July 16, 1968 L. P. BUCKLEY, JR., ET AL 3,392,696

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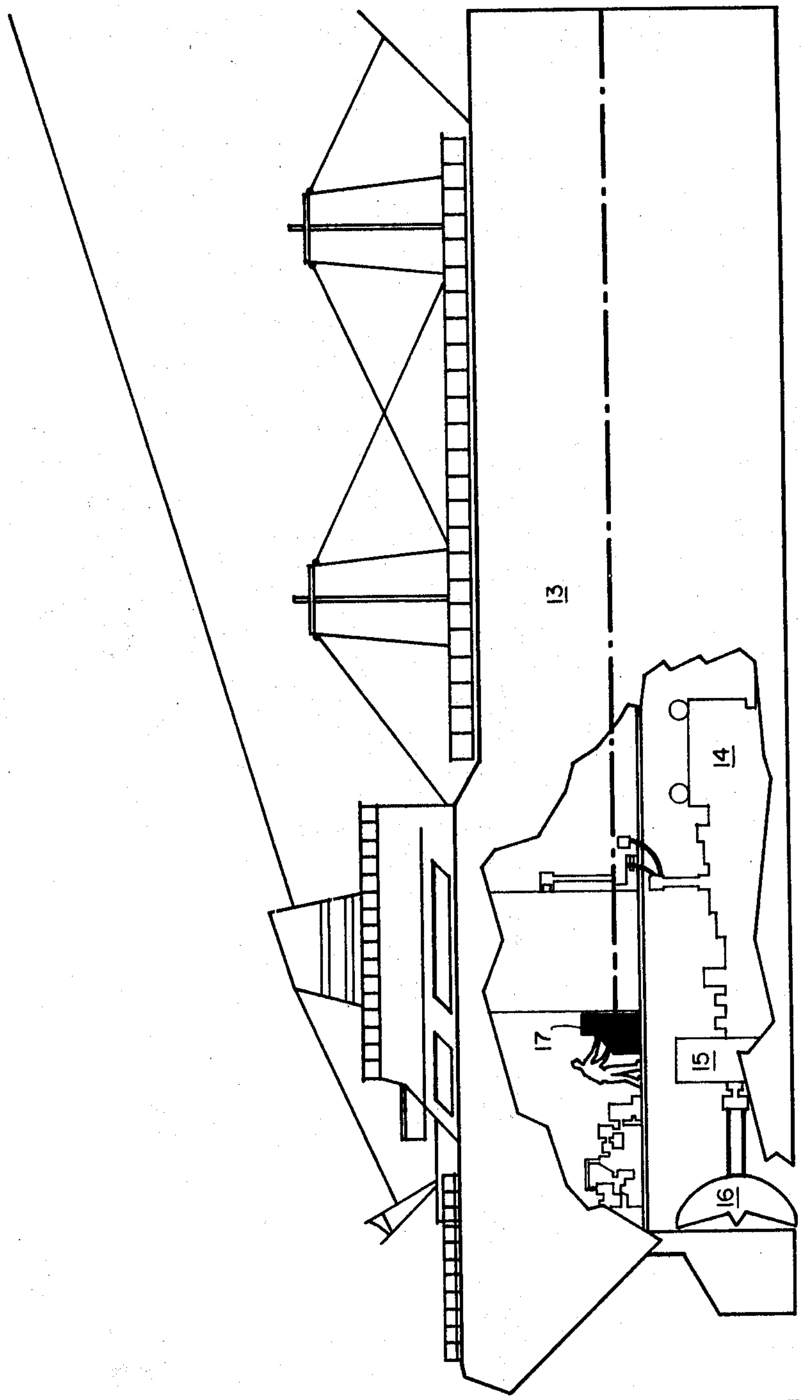

FIG. 1

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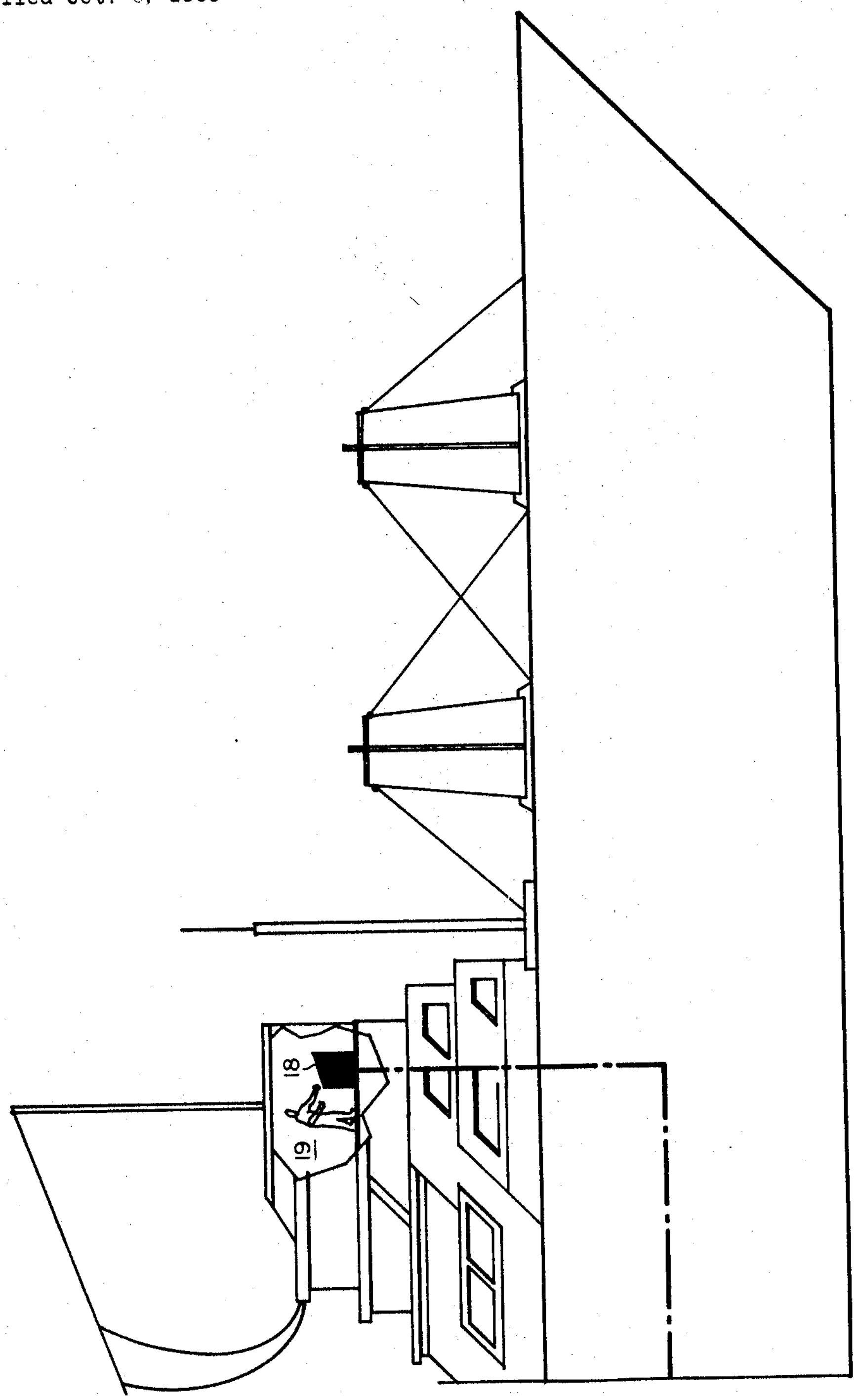

