obvious that the movement of the control surface **16** will be in direct proportion to the amount of roll sensed by the gyro **51**, varying from maximum roll and maximum control surface movement to no roll and no control surface movement, thereby resulting in relatively smooth changes in course of the body when required by a change in course of the towing vehicle.

It may now be seen that the present invention provides a horizontal or azimuth control system for a submersible body adapted to be submersibly towed by a surface or airborne vehicle wherein the location and type of tow cable connection and the characteristics of the body cooperate in a unique manner with roll error sensing means to provide accurate and sensitive horizontal control of the towed body thereby causing it to follow, especially when submerged, directly astern of the towing vehicle regardless of any towing maneuver in azimuth involved, as searching for and/or tracking a surface or submerged target.

While the invention has been described in detail with the reference to the detection of dirigible surface or submerged objects, such as for example, ships and submarines, it is obviously not so limited as it may be employed to advantage in any towed submersible body wherein it is desired that the body faithfully follow the towing vehicle in azimuth.

While the present invention has been described in its preferred embodiment it is realized that modifications may be made, it is desired that it be understood that no limitations upon the invention are intended other than may be imposed by the scope of the appended claims.

Having now disclosed my invention, what I claim as new and desire to secure by Letters Patent of the United States is:

1. In a towed submersible body having a control surface disposed for horizontal steering and adapted to be towed from a point about the center of gravity and lying in a longitudinal plane passing through the center of gravity and the center portion of the body an azimuth control system comprising: a source of current; an electric motor operably associated wth said control surface; and a field winding circuit connected to said source of current for actuating said electric motor, said field winding circuit comprising a motor field winding and means sensitive to a change of position about the longitudinal axis of said body connected to said field winding whereby a change in position of said body about its longitudinal axis will cause actuation of said motor.

2. In a towed submersible body having an upstanding pivotally mounted control surface and adapted to be towed from a point above the center of gravity and lying in a vertical longitudinal plane passing through the center of gravity and the center portion of the body an azimuth control system comprising: a source of current; a reversible electric motor operably associated with said control surface; and a field winding circuit connected to said source of current for actuating said electric motor, said field winding circuit comprising a motor field winding and means sensitive to a change of position about the longitudinal axis of said body connected to said field winding whereby a change in position of said body about its longitudinal axis will cause actuation of said motor.

3. In a towed submersible body having an upstanding pivotally mounted control surface and adapted to be towed from a point above the center of gravity and lying in a vertical longitudinal plane passing through the center of gravity and the center portion of the body an azimuth control system comprising: a source of current; a reversible electric motor operably associated with said control surface; and a field winding circuit connected to said source of current for actuating said electric motor, said field winding circuit comprising a motor field winding and means operatively sensitive to an angular change of position connected to said field winding whereby an angular change in position of said tow point will cause actuation of said control surface in the direction of said angular change of position of said tow point.

4. In an elongated body hydrodynamically and aerodynamically stable having a front portion, a rear portion and a smooth upper surface and adapted to be towed by a cable from a self-propelled vehicle an azimuth control system comprising: a tow point disposed intermediate the front portion and the rear portion and above the center of gravity of said body and lying in a vertical longitudinal plane passing through the center of gravity of said body; an upstanding control surface pivotally carried by said rear portion; a source of electric current; a reversible electric motor operably connected to said control surface; and a motor field winding circuit for controlling said motor and connected to said source of current comprising a field winding and means operatively sensitive to an angular change of position of said tow point.

5. In an elongated body hydrodynamically and aerodynamically stable having a front portion, a rear portion and a smooth upper surface and adapted to be towed by a cable from a self-propelled vehicle an azimuth control system comprising: a tow point disposed intermediate the front portion and the rear portion and above the center of gravity of said body and lying in a vertical longitudinal plane passing through the center of gravity of said body; an upstanding control surface pivotally carried by said rear portion; a source of electric current; a reversible electric motor operably connected to said control surface; and a motor field winding circuit for controlling said motor and connected to said source of current comprising a field winding, a gyroscope adapted to produce an error signal proportional to the amount of angular displacement of said tow point, and wheatstone bridge means disposed between said gyroscope and said field winding whereby the direction of rotation and actuation of said motor is controlled by said error signal.

6. In an elongated body hydrodynamically and aerodynamically stable having a front portion, a rear portion

and a smooth upper surface and adapted to be towed by a cable from a self-propelled vehicle an azimuth control system comprising: a tow point disposed intermediate the front portion and the rear portion and above the center of gravity of said body and lying in a vertical longitudinal plane passing through the center of gravity of said body; an upstanding control surface pivotally carried by said rear portion; a source of electric current; a reversible electric motor operably connected to said control surface; and a motor field winding circuit for controlling said motor and connected to said source of current comprising a field winding, first and second switch means normally open and operable upon a predetermined angular change of position, third and fourth switch means normally closed and operable upon a predetermined angular change of position, fifth and sixth switch means in series respectively with said first and second and said third and fourth switch means, and a cam adapted to be operated by said motor and to actuate said fifth and sixth switch means whereby said motor will be actuated only upon a predetermined angular displacement of said tow point from and toward its normally vertical position.

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