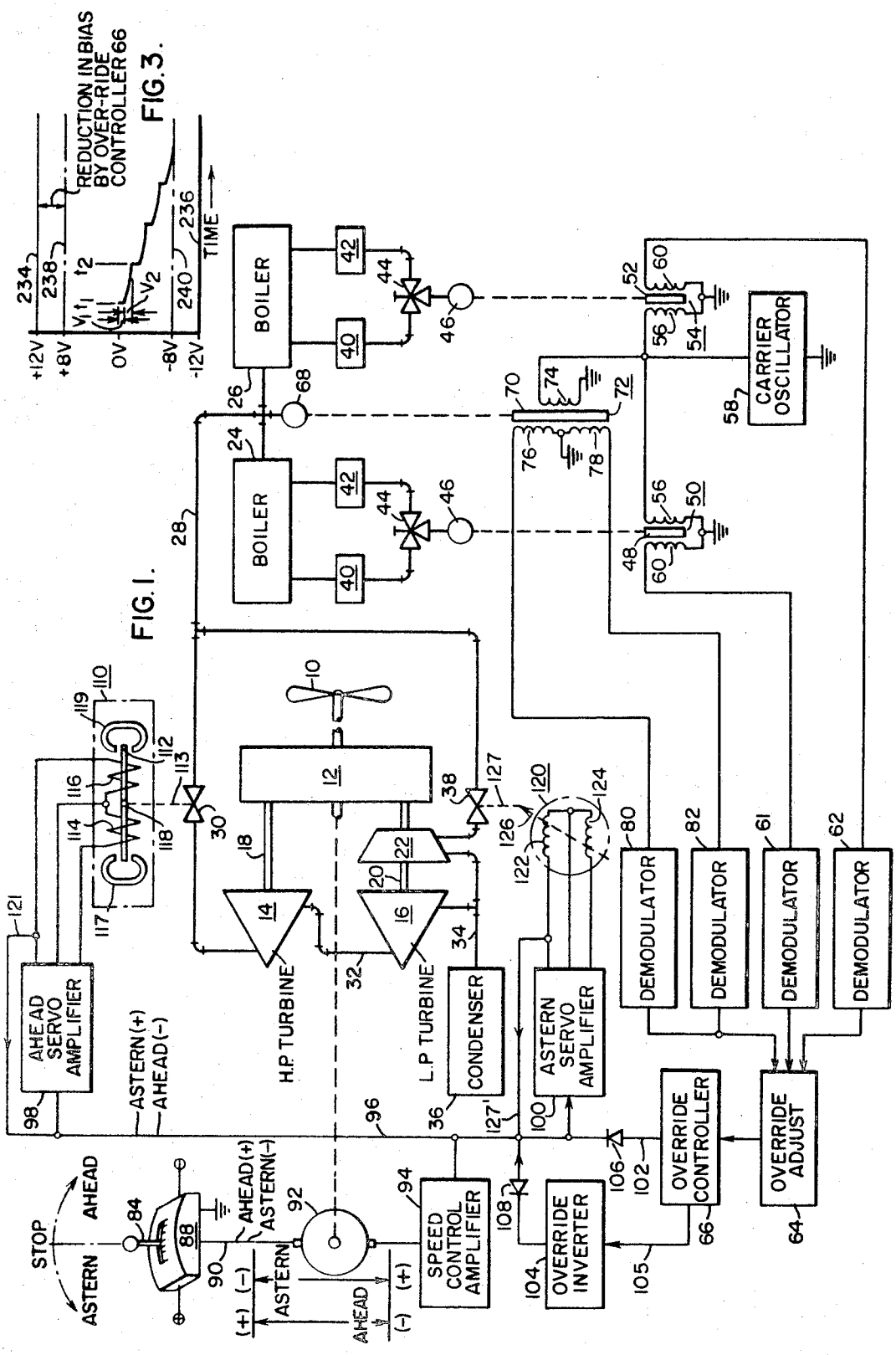
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STEAM PROPULSION CONTROL SYSTEM

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STEAM PROPULSION CONTROL SYSTEM

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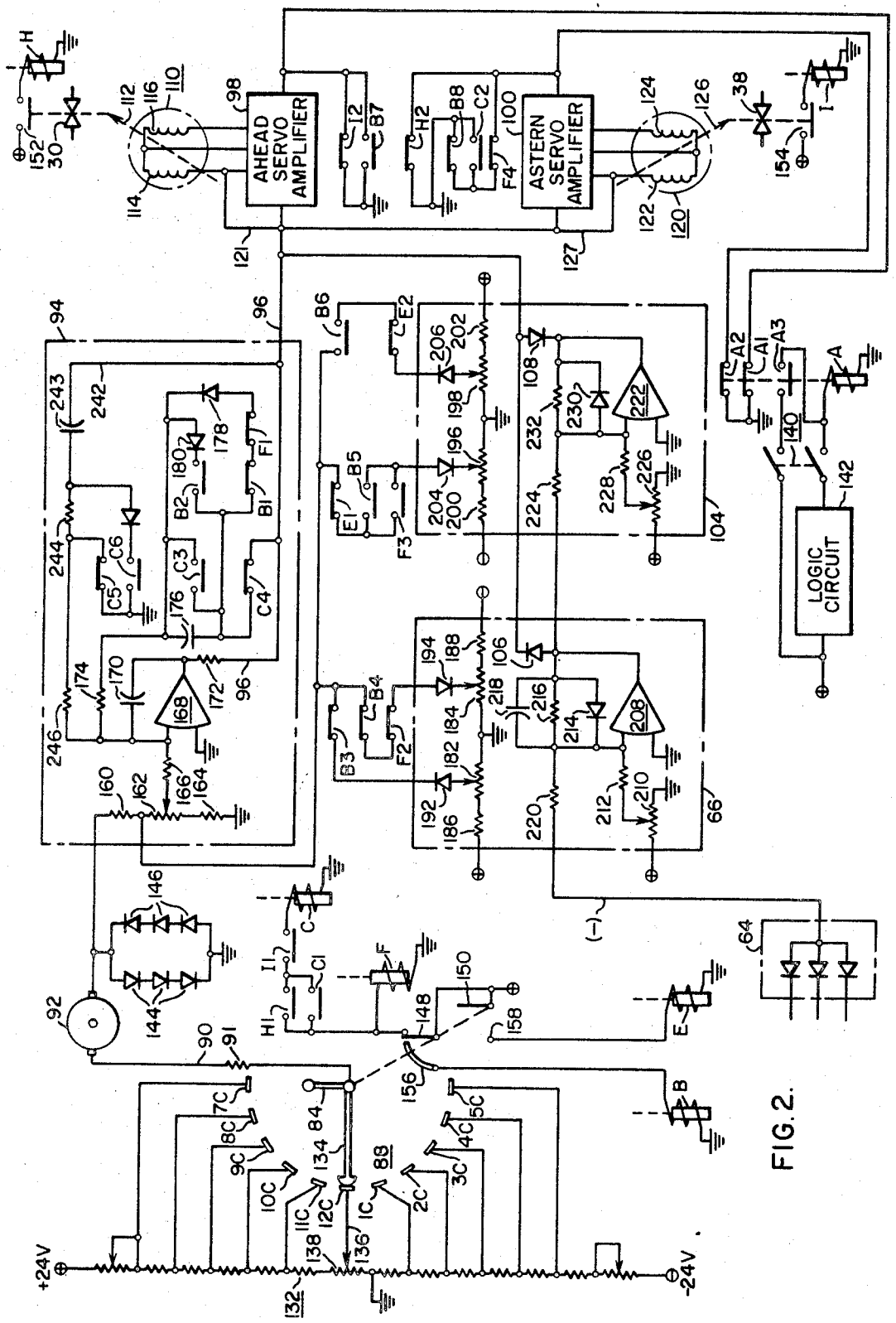


FIG. 2.