FIG. 1A

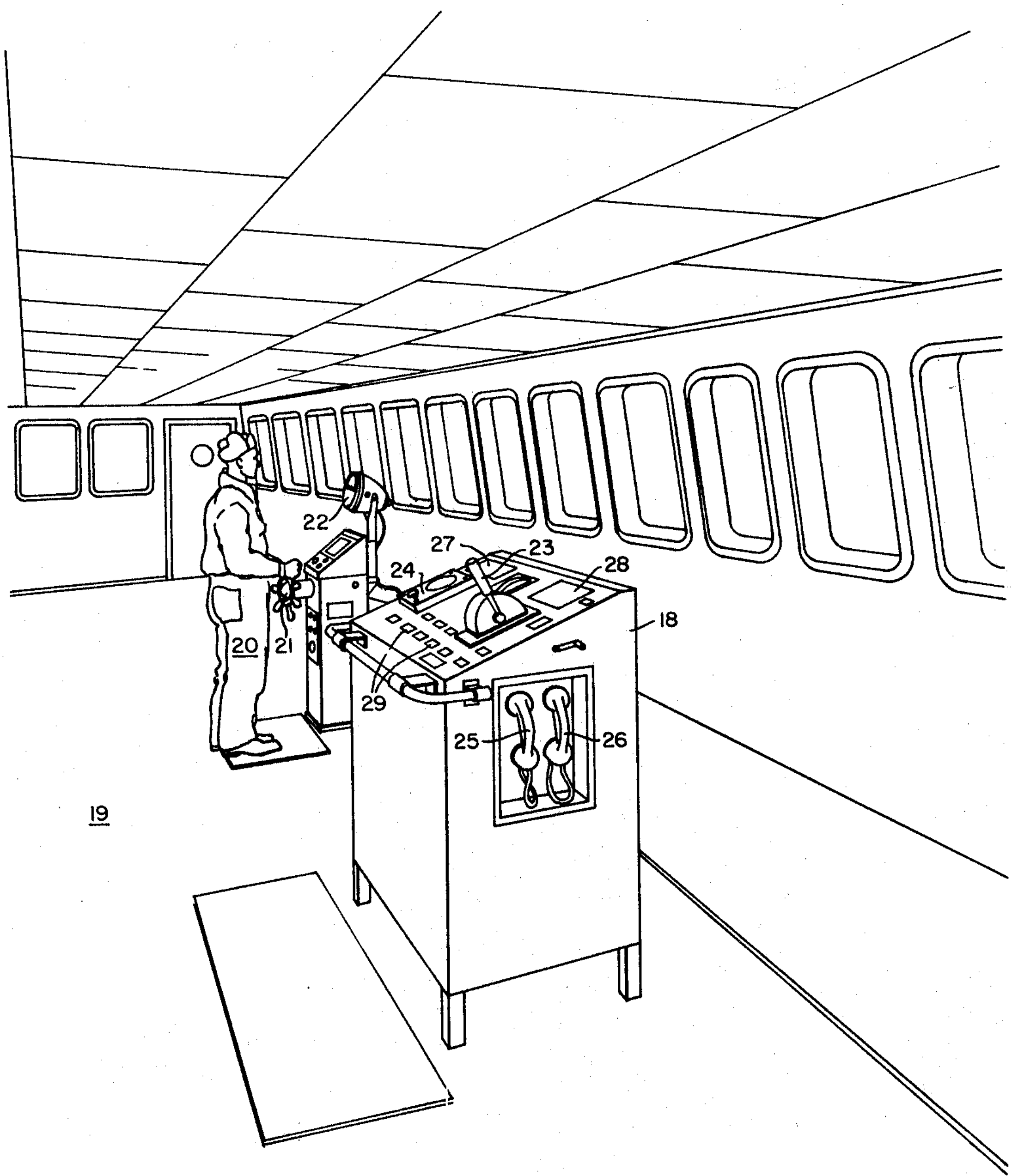

FIG. 2

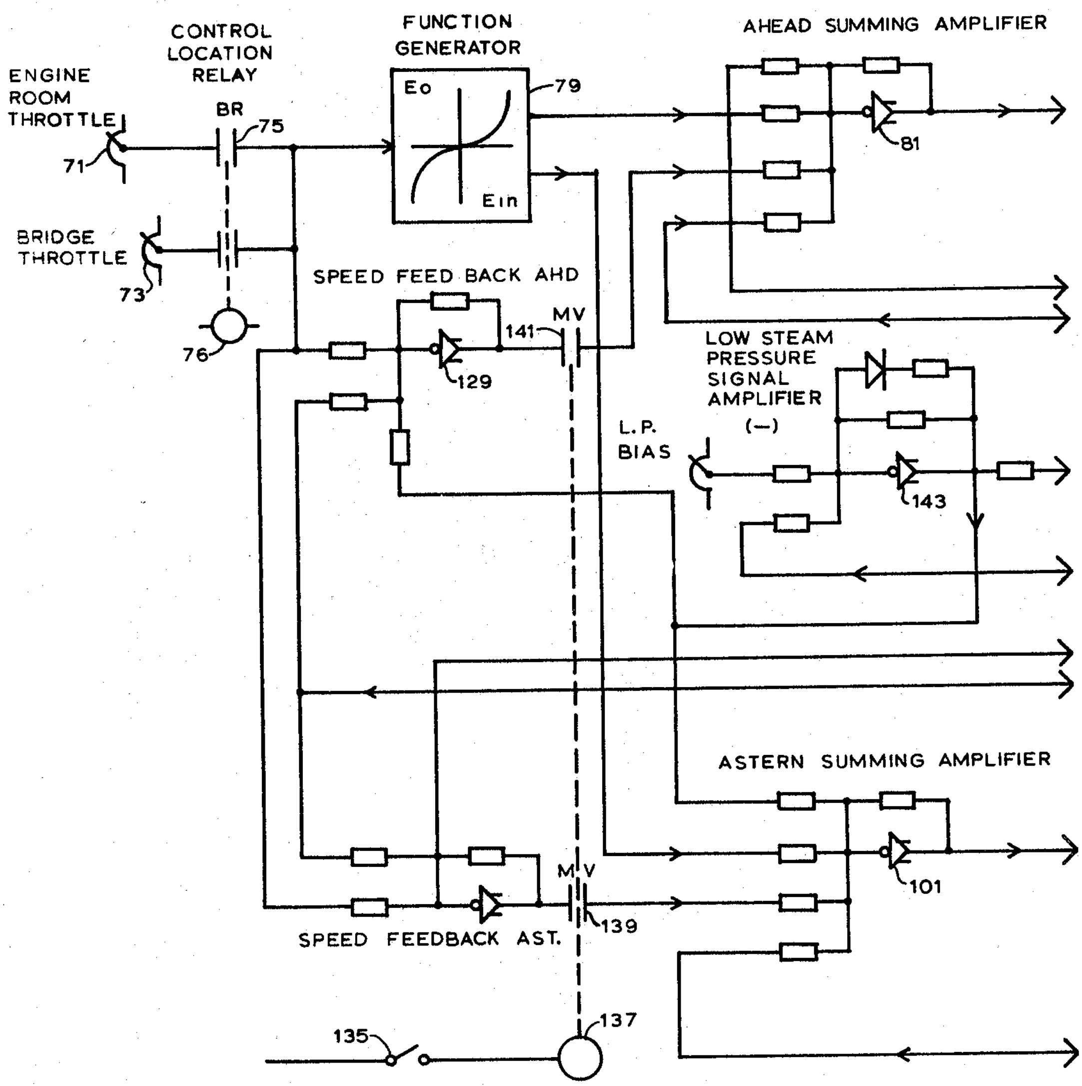
CONTROL
LOCATION
RELAY
FUNCTION
GENERATOR
AHEAD SUMMING AMPLIFIER
ENGINE
ROOM
THROTTLE
BR
75
Eo
79
81
71
Ein
BRIDGE
THROTTLE
73
SPEED FEED BACK AHD
MV
141
76
129
LOW STEAM
PRESSURE
SIGNAL
AMPLIFIER
(—)
L.P.
BIAS
143
ASTERN SUMMING AMPLIFIER
101
MV
139
SPEED FEEDBACK AST.
135
137

FIG. 3

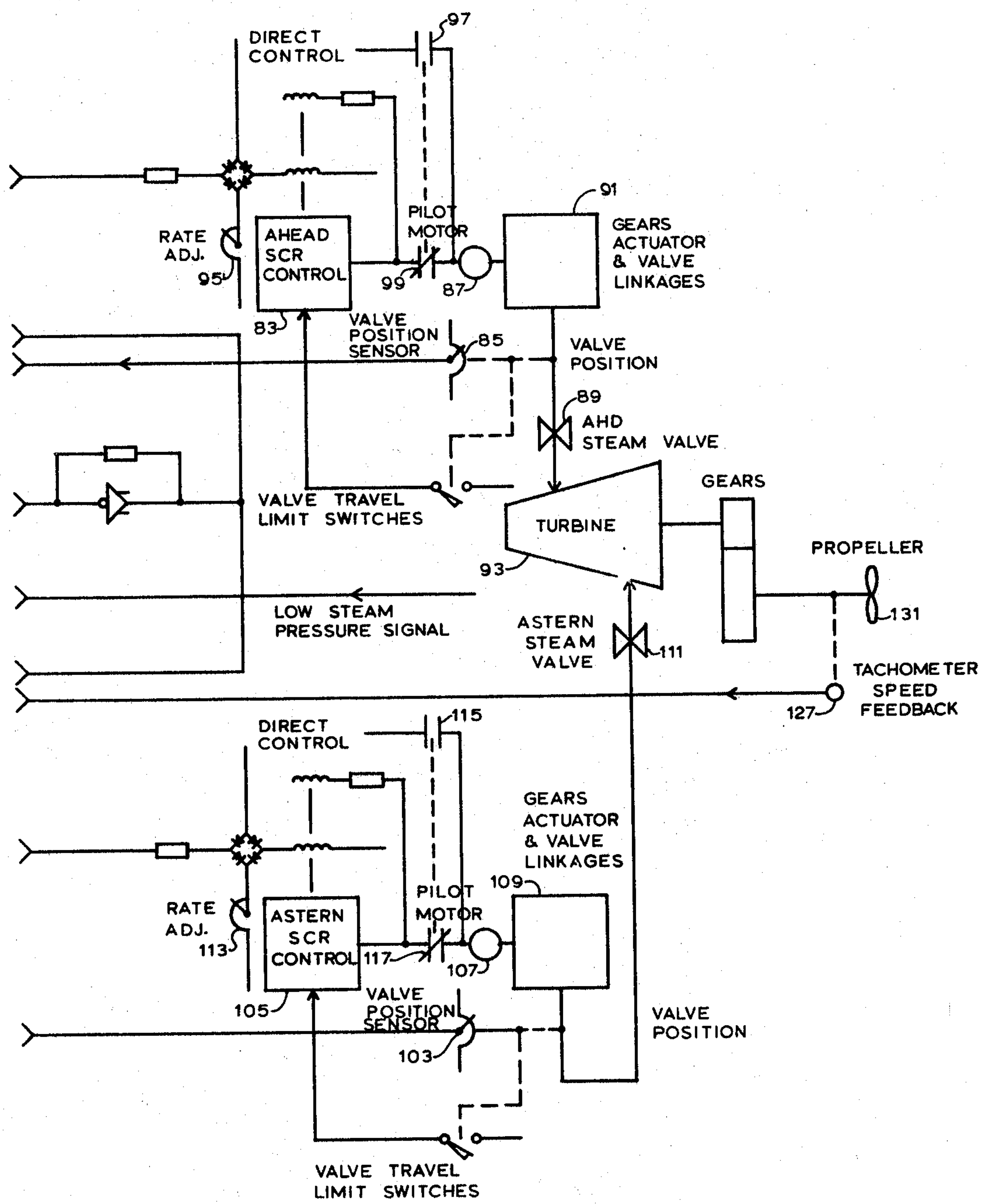
DIRECT CONTROL
97
91
GEARS ACTUATOR & VALVE LINKAGES
PILOT MOTOR
RATE ADJ.
95
AHEAD SCR CONTROL
99
87
83
VALVE POSITION SENSOR
85
VALVE POSITION
89
AHD STEAM VALVE
VALVE TRAVEL LIMIT SWITCHES
GEARS
TURBINE
93
PROPELLER
131
LOW STEAM PRESSURE SIGNAL
ASTERN STEAM VALVE
111
TACHOMETER SPEED FEEDBACK
127
DIRECT CONTROL
115
GEARS ACTUATOR & VALVE LINKAGES
109
PILOT MOTOR
RATE ADJ.
113
ASTERN SCR CONTROL
117
107
105
VALVE POSITION SENSOR
103
VALVE POSITION
VALVE TRAVEL LIMIT SWITCHES