United States Patent Office 3,405,676 Patented Oct. 15, 1968

3,405,676

STEAM PROPULSION CONTROL SYSTEM

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Filed Apr. 6, 1966, Ser. No. 540,556
14 Claims. (Cl. 115—.5)

ABSTRACT OF THE DISCLOSURE

Apparatus disclosed includes a steam turbine driven reversible ship propulsion system having respective ahead and astern control valves driven by separate servo systems, which are in turn selectively driven by a proportional plus integral operational amplifier whose input responds to a summation of signals representing actual and desired propeller speeds. Apparatus responsive to off-normal conditions, such as low boiler pressure, produce "off-normal" signals which modify the speed control signals applied to the servo systems in a manner to limit the valve openings so that the capability of the system cannot be exceeded. Means is also provided to restrict the integrating capability of the operational amplifier so that it integrates only when the desired speed signal dominates the actual speed signal.

This invention relates to control systems for steam turbines and the like, and more particularly to a steam turbine propulsion control system for ships wherein the ship can be controlled directly from the bridge.

In the past, ship propulsion turbines have normally been controlled by steam valves manually adjusted in the engine room is response to signals from the bridge. For example, if it were desired to reverse the ship's propeller from ahead to astern as in docking, an order was transmitted from the bridge to the engine room operator who would then manually close the ahead valve and thereafter manually open the astern valve. In addition to following commands from the bridge, the engine room operator has also been responsible for limiting the propulsion turbine's transient steam requirements to within the capability of the boiler. That is, he has been responsible for protecting the complete power system from undesirable modes of operation such as overpressure or underpressure conditions and high or low water levels in the boiler. Needless to say, this method for ship control, while used extensively, leaves much to be desired particularly as regards the maneuverability of the ship.

As an overall object, the present invention provides an automatic propulsion control system for ships and the like wherein the ship turbines are controlled automatically from the bridge, and without the assistance of personnel in the engine room. As will be understood, this places the ship under the direct control of the bridge and facilitates much faster response characteristics in the control of the ship as are needed, for example, when the ship is being docked.

Another object of the invention is to provide a ship propulsion control system of the type described incorporating means for sensing off-normal conditions or equipment failures, and wherein off-normal conditions or equipment failures will override the normal automatic function of the system and prevent damage to any part of the propulsion equipment.

In accordance with the invention, a servo system is provided including means under the control of the bridge for producing a desired speed signal, means for producing an actual speed signal proportional in magnitude to the speed of rotation of the ship's propeller, apparatus for comparing the actual and desired speed signals to

produce a speed error signal when the desired and actual speed signals are not of the same magnitude, and apparatus responsive to the speed error signal for controlling the admission of steam to the ship's turbines. In the embodiment of the invention shown herein, the desired speed signal is produced by means of a potentiometer adapted to produce a direct current voltage of one polarity for the ahead direction and a direct current voltage of the opposite polarity for the astern direction, the magnitude of the voltage being proportional to the desired speed in either the ahead or astern direction. The actual speed signal is generated by means of a tachometer generator connected to the ship's propeller; and the actual and desired speed signals or voltages are added in series to produce the speed error signal which is applied through operational amplifiers to servomotors which control the main ahead and astern steam valves for the ship's turbines.

Further, in accordance with the invention, off-normal conditions such as low boiler pressure are sensed to generate an off-normal signal which reduces or limits the steam valve opening when an off-normal condition occurs such that the capability of the system cannot be exceeded. Thus, the system not only provides for normal control of the propulsion system, but also eliminates the need for system monitoring by engine room personnel.

The above and other objects and features of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings which form a part of this specification, and in which:

FIGURE 1 is a schematic diagram of the overall propulsion and control system of the invention;

FIG. 2 comprises a detailed schematic diagram of various components of the electrical control system shown in FIG. 1; and

FIG. 3 is a graph illustrating certain of the control characteristics of the system of FIGS. 1 and 2.

General overall description of system, FIG. 1

With reference now to the drawings, and particularly to FIG. 1, a ship propeller **10** is driven through a gear reducer **12** by means of high pressure and low pressure steam turbines **14** and **16**, respectively. Turbine **14** is connected to gear reducer **12** and, hence, to the propeller **10** through rotatable shaft **18**. In a similar manner, the low pressure turbine **16** is connected to the gear reducer **12** through shaft **20** having conventional reversing turbine blades **22** thereon.

Steam for the turbines **14**, **16** and **22** is supplied by means of a pair of boilers **24** and **26** connected to a common header **28**. From header **28**, the steam can flow through a main ahead valve **30** to the high pressure side of turbine **14**; thence from the low pressure side of turbine **14** and through header **32** to the high pressure side of turbine **16**. Finally, the steam at low pressure passes from the low pressure side of turbine **16** through header **34** to a condenser **36**. Under the circumstances just described, the ship is moving in the ahead direction. In order to reverse the propeller **10** and cause the ship to move in the astern direction, the valve **30** is closed and a main astern valve **38** opened, whereupon steam will flow to the reversing blades **22** on shaft **20** and thence through header **34** to the condenser **36**. The arrangement just described is, of course, a common and well known marine propulsion system. As was explained above, the valves **30** and **38** have, in the past, been controlled manually by the ship's engine room operator in response to signals from the bridge.

While two boilers **24** and **26** are shown in the specific example of FIG. **1**, it will be understood, of course, that a single boiler could be utilized if desired, depending upon the requirements of the system. If the water level in the

boilers 24 and 26 should exceed a certain maximum limit, water will pass into the turbines 14 and 16. Conversely, enough water must be maintained in the boilers 24 and 26 to prevent them from burning up. Accordingly, each boiler is provided with level transmitters 40 and 42. The transmitters 40 and 42 may be of the type manufactured by the Bailey Meter Company and identified as Model LJ-2330B. Essentially, such transmitters are adapted to convert a water level indication into a pneumatic pressure.