FIG. 3A

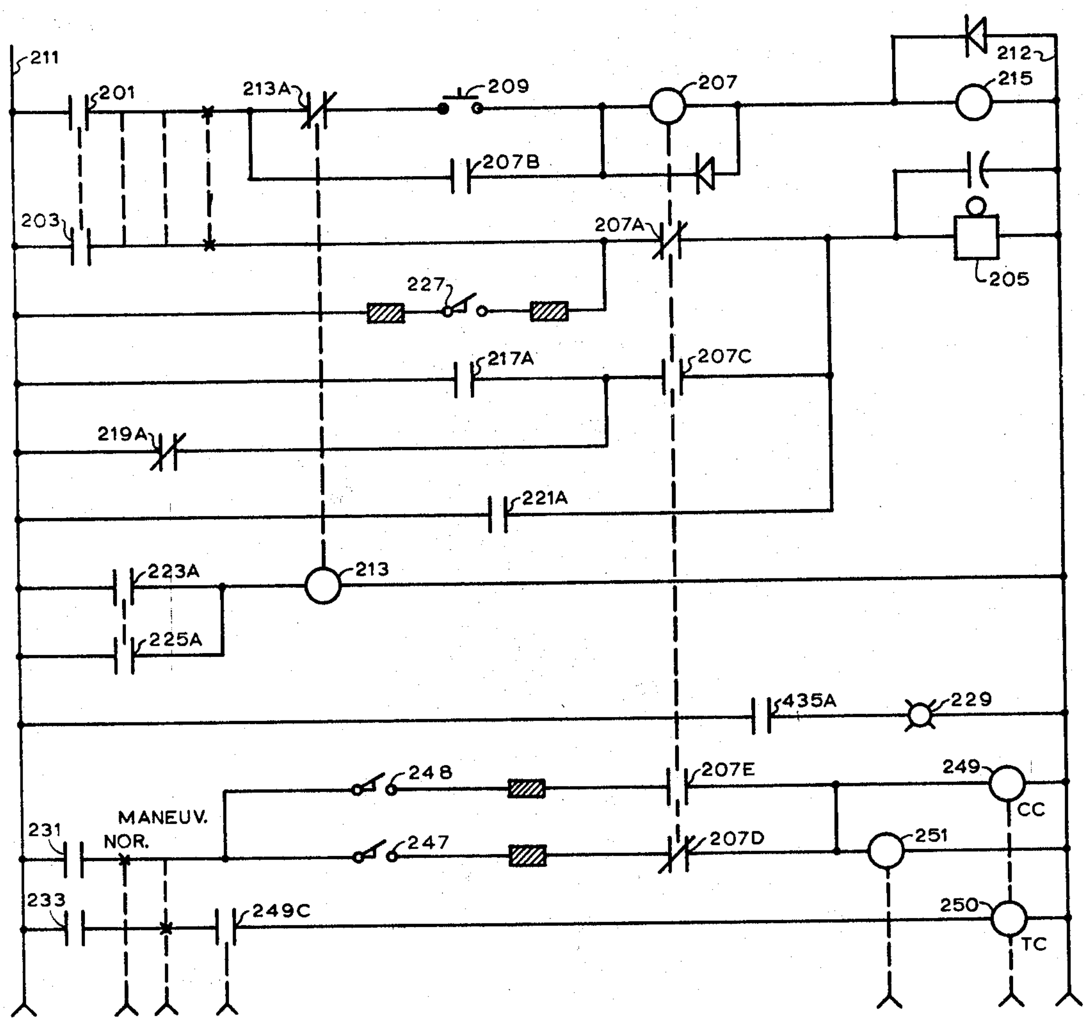
211
201
203
213A
209
207
207B
207A
212
215
205
227
217A
207C
219A
221A
223A
225A
213
435A
229
248
207E
249
CC
231
MANEUV.
NOR.
247
207D
251
233
249C
250
TC

FIG. 4

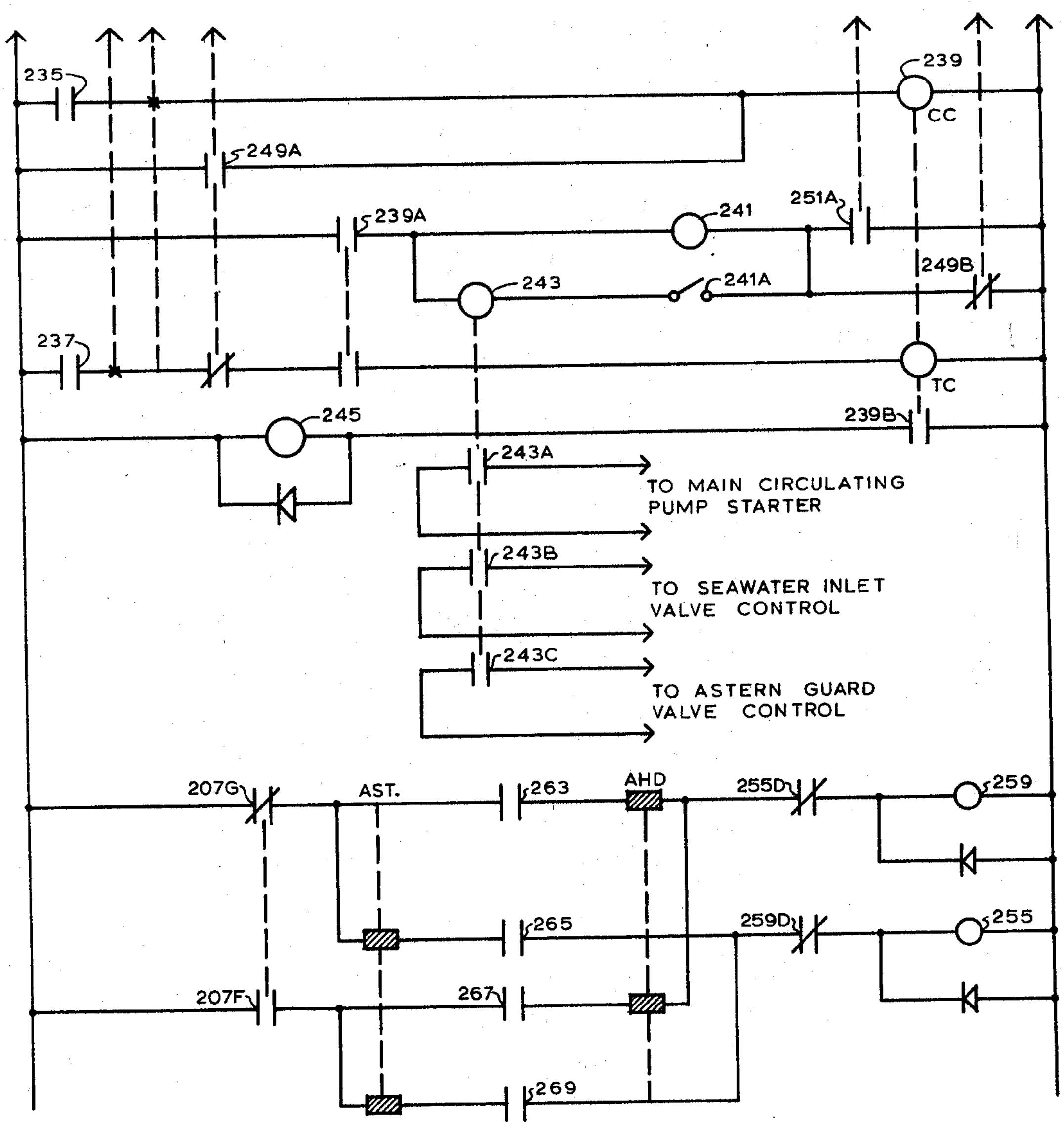
235
249A
239A
241
251A
239
CC
243
241A
249B
237
TC
245
239B
243A
TO MAIN CIRCULATING PUMP STARTER
243B
TO SEAWATER INLET VALVE CONTROL
243C
TO ASTERN GUARD VALVE CONTROL
207G
AST.
263
AHD
255D
259
265
259D
255
207F
267
269

FIG. 4A

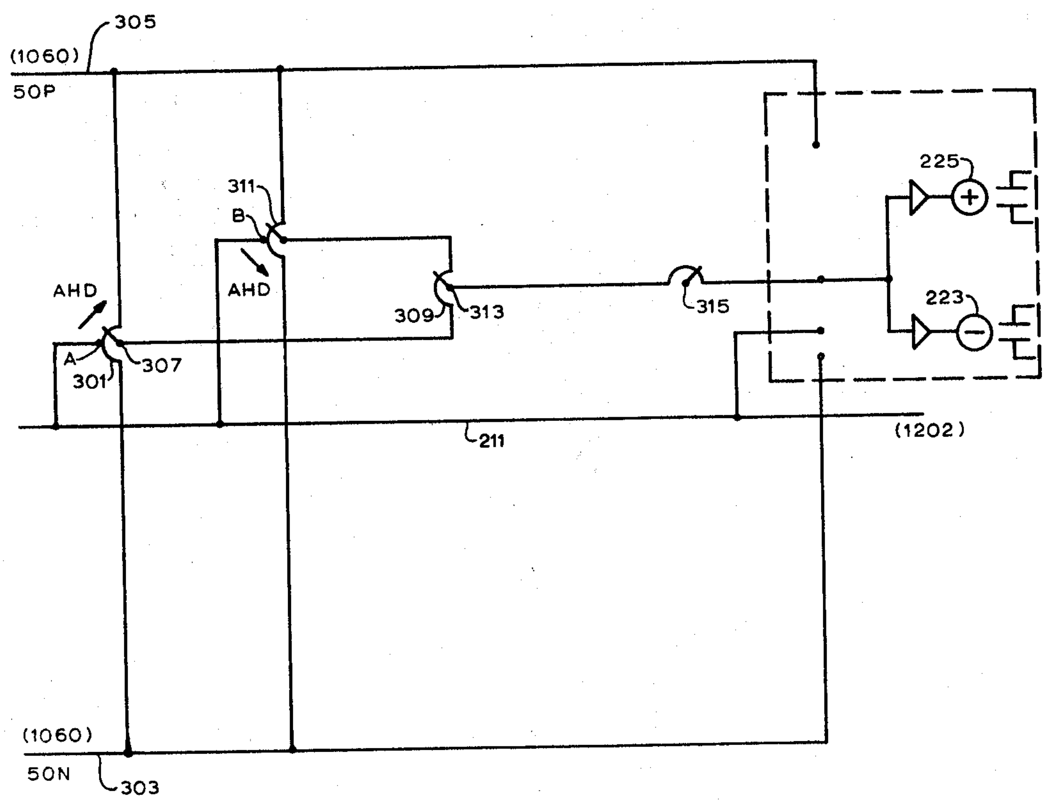
305
(1060)
50P
311
B
AHD
AHD
A
301
307
309
313
315
225
223
211
(1202)
(1060)
50N
303

FIG. 5

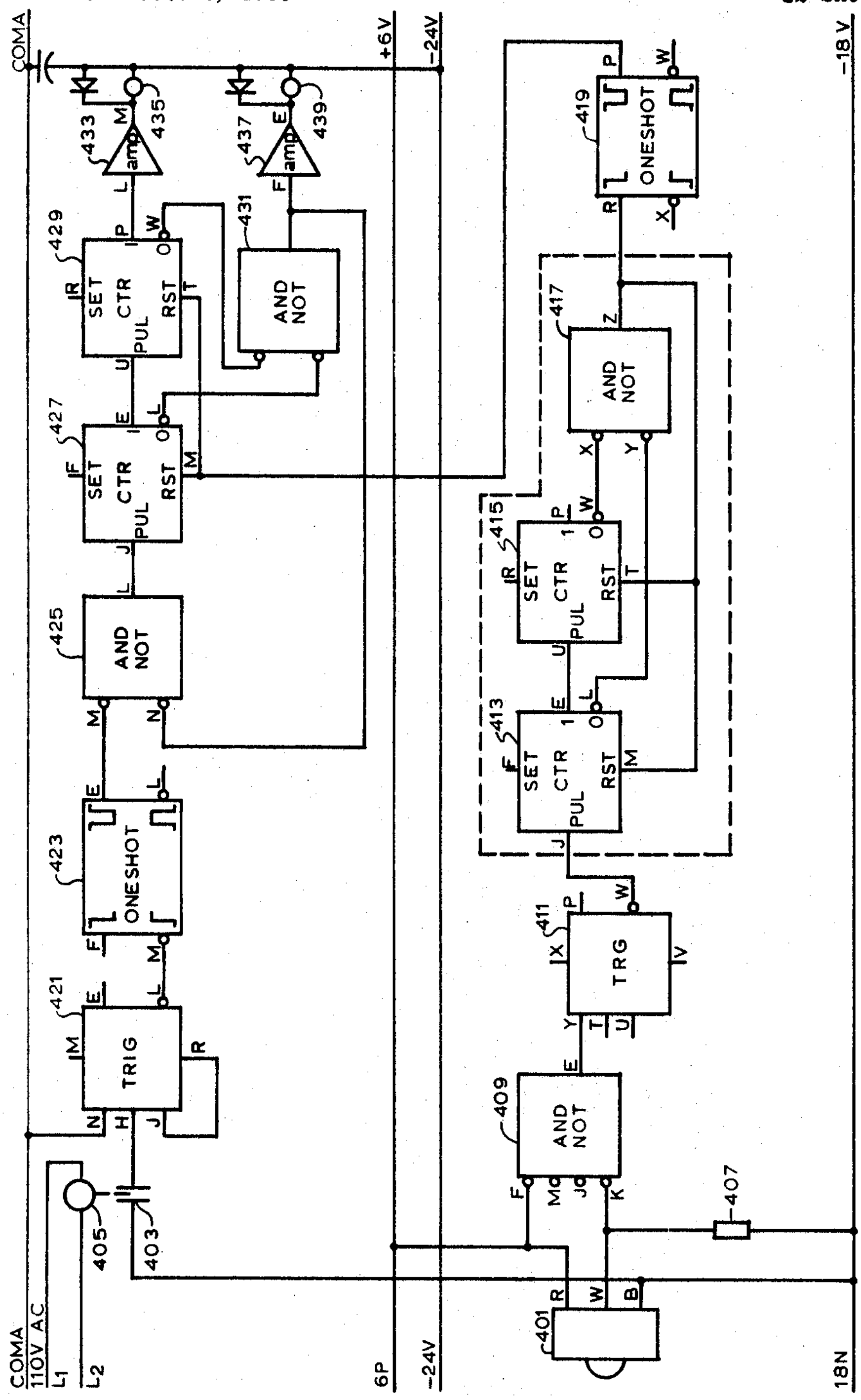
COMA
+6V
-24V
-18V
ONESHOT
AND NOT
SET CTR PUL RST
TRIG
TRG
amp
COMA 110V AC L1 L2
6P
-24V
18N