Pressures from either of the respective transmitters 40 and 42 are, in turn, applied through a three-way valve 44 to a pneumatic diaphragm 46. The diaphragm 46 for boiler 24, for example, is mechanically connected to a movable core 48 in a first electromechanical transducer 50. In a similar manner, the diaphragm 46 for boiler 26 is mechanically connected to the movable core 52 for a second electromechanical transducer 54. Each of the transducers 50 and 54 includes a primary winding 56 connected across the output of a carrier oscillator 58 such that the output signal appearing across the secondary winding 60 of either transducer is an oscillatory signal having a magnitude and phase dependent upon the position of the movable core 48 or 52, as the case may be. The signal across winding 60 of transducer 50, for example, is rectified and filtered in demodulator circuit 61. Similarly, the signal across winding 60 of transducer 54 is rectified and filtered in demodulator circuit 62. The direct current outputs of circuits 61 and 62 are applied to an override adjustment circuit 64 which will produce an output whenever the direct current signals at the outputs of circuits 61 or 62 exceed a predetermined level.

Thus, if the water level within boiler 24 should move above the maximum permissible level, the core 48 may move upwardly, for example, to the point where the signal applied to override adjustment circuit 64 from the demodulator 61 causes an output from circuit 64. Similarly, when the water level in boiler 24 falls below the minimum desired level, movement of the core 48 downwardly will again cause an output from the overriding adjustment circuit 64. The operation of transducer 54 and circuit 62 is the same for boiler 26 and, hence, it can be said that whenever the water level within either boiler 24 or 26 rises above or below predetermined set limits as determined by the override adjustment circuit 64, an output signal will be applied to an override controller 66.

Reverting again to the boilers 24 and 26, the output pressure from the boilers 24 and 26 in header 28 is sensed by a diaphragm 68 which, in turn, actuates a movable core 70 in a third electromechanical transducer 72. The transducer 72, like transducers 50 and 54, is provided with a primary winding 74 connected across the output of carrier oscillator 58. The transducer 72, however, is provided with two output windings 76 and 78. With this arrangement, and assuming that the core 70 moves in one direction, the magnitude of the signal appearing across one winding 76, for example, will increase while that across the other winding decreases. Conversely, upon downward movement of the core 70, the reverse situation exists.

The signals appearing across windings 76 and 78 are rectified and filtered in circuits 80 and 82, respectively, the outputs of these circuits being combined and applied to the override adjustment circuit 64. Whenever the pressure in header 28 falls below a predetermined limit as determined by the override adjustment circuit 64, an output will be applied to the override controller 66. Although the override adjustment circuit 64 may take various forms, conventionally it will comprise diodes which are biased in the reverse direction such that they will conduct to produce an output signal to circuit 66 only when the bias voltage is exceeded. This bias voltage is preferably adjustable such that the maximum and minimum pressures, and the upper and lower levels of the water within boilers 24 and 26, can be adjusted. Thus, the override adjustment circuit 64 will produce an output signal whenever an off-normal boiler condition occurs such as reduced pressure, low water level, or high water level. Of course, the other off-normal conditions could be utilized to trigger the override adjustment circuit 64; and, in this respect, the output of the circuit 64 will hereinafter be referred to in the specification and claims as an "off-normal signal" which is produced when any one of a number of different off-normal conditions occur.

The main control for the propulsion system comprises a throttle control lever 84 movable from a central or stop position to an ahead position where the ship moves ahead; and movable backwardly from the stop position for the astern direction. The throttle lever 84 is connected to a reference divider or potentiometer 88, hereinafter described in detail, such that the output of the movable tap on the potentiometer appearing on lead 90 will have a polarity dependent upon whether the throttle lever 84 is moved to an ahead position or an astern position, and a magnitude dependent upon the amount of the movement of the throttle lever in either direction from its central or stop position. In the particular control system hereinafter described in detail, the output on lead 90 will be positive with respect to ground when the throttle lever is moved to an ahead position and negative with respect to ground when it is moved to an astern position. Furthermore, its magnitude will increase in the positive direction when the throttle lever is moved further in a clockwise direction from the stop position as shown in FIG. 1, and will increase in magnitude in the negative direction as it is moved in a counterclockwise direction from the stop position. The output on lead 90 is proportional to desired speed, and its polarity indicative of the desired direction of movement of the ship. Hence, it will hereinafter be referred to in the specification and claims as the "desired speed signal."

The desired speed signal on lead 90 is added in series with the output of a tachometer generator 92 mechanically connected to the propeller 10 of the ship. Hence, the output of the tachometer generator 92 is proportional to the actual speed of the propeller, and the polarity of the signal across the output terminals of generator 92 is indicative of the direction of actual propeller rotation, either astern or ahead. Hence, the output of tachometer generator 92 will hereinafter be referred to in the specification and claims as the "actual speed signal."

The actual speed signal across tachometer generator 92 normally has a polarity opposing that on lead 90 whenever the lever 84 is moved from a previously set position. As will be seen, whenever the actual speed of the propeller coincides with the desired speed as determined by the position of throttle lever 84, the output of reference divider 88 comprising the desired speed signal will be equal to, and opposite in polarity to, the actual speed signal produced by the tachometer generator 92 such that the input to speed control amplifier 94 will be zero. However, whenever the desired speed signal differs from the actual speed signal, an error signal will be produced which is applied to the speed control amplifier 94 to vary the steam input to the turbines 14 and 16 and thereby adjust the speed of the propeller such that it coincides with the desired speed.

The speed control amplifier will hereinafter be described in detail; however, for purposes of the present general description, it will be sufficient to state that it applies a "speed control signal" to lead 96 which is applied to an ahead servo amplifier 98 as well as to an astern servo amplifier 100. Whenever an astern control signal appears on lead 96, it will be positive with respect to ground; whereas an ahead control signal will be negative with respect to ground.

An output lead 102 from the override controller 66 is connected directly to the lead 96. The output of the override controller 66 is also applied to an override inverter 104 via lead 105. It will be noted that the lead 102 contains a diode 106 and that the output of the override in-

verter **104** as applied to lead **96** is provided with a diode **108**, the diodes **106** and **108** being connected in opposing polarity relationship. As will hereinafter be explained, the override controller **66** and inverter **104** comprise, in essence, devices for biasing the diodes **106** and **108** in the reverse direction. Normally, the reverse bias on each diode **106** or **108** is about 12 volts; whereas the magnitude of the error signal on lead **96**, whether it be positive or negative, is much less than this. Consequently, under normal conditions, neither one of the diodes **106** nor **108** will conduct. However, should an off-normal signal appear at the output of circuit **64** due to one of the off-normal conditions heretofore described, the reverse bias on the diodes **108** and **106** will be lowered. If, under these conditions, the magnitude of the speed control signal on lead **96** should exceed the reverse bias, the diode **106** or **108** will conduct to effectively "bleed off" or modify the speed control signal on lead **96** such that its magnitude is limited. For example, if the throttle lever **84** should be rotated in a clockwise direction from the stop position to the full speed ahead position while the boiler pressure is low, the position of the core **70** in transducer **72** will cause an output off-normal signal from circuit **64** which will lower the reverse bias on diodes **108** and **106**. Assuming that the output speed control signal of the speed control amplifier **94** is larger than the reverse bias on diodes **106** and **108**, the magnitude of the speed control signal as applied to circuits **98** and **100** will be limited. This, of course, prevents any attempts to admit large quantities of steam into the turbines when one of the aforesaid off-normal conditions occur.