FIG. 6

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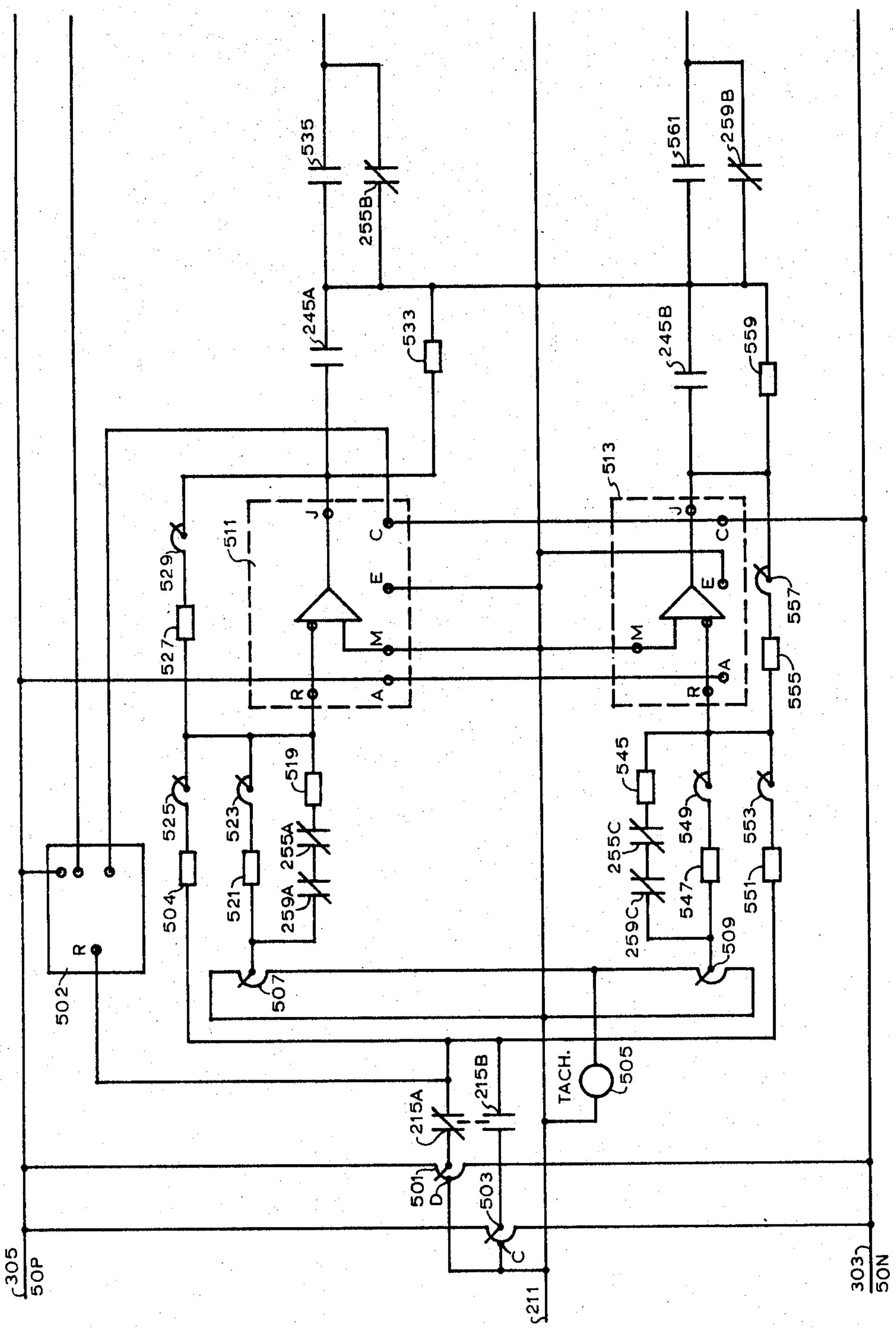

FIG. 7

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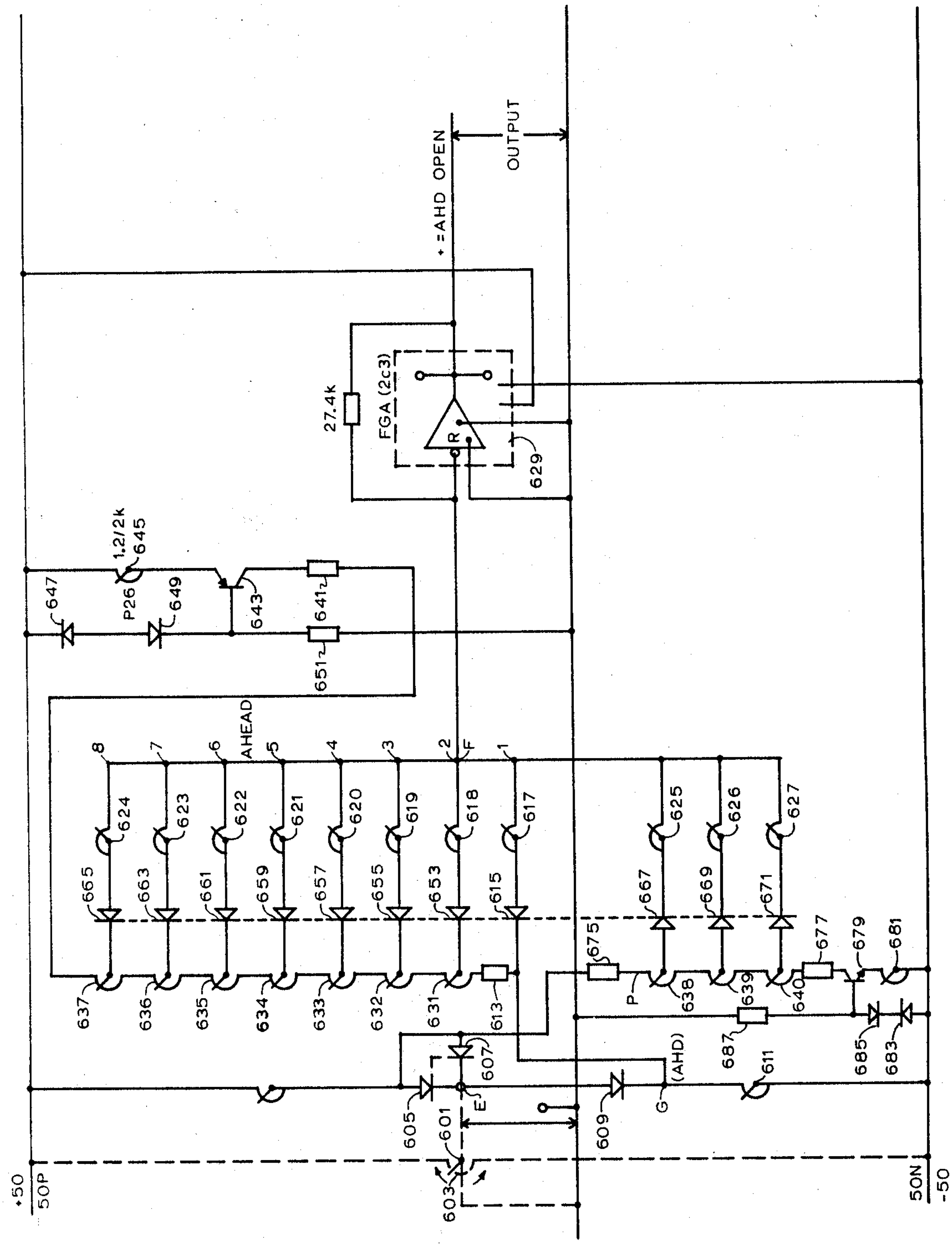