The ahead servo amplifier **98** is part of an ahead servo motor system which also includes a first servo motor **110** coupled to the output of amplifier **98**. The servo motor **110** may comprise a core **112** of magnetically permeable material having two windings **114** and **116** thereon and wound in opposite directions. Magnetic fields are applied transversely across the ends of core **112** by means of C-shaped magnets **117** and **119**. The output of the ahead servo amplifier **98** is applied to the windings **114** and **116** in a push-pull arrangement such that when the speed control signal on lead **96** is negative and increasing in the negative direction, the core **112** will be rotated about pivot point **118** in one direction. When the signal on lead **96** is negative but decreasing, the core **112** will rotate in the opposite direction. The core **112**, in turn, is mechanically coupled to the valve **30** such that as the magnitude of the negative speed control signal on lead **96** increases, the core **112** will rotate in one direction to open valve **30** further; while when the magnitude of the negative signal on lead **96** decreases, the core **112** will rotate in the opposite direction to thereby cause the valve **30** to close further. The core **112** is connected to valve **30** through a suitable hydro-mechanical servo mechanism, schematically illustrated by broken line **113**. When a negative voltage on lead **96** is neither increasing nor decreasing, the core **112** and valve **30** will remain in their previously-established conditions due to the negative feedback path **121** around amplifier **98** providing a conventional servo loop.

The astern servo amplifier **100** is part of an astern servo motor system which also includes a second servo motor **120** coupled to the output of amplifier **100**. Like motor **110**, servo motor **120** has a pair of windings **122** and **124** connected in a push-pull arrangement together with a movable core **126** mechanically connected to the astern valve **38** through a suitable hydro-mechanical servo mechanism schematically illustrated by the broken line **127**, so as to open or close this valve in response to a positive speed control signal on lead **96**. That is, positive control signals which are increasing in the positive direction will cause valve **38** to open further; while decreasing positive control signals will cause the valve **38** to close. Whenever a positive control signal on lead **96** is not changing, the valve **38** will remain in its previously established position due to the negative feedback path **127'** around amplifier **100** providing a conventional servo loop. As will be understood, the valves **30** and **38** are of the type which can also be operated manually.

The operation of the system of FIG. 1 can be summarized as follows: Assuming, for example, that it is desired to move in the ahead direction from a stop position, the throttle lever **84** is rotated in a clockwise direction, thereby producing a desired speed signal on lead **90**. Since, at this particular time, the propeller **10** is not rotating, the voltage across tachometer generator **92** will be zero, and a speed control signal appears at the output of amplifier **94**. This speed control signal will be of negative polarity and of increasing magnitude. Hence, it will actuate the servo motor **110** through amplifier **98** to open the ahead steam valve **30**. Once the voltage at the output of reference divider **88** matches that produced by tachometer **92**, the voltage on lead **96** of negative polarity remains constant at a fixed level roughly proportional to the desired speed setting of the control lever **84**. The servo amplifier **98**, however, will open the valve **30** only to effect the desired speed setting, whereupon the output of the servo amplifier will remain fixed by virtue of negative feedback path **121** in accordance with usual practice. Of course, the feedback path **121** can be replaced by a mechanical-type feedback arrangement connected to the core **112** or other parts of the valve **30**. Now, if it is assumed that it is desired to reduce the speed of the ship, throttle lever **84** will be rotated in a counterclockwise direction. In this case, the magnitude of the voltage on lead **96** will decrease, whereupon the valve **30** will close further to reduce the amount of steam supplied to the turbines **14** and **16**. The operation for the astern servo amplifier and servo motor **120** is, of course, the same except that in this case the polarity of the voltage on lead **96** is positive rather than negative.

Reference divider

With reference now to FIG. 2, the detailed circuitry of the invention is shown. The reference divider **88** comprises a voltage divider **132** having its center point grounded and its opposite ends connected to the positive and negative terminals of direct current voltage sources, in this case voltage sources of about 24 volts. Various points on the voltage divider **132** are connected to contacts identified as 1C through 12C adapted to be engaged by a rotary wiper brush **134** which is connected to the throttle lever **84** and rotatable therewith. Wiper brush **134**, in turn, is connected to the lead **90**. It will be understood that as the wiper brush **134** rotates in a counterclockwise direction from its center or stop position, the voltage on lead **90** (i.e., the desired speed signal) will be negative with respect to ground. Furthermore, the further the wiper brush **134** rotates in a counterclockwise direction from its stop position, the greater the magnitude of the negative voltage on lead **90**. Conversely, as the wiper brush **134** rotates in a clockwise direction from its center or stop position, the voltage or desired speed signal on lead **90** will be positive with respect to ground and will increase in magnitude as the wiper brush **134** rotates further from its center position. Thus, the reference divider **88** can be positioned at any one of five ahead speed positions, five astern speed positions, and a stop position. As will be seen, each throttle switch position provides closure of a number of independent circuits which will fulfill all necessary logic and information functions associated with the speed throttle and propulsion plant operation. It will be noted, however, that when the wiper brush **134** is at the center or stop position, the contact **12C** to which it is connected is not at ground potential (i.e., zero voltage), but rather is connected through lead **136** to a tap on variable resistor **138** in the voltage divider **132**. Hence, depending upon the position of the movable tap on resistor **138**, a slight positive voltage will exist on lead **90**, even when the throttle lever **84** is at the center or stop position.

Logic control-transfer between engine room and bridge

In order for the bridge of the ship to assume control of the turbines **14** and **16**, certain equipment conditions must first be met. Relay A senses the existence of these required conditions before permitting control and operation of the propulsion turbines from the bridge. In this respect, the output of ahead servo amplifier **98** is normally grounded through normally closed contacts A1 of the relay A. Similarly, the output of the astern servo amplifier **100** is normally grounded through normally closed contacts A2 of the relay A. Hence, as long as the relay A is not energized, the valves **30** and **38** cannot be controlled by the throttle lever **84** directly from the bridge.

Control may be transferred from the engine room to the bridge only when a master switch **140** is closed and certain other conditions are met. These certain other conditions are represented in FIG. 2 by the logic circuit **142** which, in essence, comprises a plurality of contacts, all of which must be closed to complete a circuit to the relay A upon closure of switch **140** before the relay can become energized. However, once relay A becomes energized, it is maintained energized by its own contacts A3 until the switch **140** is opened. The switches which are closed to complete the circuit through the logic circuit **142** need not be described herein in detail. It will be sufficient to state that when all of the necessary conditions for bridge control are met, the contacts within circuit **142** will close to thereby initially energize relay A and permit bridge control to take over.

Reverting again to the throttle lever **84**, it is provided with additional wiper brushes **148** and **150** which rotate with the wiper brush **134**. With the throttle lever **84** in its central or stop position, wiper brush **148** will act to energize a relay F; and, assuming that contacts H1 and I1 are closed, it will also energize relay C. Relay contacts H1 and I1 are on relays H and I, respectively, which relays are energized by closure of limit switches **152** and **154** respectively. Limit switch **152** is closed when the ahead valve **30** is completely closed; whereas limit switch **154** is closed when the astern valve **38** is completely closed. It can be seen, therefore, that the relay C will become energized only when the throttle lever **84** is at its center or stop position and both the ahead and the astern valves **30** and **38** are closed. Once the relay C becomes energized, it will remain energized through contacts C1, just so long as the astern valves **38** remains closed and the contacts I1 are closed. The overall effect of this is that once the relay C is energized, it will remain energized even through the ahead valve **30** is opened.

When the throttle lever **84** is moved counterclockwise to an astern position, the wiper brush **148** will engage arcuate contact **156** to thereby energize relay B. Hence, relay B will be energized whenever the throttle lever is in an astern position. Finally, the wiper brush **150** will engage contact point **158** to energize relay E only when the throttle lever **84** is in its maximum astern position (i.e., on contact 5C). At all other times, the relay E is deenergized.

Speed control amplifier

The output of the tachometer generator **92** is connected to ground through two parallel current paths, each of which includes three diodes **144–146** connected to conduct current in opposite directions. The purpose of these diodes is to clamp the speed error signal at the output of the tachometer **92** such that it will not exceed the capabilities of the system. Assume, for example, that the throttle lever **84** is suddenly moved from the stop position to contact 7C (i.e., maximum speed ahead). Under these conditions, the signal on lead **90** will approach plus 24 volts; and since the output of the tachometer **92** is essentially zero at this time, a voltage of almost 24 volts, as attenuated by resistor **91** and tachometer **92**, would be applied to the input of the speed control amplifier **94** exceeding the system capability. Accordingly, the clamp comprising the diodes **144** and **146** clamps the output from the wiper brush **134** and tachometer **92** to plus or minus about 1.8 volts. This is well within the capability of the speed control amplifier **94**. Of course, as the speed of the propeller is gradually brought up to maximum speed ahead, the voltage generated by the tachometer **92** will gradually approach that on the wiper brush **134** until the two are equal and the input to the speed control amplifier **94** is zero.

The speed error signal at the output of tachometer **92**, as clamped by the diodes **144** and **146** is applied across a voltage divider in amplifier **94** comprising three resistors **160**, **162** and **164** connected in series. Resistor **162** is provided with a variable tap which is connected through a fixed resistor **166** to the input of an operational amplifier **168**. A capacitor **170** is connected in shunt with the operational amplifier **168** to filter ripple out of the tachometer generator output. The output of the operational amplifier is applied through a resistor **172** to the lead **96** and hence to the ahead servo amplifier **98** and astern servo amplifier **100**.

The operational amplifier arrangement in speed controller **94** acts as a proportional plus integral controller; and in this respect it is provided with a first feedback path including resistor **174** and capacitor **176** in series. The output of the controller for a step input error signal will appear as in FIG. 3. Thus, when the input error signal to the amplifier **94** changes abruptly about zero as when wiper brush **134** is moved from contact 12C to contact 11C, the output will also change abruptly at time t_1 lowering the voltage at the output of amplifier **168** by the amount equal to V_1. However, after this initial step or proportional output, the amplifier will integrate between the times t_1 and t_2, thereby changing the output voltage by an amount equal to V_2, but over a longer period of time. Thus, assuming that the propeller speed has reached equilibrium with the throttle setting and that the throttle lever **84** is moved from one contact point to the next, steam valve **30** will open abruptly during the proportional step function operation of amplifier **168** and thereafter open relatively slowly between the times t_1 and t_2. The proportional control feature is, of course, necessary to give the ship initial fast response characteristics as are necessary, for example, during docking.

In shunt with the capacitor **176** is a first current path including diode **178**, normally closed contacts F1 of the relay F and normally closed contacts B1 of relay B. A second current path in shunt with the capacitor **176** includes a second diode **180** and normally open contacts B2 of the relay B. As was mentioned above, when the ship is moving in the ahead direction, the output voltage on lead **96** as applied to the servo amplifiers **98** and **100** will be negative with respect to ground; whereas it will be positive with respect to ground when the ship is moving in the astern direction. When the throttle lever **84** is in an ahead position, neither of the relays B nor F will be energized. Consequently, current can flow through diode **178**, assuming that its anode (i.e., lead **96**) is positive with respect to its cathode. It may happen that when the throttle lever **84** is rotated in a counterclockwise direction to produce a lower desired speed signal on lead **90** the output of tachometer will overrun the desired speed signal until the ship slows down to the point where the speed is again at the desired speed. Under these conditions, and assuming that the diode **178** was not included in the circuit, the operational amplifier **168** would integrate into the opposite region when the speed of the propeller exceeds the desired speed. That is, the capacitor **176** would charge in the opposite direction; and if it were then desired to again increase the speed of the ship in the ahead direction, an unreasonable amount of delay time would be involved. This, however, is prevented by means of the diode **178**. If the throttle lever **84** is at its center or stop position, relay F becomes energized, contacts F1 open, and diode **178** is no longer effective.

The diode **180** functions in a similar manner, except that it is operative by virtue of closure of contacts B2 only when the throttle lever is in an astern position such that the voltage on lead **96** is positive with respect to ground. During this time, contacts B1 are open to disable the diode **178**.

Rate adjustment potentiometers

The rate at which the ahead valve **30** opens or closes is adjusted by means of a pair of potentiometers **182** and **184**. The potentiometer **182**, for example, is connected in series with resistor **186** between ground and a source of positive potential. Similarly, the potentiometer **184** is connected in series with resistor **188** between ground and a source of negative potential. The movable tap on potentiometer **182** is connected through diode **192** and normally closed contacts B3 of relay B to the junction of resistors **160** and **162** at the input to the speed control amplifier **160**. Likewise, the movable tap on potentiometer **184** is connected through diode **194**, normally closed contacts F2 of relay F and normally closed contacts B4 of relay B to the junction of resistors **160** and **162**. If the throttle lever **84** is rotated to the ahead position, the relays B and F will be deenergized. Consequently, the relay contacts B3, B4 and F2 will also be closed. If the signal input to the speed control amplifier **94** should exceed the bias on diode **192** when the throttle lever **84** is in an ahead position and the voltage input to the amplifier **94** negative, the diode **192** will serve to limit the magnitude of the input signal to the amplifier **94** and, hence, the rate at which the ahead valve **30** is closed. Similarly, with the throttle lever **84** in an ahead position and assuming that the input to amplifier **94** is positive, diode **194** will serve to limit the magnitude of the input to amplifier **94** as determined by the bias voltage established by the setting of the movable tap on potentiometer **184**. This limits the rate at which the ahead valve is opened.