FIG. 8

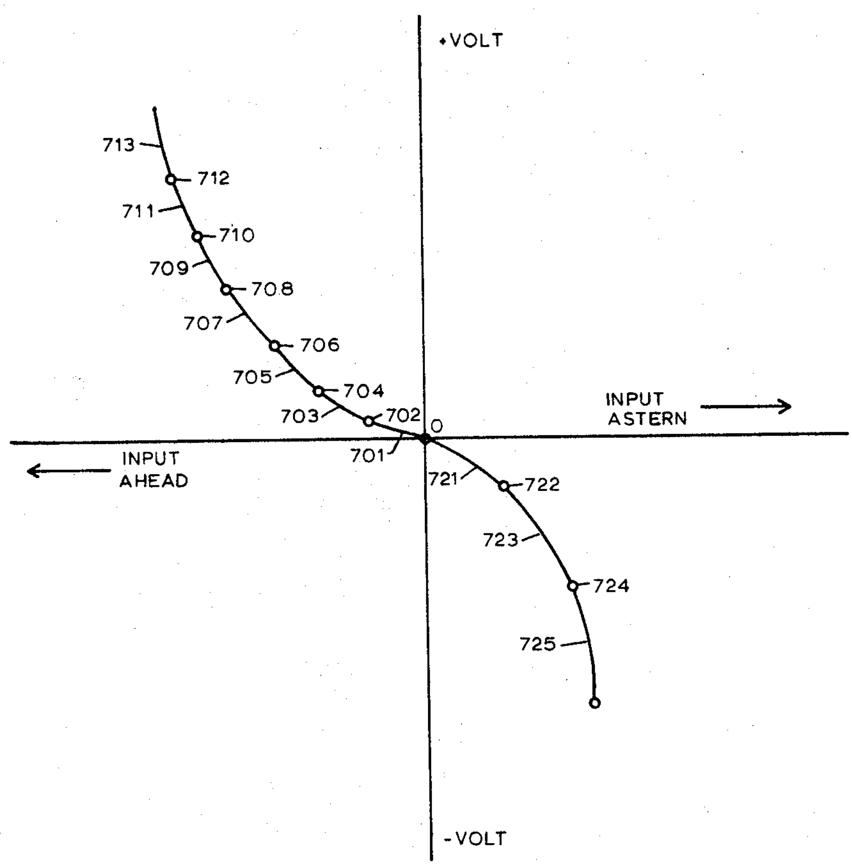
+VOLT
-VOLT
INPUT ASTERN
INPUT AHEAD
0
713
712
711
710
709
708
707
706
705
704
703
702
701
721
722
723
724
725

FIG. 9

United States Patent Office 3,392,696
Patented July 16, 1968

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3,392,696
SHIP

Leo P. Buckley, Jr., and Randolph L. Houlton, Roanoke, Va., assignors to General Electric Company, a corporation of New York
Filed Oct. 6, 1965, Ser. No. 493,517
2 Claims. (Cl. 115—34)

ABSTRACT OF THE DISCLOSURE

A ship is shown with a propulsion unit. The power response reference for the propulsion unit of the ship is set at predetermined level. The power response of the propulsion unit is measured, and then the measured power response is compared with the power response reference. The difference between the measured power response and the reference power response controls the propulsion unit to bring the power response of the propulsion unit towards the reference power response.

This invention is directed to a ship, and more particularly to a ship wherein the power response from the propulsion unit is controlled automatically.

Since the age of sail, ships have been powered by several types of propulsion units. In recent years steam turbines and diesel engines have been the two principal types of conventional propulsion units. These propulsion units transform the power delivered by the propulsion units to thrust by means of one or more screw propellers at the stern of the ship. The propellers may be connected with the propulsion unit by direct lines of shafting, by mechanical gearing, or by electrical transformation. The power from the propulsion unit determines the speed at which the ship travels through the water.

The desired speed of the ship is normally determined by the officer in command on the bridge of the ship. Most merchant ships normally operate at or near full power, while naval ships normally cruise at only a fraction of full power. The instructions of the officer on the bridge are normally telegraphed from the bridge to the engineering officer in the engine room, and the engineering officer in the engine room acknowledges the instructions. The engine room crew then proceeds to execute the instructions.

The manner in which the engine room crew executes the bridge instructions may vary according to the propulsion unit powering the ship. The instructions may call for an increase or decrease in power response or a change in direction of the output of the propulsion unit to change the direction of travel of the ship in the water. In steam turbines steam valves must be opened and closed to increase or decrease the amount of steam applied to the turbine. Steam may have to be removed from the ahead turbine and applied to the astern turbine to reverse the ship or to bring the ship to a stop. In diesel engines, the engine room crew takes other steps to increase or decrease the speed or reverse the direction of the ship in the water. The power response time of the propulsion unit is necessarily slow due to the communication between the commanding officer on the bridge and the engine room officer, then the subsequent communication to the engine room crew, and the time required for the engine room crew to change the valves and other controls to execute the original instructions of the commanding officer on the bridge. The engine room crew must then closely monitor the propulsion unit output to maintain the propulsion unit output called for by the commanding officer on the bridge. The commanding officer on the

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bridge has no direct control over the propulsion unit output and must rely on the cooperation of the engine room officer and the engine room crew.

It is accordingly difficult to obtain close regulation of the power response from the propulsion unit. During maneuvering with frequent speed changes required, it is especially difficult to obtain close regulation of the power response from the propulsion unit.

It is therefore an object of this invention to provide a new and improved ship with a propulsion unit controlled automatically.

It is another object of this invention to provide a new and improved ship wherein the power response from the propulsion unit may be directly controlled from the bridge.

It is another object of this invention to provide a new and improved ship having a close regulation of the power response of the propulsion unit.

Another object of this invention is to provide a new and improved ship with a steam turbine propulsion unit wherein boiler transients are minimized in slowing down the ship.

It is an object of this invention to provide a new and improved ship with a steam turbine propulsion unit which may be easily slowed down.

Still another object of this invention is to provide a new and improved ship with a steam turbine propulsion unit where the power response of the propulsion unit is limited when the pressure to the propulsion unit falls below a safe level.

Another object of this invention is to provide a new and improved ship wherein the power response of the propulsion unit is dependent on a plurality of predetermined conditions.

According to this invention, therefore, the power response of the propulsion unit of a ship is closely controlled. A predetermined power response reference for the propulsion unit is preset. The power response of the propulsion unit is measured, and then the measured power response is compared with the power response reference. The difference between measured power response and the reference power response controls the propulsion unit to bring the power response of the propulsion unit towards the reference power response.

When a steam turbine is used as the propulsion plant, the turbine has ahead and astern sections, each turning the propeller in opposite directions. When the steam turbine is driving the ship in one direction and the decision is made to stop the ship, the predetermined power response reference is reduced to a stop power response reference. The power response is measured and compared with the stop power response reference. The difference between the measured power response and the stop power response reference is applied to the steam turbine for a predetermined period of time to turn the propeller in the opposite direction from which it has been turning to bring the ship to a faster controlled stop.

The invention is set forth with particularity in the appended claims. The principles and characteristics of the invention, as well as other objects and advantages are revealed and discussed through the medium of the illustrative embodiments appearing in the specification and drawings which follow.

In the drawings:

FIGURES 1 and *1a* comprise a diagrammatic view of a ship with the propulsion unit controlled automatically according to this invention.

FIGURE 2 is a view of the bridge showing the throttle control on the bridge.

FIGURES 3 and 3*a* comprise a block diagram of the control for the propulsion unit.

FIGURES 4, 4*a* and 5 are schematics of the throttle control.

FIGURE 6 is a schematic of the zero shaft speed detector.

FIGURE 7 is a schematic of the speed feedback control.

FIGURE 8 is a schematic of the function generator.

FIGURE 9 is a representation of the output of the function generator.