The rate of opening of the astern valve **38** is controlled by means of a similar arrangement including potentiometers **196** and **198**, these potentiometers being connected in series with resistors **200** and **202**, respectively. The movable tap on potentiometer **196** is adapted for connection to the input to amplifier **94** through diode **204**, normally closed contacts E1 of relay E, and either normally open contacts B5 of relay B or normally open contacts F3 of relay F. The movable tap on potentiometer **198** is adapted for connection to the input to operational amplifier **94** through diode **206**, normally closed contacts E2 of relay E and normally open contacts B6 of relay B.

When the throttle lever **84** is in an astern position, the contacts B5 will be closed as will contacts E1, assuming that the lever is not in the maximum astern position. Similarly, contacts B6 and E2 will be closed. Hence, the diodes **204** and **206** will limit the negative and positive input signals to amplifier **94** and, hence, the rate of opening or closing of valve **38**. Relay contacts E1 and E2 are provided in the system for the reason that when the throttle lever is moved to the maximum astern position, it is usually in an effort to prevent a collision. For this reason, no limit is imposed on the rate of opening of the astern valve **38** when the throttle lever is in the extreme astern position. Relay contacts F3 are included in the circuit since if the throttle lever is moved from an astern position to a stop position, for example, the astern valve may still be closing and the previously established limit will still be in effect.

Interlocking of servo amplifiers

With reference to the servo amplifiers **98** and **100**, it will be noted that in addition to contacts A1 and A2, a number of other contacts are provided for grounding the output of the servo amplifiers to prevent operation of the valves **30** and **38**. Thus, the ahead servo amplifier **98** is provided with normally closed contacts I2 of the relay I which is energized whenever the astern valve **38** is closed. If the astern valve is open, the contacts I2 will be closed and the ahead valve cannot be opened. A similar arrangement is provided for servo amplifier **100** wherein contacts H2, which are normally closed, are in that position when valve **30** is open to prevent opening of the astern valve **38**. In this manner, it will be appreciated that both valves **30** and **38** cannot be open at the same time. The ahead servo amplifier **98** is provided with normally open relay contacts B7 which close only when the throttle lever **84** is in an astern position. Thus, the valve **30** cannot open when the throttle lever **84** is in an astern position. Similarly, when the throttle lever is in an ahead position, contacts B8 for servo amplifier **100** will close, thereby preventing opening of the astern valve **38**, even though relay F is energized to open contacts F4 and relay C is deenergized such that contacts C2 are open. This condition will occur when the throttle lever is at its central or stop position and the astern valve is open.

Override controller

With reference now to the override controller **66**, it comprises an operational amplifier **208** which operates as a proportional amplifier with a time constant. Normally, the output of the operational amplifier is set at about minus 12 volts as by means of a potentiometer **210** connected between ground and a source of positive potential, the movable tap on the potentiometer **210** being connected to the input of the amplifier **208** through resistor **212**. The amplifier **208** is provided with two feedback paths, one of which includes a diode **214** and the other of which includes a resistor **216** and capacitor **218** in parallel, these latter circuit elements acting as a filter. The override error signal from the override adjustment circuit **64** is applied to the input of the amplifier **208** through a resistor **220**, the arrangement being such that the override signal, being of negative polarity, will reduce the magnitude of the negative output signal of the operational amplifier **208**. This reduction in the output from the operational amplifier **208** reduces the bias on diode **106**.

The output of the operational amplifier **208** is applied to the input of an operational amplifier **222** in the override inverter **104** through a resistor **224**. A bias may be applied to the amplifier **222** by means of potentiometer **226** having its movable tap also connected to the input of amplifier **222** through resistor **228**. Amplifier **222**, like amplifier **208**, is provided with two feedback paths one of which includes a diode **230** and the other of which includes a resistor **232**. The output from the amplifier **222** will be a positive voltage of magnitude equal to the negative voltage at the output of amplifier **208** plus any bias voltage applied to resistor **226**. The output of amplifier **208**, in turn, serves to bias the diode **108** in the reverse direction.

The operation of the override controller can perhaps best be understood by reference to FIG. 3. Thus, the normal bias on the diodes **106** and **108** is minus 12 volts and plus 12 volts, respectively, as represented by the lines **234** and **236**. Should the control signal applied to the servo amplifiers **100** and **98** rise above plus 12 volts or below minus 12 volts, respectively, diode **106** or **108** will conduct to effectively "bleed off" or modify the control signal on lead **96** such that it does not exceed 12 volts. Now, if an off-normal condition should occur, the bias voltage on the diodes **106** and **108** may be reduced to eight volts as represented by the lines **238** and **240**. Such a condition might occur, for example, because of low boiler pressure. Under these circumstances, the magnitude of the control signal applied to the servo amplifiers **98** and **100** is limited to plus or minus 8 volts. Hence, the opening of valves **30** and **38** is also limited.

Roll-over circuit

When the throttle lever **84** is at its central or stop position and the ship is at rest, it is necessary for the turbines **14** and **16** to be started and stopped every few minutes in order that rotor straightness can be main-

tained. That is, due to uneven heating of the turbines, the rotors will become warped if they are not rotated from time-to-time. Therefore, a "roll-over" control is provided in conjunction with the normal control circuitry heretofore described in order to rotate the turbines from time-to-time.

When the throttle lever **84** is at its central position and the astern valve **38** and ahead valve **30** are both closed, the relays H and I will become energized. This closes the contacts H1 and I1 to energize relay C. When relay C becomes energized, relay contacts C3 in the speed control amplifier **94** are closed and relay contacts C4 open. Closure of contacts C3 shorts the capacitor **176** and insures that when throttle lever **84** is again moved from its central or stop position, no residual charge will exist on the capacitor **176**. Opening of the contacts C4, of course, prevents normal operation of amplifier **168** since the feedback path containing capacitor **176** is now interrupted. When relay C becomes energized, it opens contacts C5 and closes contacts C6. A second feedback path **242** is now connected between the input and output of amplifier **168**.

As was mentioned above, when the throttle lever **84** is in its central or stop position, a slight positive voltage will appear on lead **90** by virtue of the fact that contact **12C** is connected to the movable tap on variable resistor **138**. Feedback path **242** is a high gain feedback circuit capable of providing a roll-over or intermittent pulsing of the ahead valve **30**. That is, by the action of the circuit, the valve **30** is opened just long enough for the propeller to be accelerated to some value less than 3 revolutions per minute. At this point, the speed is sensed by the tachometer **92** to counteract with a light positive voltage on lead **90**, and the speed controller output on lead **96** quickly changes from about minus 1 to minus 2 volts necessary for just opening the ahead valve, to the maximum positive voltage permitted by the override inverter causing a "hard closing" of the ahead valve. If the ship has no headway, the turbine speed will gradually reduce to zero and the speed controller will begin to integrate from the positive "hard closed" region back into the negative region necessary for the next roll-over pulse. This is achieved by means of capacitor **243** in series with resistors **244** and **246** in feedback path **242**. The roll-over repetition rate is adjusted by variable resistor **138**. The roll-over circuitry per se is the subject of copending application Ser. No. 540,567, filed concurrently herewith and assigned to the assignee of the present application.

While the invention has been shown in connection with a certain specific embodiment, it will be readily apparent to those skilled in the art that various changes in form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention.

We claim as our invention:

1. In a speed control system for a fluid-driven ship propulsion turbine, the combination of means for producing a desired propeller speed signal, means for producing an actual propeller speed signal, means for comparing the desired and actual speed signals to derive a speed error signal when the desired and actual speed signals differ, valve means for controlling the admission of fluid under pressure to said turbine, servo motor means for actuating said valve means, and apparatus including integrating means responsive to said speed error signal for driving said servo motor means to adjust the valve means in response to a speed error signal, said integrating means being operative to integrate when the desired speed signal dominates the actual speed signal and inoperative to integrate when the actual speed signal dominates the desired speed signal.

2. In speed control apparatus for a ship propulsion system including a main ahead valve for admitting fluid under pressure to turbine means to rotate the ship's propeller in one direction and a main astern valve for admitting fluid under pressure to said turbine means to rotate the ship's propeller in the opposite direction; the combination of ahead servo motor means for actuating the main ahead valve, astern servo motor means for actuating the main astern valve, means for producing a desired propeller speed signal having a first characteristic indicative of the desired direction of movement and a second characteristic indicative of the desired speed in either direction, means for producing an actual propeller speed signal having a first characteristic indicative of the actual direction of movement of the ship and a second characteristic indicative of the actual speed of the propeller in the desired direction, means for comparing the desired and actual speed signals to produce a speed error signal when the desired and actual speed signals differ, means including integrating means responsive to said speed error signal for producing a direct current control voltage which has one polarity when the characteristics of the desired speed signal dictate an ahead direction and the opposite polarity when the characteristics of the desired speed signal dictate an astern direction, said integrating means being operative to integrate when the error signal is in the same direction as the desired speed signal, means for rendering the integrating means inoperative to integrate when the error signal is in the same direction as the actual speed signal, servo amplifier means responsive to said direct current control voltage for causing the ahead servo motor means to actuate the main ahead valve when the direct current control voltage is of one polarity, and servo amplifier means responsive to said direct current control voltage for causing the astern servo motor means to actuate the main astern valve when the direct current control voltage is of the opposite polarity.

3. In speed control apparatus for a ship propulsion system including a main ahead valve for admitting fluid under pressure to turbine means to rotate the ship's propeller in one direction and a main astern valve for admitting fluid under pressure to said turbine means to rotate the ship's propeller in the opposite direction; the combination of ahead servo motor means for actuating the main ahead valve, astern servo motor means for actuating the main astern valve, means for producing a desired propeller speed signal having a first characteristic indicative of the desired direction of movement and a second characteristic indicative of the desired speed in either direction, means for producing an actual propeller speed signal having a first characteristic indicative of the actual direction of movement of the ship and a second characteristic indicative of the actual speed of the propeller in the desired direction, means for comparing the desired and actual speed signals to produce a speed error signal when the desired and actual speed signals differ, means responsive to said speed error signal for producing a direct current control voltage which has one polarity when the characteristics of the desired speed signal dictate an ahead direction and the opposite polarity when the characteristics of the desired speed signal dictate an astern direction, servo amplifier means responsive to said direct current control voltage for driving the ahead servo motor means to actuate the main ahead valve when the direct current control voltage is of one polarity, servo amplifier means responsive to said direct current control voltage for driving the astern servo motor means to actuate the main astern valve when the direct current control voltage is of the opposite polarity, means for preventing opening of the astern valve when the ahead valve is open, and means for preventing opening of the ahead valve when the astern valve is open.

4. In speed control apparatus for a ship propulsion system including a main ahead valve for admitting fluid under pressure to turbine means to rotate the ship's propeller in one direction and a main astern valve for admitting fluid under pressure to said turbine means to rotate the ship's propeller in the opposite direction; the combination of ahead servo motor means for actuating the main ahead valve, astern servo motor means for

actuating the main astern valve, means for producing a desired propeller speed signal having a first characteristic indicative of the desired direction of movement and a second characteristic indicative of the desired speed in either direction, means for producing an actual propeller speed signal having a first characteristic indicative of the actual direction of movement of the ship and a second characteristic indicative of the actual speed of the propeller in the desired direction, means for comparing the desired and actual speed signals to produce a speed error signal when the desired and actual speed signals differ, means responsive to said speed error signal for producing a direct current control voltage which has one polarity when the characteristics of the desired speed signal dictate an ahead direction and the opposite polarity when the characteristics of the desired speed signal dictate an astern direction, servo amplifier means responsive to said direct current control voltage for causing said ahead servo motor means to actuate the main ahead valve when the direct current control voltage is of one polarity, servo amplifier means responsive to said direct current control voltage for causing the astern servo motor means to actuate the main astern valve when the direct current control voltage is of the opposite polarity, and means for preventing opening of the astern valve when a characteristic of the desired speed signal indicates an ahead direction, and means for preventing opening of the ahead valve when a characteristic of the desired speed signal indicates an astern direction.

5. In a speed control system for a fluid-driven ship propulsion turbine, the combination of means for producing a desired propeller speed signal, means for producing an actual propeller speed signal, means for comparing the desired and actual speed signals to derive a speed error signal when the desired and actual speed signals differ, valve means for controlling the admission of fluid under pressure to said turbine, servo motor means for actuating said valve means, apparatus including integrating means responsive to said speed error signal for driving said servo motor means to adjust the valve means in response to a speed error signal, said apparatus for driving the servo motor means having an output supplying a direct current control voltage to said servo motor means, circuit means including reverse-biased diodes connected to the output of said apparatus for limiting the magnitude of said direct current control voltage as applied to the servo motor means, and means for lowering the bias on said diodes in response to the occurrence of an off-normal condition in the propulsion system for said ship whereby the maximum magnitude of the direct current control voltage as applied to the servo motor means is correspondingly lowered.

6. The control system of claim **5** including electromechanical transducer means for sensing an off-normal condition in the propulsion system of said ship, a source of oscillatory voltage for energizing said electromechanical transducer means, means for rectifying the output of said electromechanical transducer means, and means including an operational amplifier operable in response to the rectified output of the transducer means for regulating the reverse bias on said diodes.

7. The control system of claim **5** wherein there are two reverse-biased diodes connected to the output of said apparatus, a first of said diodes having its cathode connected to the output of said apparatus and a second of the diodes having its anode connected to the output of said apparatus, a first operational amplifier having its output connected to the anode of said first diode, a second operational amplifier having its output connected to the cathode of said second diode, means for producing an off-normal signal when an off-normal condition occurs in the propulsion system of said ship, means for applying said off-normal signal to the input of said first operational amplifier, and means for applying the output of said first operational amplifier to the input of said second operational amplifier.

8. In a speed control system for a fluid-driven ship propulsion turbine, the combination of means for producing a desired propeller speed signal, means for producing an actual propeller speed signal, means for comparing the desired and actual speed signals to derive a speed error signal when the desired and actual speed signals differ, valve means for controlling the admission of fluid under pressure to said turbine, servo motor means for actuating said valve means, and apparatus responsive to said speed error signal for driving said servo motor means to adjust the valve means in response to a speed error signal, said apparatus comprising an operational amplifier having a negative feedback path including a resistor and a capacitor in series whereby the output of the operational amplifier in response to a step input will be a proportional step output followed by an integrating output.

9. The control system of claim **8** wherein the desired speed signal comprises a direct current voltage the magnitude and polarity of which are varied manually under the control of the bridge of the ship, the actual speed signal comprises a direct current voltage generated by a tachometer generator mechanically coupled to the ship's propeller, and means for adding said desired and actual speed signals in series to produce a direct current voltage comprising said speed error signal.

10. The combination of claim **8** wherein said capacitor is shunted by a unidirectional device poled in the direction of negative feedback occurring when said error signal is in the same direction as the actual speed signal.

11. In speed control apparatus for a ship propulsion system including a main ahead valve for admitting fluid under pressure to turbine means to rotate the ship's propeller in one direction and a main astern valve for admitting fluid under pressure to said turbine means to rotate the ship's propeller in the opposite direction; the combination of ahead servo motor means for actuating the main ahead valve, astern servo motor means for actuating the main astern valve, means for producing a desired propeller speed signal having a first characteristic indicative of the desired direction of movement and a second characteristic indicative of the desired speed in either direction, means for producing an actual propeller speed signal having a first characteristic indicative of the actual direction of movement of the ship and a second characteristic indicative of the actual speed of the propeller in the desired direction, means for comparing the desired and actual speed signals to produce a speed error signal when the desired and actual speed signals differ, means including integrating means responsive to said speed error signal for producing a direct current control voltage which has one polarity when the characteristics of the desired speed signal dictate an ahead direction and the opposite polarity when the characteristics of the desired speed signal dictate an astern direction, servo amplifier means responsive to said direct current control voltage for causing the ahead servo motor means to actuate the main ahead valve when the direct current control voltage is of said one polarity, direct current control voltage of said one polarity and increasing magnitude causing said main ahead valve to open, direct current control voltage of said one polarity but of decreasing magnitude causing said main ahead valve to close, and servo amplifier means responsive to said direct current control voltage for causing the astern servo motor means to actuate the main astern valve when the direct current control voltage is of said opposite polarity, direct current control voltage of said opposite polarity and increasing magnitude causing said main astern valve to open, and direct current control voltage of said opposite polarity but of decreasing magnitude causing said main astern valve to close.

12. In a speed control system for a fluid-driven ship propulsion turbine, the combination of:

(a) means for producing a desired propeller speed signal comprising voltage divider means connected between the output terminals of a source of direct current voltage and having an intermediate grounded tap and a plurality of contact points on both sides of the tap, whereby the voltage on contact points on one side of the tap will be positive with respect to ground and the voltage on contact points on the other side of the tap will be negative with respect to ground, and a wiper brush engageable with said contact points in succession whereby the voltage appearing between said wiper brush and ground will comprise said desired speed signal, the magnitude and polarity of the desired speed signal being dependent upon the contact point which the wiper brush engages;

(b) means for producing an actual propeller speed signal, said actual speed signal comprising a direct current voltage; and said means for producing said actual speed signal comprising tachometer generator means mechanically coupled to the ship's propeller, said tachometer generator means having first and second output terminals;

(c) error generating means for comparing the desired and actual speed signals to derive a speed error signal when the desired and actual speed signals differ, said error generating means comprising means connecting said wiper brush to one of said tachometer generator terminals, and circuit means including resistance means connecting the other of said tachometer generator terminals through said resistance means to ground, said circuit means having a circuit point, at least a portion of said resistance means being included between said circuit point and ground; whereby said circuit point provides a voltage representing said error;

(d) valve means for controlling the admission of fluid under pressure to said turbine;

(e) servo motor means for actuating said valve means;

(f) apparatus including integrating means responsive to said speed error signal for driving said servo motor means to adjust the valve means in response to a speed error signal, said apparatus having input means connected to said circuit point; and

(g) first unidirectional current means for conducting current from said other terminal of the tachometer generator means to ground in one direction, and second unidirectional current means connected to said other terminal of the tachometer generator means for conducting current to ground in the other direction, said first and second unidirectional current means serving to limit the magnitude of the error signal applied to said apparatus for driving the servo motor means.

13. In speed control apparatus for a ship propulsion system including a main ahead valve for admitting fluid under pressure to turbine means to rotate the ship's propeller in one direction and a main astern valve for admitting fluid under pressure to said turbine means to rotate the ship's propeller in the opposite direction; the combination of ahead servo motor means for actuating the main ahead valve, astern servo motor means for actuating the main astern valve, means for producing a desired propeller speed signal having a first characteristic indicative of the desired direction of movement and a second characteristic indicative of the desired speed in either direction, means for producing an actual propeller speed signal having a first characteristic indicative of the actual direction of movement of the ship and a second characteristic indicative of the actual speed of the propeller in the desired direction, means for comparing the desired and actual speed signals to produce a speed error signal when the desired and actual speed signals differ, means including an operational amplifier responsive to said speed error signal for producing a direct current control voltage which has one polarity when the characteristics of the desired speed signal dictate an ahead direction and the opposite polarity when the characteristics of the desired speed signal dictate an astern direction, said operational amplifier having a negative feedback circuit including in series a resistor and a capacitor, means for unidirectionally shunting the capacitor in the same direction as that of the negative feedback that occurs when the actual speed signal dominates the desired speed signal, servo amplifier means responsive to said direct current control voltage for causing the ahead servo motor means to actuate the main ahead valve when the direct current control voltage is of said one polarity, and servo amplifier means responsive to said direct current control voltage for causing the astern servo motor means to actuate the main astern valve when the direct current control voltage is of said opposite polarity.

14. The combination of claim **11** wherein said means responsive to said speed error signal includes proportional plus integral controller means.

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