Referring now to FIGURE 1, a ship **13** is provided with a steam turbine **14** as a propulsion plant connected through a reduction gear **15** to a propeller **16**. The opening and closing of the steam valves for the steam turbine **14** are controlled at the engine room console **17**. The engine room console **17** is electrically connected to the bridge console **18** on the bridge **19** of the ship. The bridge console **18** shown in the environment bridge **19** is shown in more detail in FIGURE 2. The bridge **19** is shown with a watchstander **20** at the wheel **21** controlling the direction of the ship through the water. A gyro **22** is available for reference by the watchstander **20**. The bridge console **18** has a throttle lever **23** for controlling the propeller speed and the propeller direction. An engine order telegraph **24** and sound powered phones **25** and **26** are available for communication with the engine room. Gages **27** and **28** indicate propeller revolutions per minute and turbine throttle power response for the benefit of the crew member operating the bridge console.

The watchstander **20** on the bridge **19** positions the throttle lever **23** to call for a desired propeller and ship speed. The reference speed signal from the throttle lever **23** is applied to the valves controlling the steam flow to the turbine **14** to position the steam valves establishing a new steam flow rate. The steam flow rate in the turbine **14** produces a power response from the steam turbine **14**. The power response from the steam turbine **14** is measured and compared with the reference speed signal from the throttle lever **23**. If the power response from the steam turbine **14** is different from the established reference, the difference acts to open or close the proper steam valves to reduce the error and bring the power response towards the established reference.

In this particular embodiment the power response from the steam turbine **14** is measured in two different ways. The first way is to measure the actual position of the steam valve establishing the steam flow rate. This actual position of the steam valve is compared with the reference power response signal from the throttle lever **13** and the difference is applied to a valve pilot motor to move the steam valve in the proper direction to establish the proper steam flow rate. The actual speed of rotation of the propeller **16** is also measured by a tachometer to provide another measurement of the power response of the steam turbine **14**. The speed of rotation of the propeller **16** is compared with the reference from the throttle lever **23** and the difference is applied to the proper steam valve to change the steam flow rate to bring the speed of rotation of the propeller **16** towards the reference.

The throttle lever **23** may be moved rapidly from the full ahead to the stop position so that the reference signal from the throttle lever becomes zero, but the propeller rotation continues so that the tachometer indicates a propeller rotation. This difference between the zero throttle reference and the forward propeller rotation activates circuits to open the astern steam valve for a short period of time to provide steam to the astern section of the turbine **14**. This application of steam in the astern section may be termed bursting. The turbine **14** then actually turns the propeller in the astern direction to bring the ship to a stop position. If momentum carries the ship forward, the propeller is rotated by the water pressure in a forward direction so that there is a signal from the tachometer causing another short period of steam application to the astern section of the turbine **14**.

The control operates in a similar manner to bring the ship to a stop when the ship is traveling in the astern direction by applying bursts of steam to the forward section of the turbine.

In other types of propulsion units the power response may be taken at other points from the propulsion unit. For instance, in a diesel engine the fuel rack position may be used. The torque may be used also. The first stage turbine pressure may be used in a steam turbine. The power response might also be measured from thrust meter, from electrical energy on an electrical drive, or from a log (ship's speed through the water) measurement.

Refer now to FIGURE 3 for a description of the block diagram of a steam turbine and its control as a propulsion unit for a ship. The throttle lever **23** shown in FIGURE 2 is connected to a potentiometer **73** in FIGURE 3 so that the potentiometer **73** produces a linear signal indicating the desired power response of the steam turbine **93**. The linear signal from potentiometer **73** is applied to function generator **79** which turns the linear signal into a signal which is approximately a cubic function of the reference signal from the throttle potentiometer **73**. The cubic function characteristic is required in the specific valve because the turbine power, which is linearly proportional to the steam valve position, is approximately proportional to the cubic function of the speed of the ship. It is therefore necessary that the valve position in the specific valve used be approximately the cubic function of the selected speed in terms of throttle lever position.

The reference power response signal from the function generator **79** is amplified by the ahead summing amplifier **81** and applied to the ahead SCR motor control **83** to cause the pilot motor **87** through gears actuator and valve linkages **91** to move the ahead steam valve **89** in the direction indicated by the reference power response to establish a corresponding steam flow rate to produce the desired power response from the steam turbine **93**. Potentiometer **85** is connected to sense the position of the ahead steam valve **89** and applies a signal to the ahead summing amplifier **81** indicating the position of the ahead steam valve **89**. The summing amplifier **81** compares the reference power response signal from the function generator **79** and the feedback signal from the valve position sensor **85** and applies the difference as an error signal to the ahead SCR motor control **83** causing the pilot motor **87** to move the valve in the proper direction. When the valve has moved to the position called for by the reference from the function generator **79**, the pilot valve motor **87** is stopped because the feedback signal from the valve position sensor **85** cancels the reference signal from the function generator **79**.

If the throttle lever **23** in FIGURE 2 is moved to a new position, the control circuit described will act to move the steam valve **89** to a new corresponding position with a resultant change in turbine power response and the ship's speed.

The ahead rate adjust circuit **95** controls the maximum amount of current which may flow through the armature of the ahead pilot motor **87** and may be adjusted to provide the desired rate adjustment.

There is also a throttle lever in the engine room which may be used to control the power response of the steam turbine **93** corresponding to the throttle lever **23** on the bridge console. An engine room throttle potentiometer **71** in FIGURE 3 produces a corresponding reference to control the power response in the same manner described for the bridge throttle.

A corresponding control circuit is provided to control the astern power response of the steam turbine **93**. The power response signal from the engine room throttle potentiometer **71** or from the bridge throttle potentiometer **73** is applied to the function generator **79**. The ahead signal from the potentiometers **71** or **73** was negative for the ahead direction and is positive for the astern direction.

The positive reference signal from the function generator **79** is amplified by the astern summing amplifier **101** and applied to the astern SCR motor control **105** causing pilot motor **107** to move the astern steam valve **111** in the direction indicated by the reference to establish a corresponding steam flow rate in the astern section of the steam turbine **93**. Potentiometer **103** is connected to sense the position of the astern steam valve **111** and applies a signal to the astern summing amplifier **101** indicating the position of the astern steam valve **111**. The summing amplifier **101** compares the reference power response signal from the function generator **79** and the feedback signal from the valve position sensor **103** and applies the difference as an error signal to the astern SCR motor control **105** causing the pilot motor **107** to move the astern valve **111** in the proper direction to establish the proper steam flow. When the valve has moved to the position called for by the reference from the function generator **79**, the pilot motor **107** is stopped because the feedback signal from the valve position sensor **103** cancels the reference signal from the function generator **79**.

In this particular embodiment the propeller speed may be used as a feedback by closing the selector switch **135**, energizing coil **137**, closing normally open contacts **139** and **141**. This may be termed the maneuvering mode of operation in this particular embodiment. When the throttle lever **23** is moved to the stop or astern position from the ahead position, the relay coil **137** is automatically energized to apply the speed feedback from the propeller. The speed feedback provides a faster and more accurate indication of the propeller speed including cavitation effects.

When the ship is to be slowed down or stopped, the throttle lever **23** on the bridge console **18** in FIGURE 2 is moved rapidly from the ahead position to the stop position, reducing the reference signal from the bridge throttle **73** in FIGURE 3 to zero. The feedback signal from the propeller shaft feedback tachometer **127** indicates that the propeller **131** is still rotating due to inertia. The ahead steam valve **89** is closed and the astern steam valve **111** is opened, allowing steam to enter the astern section of the steam turbine **93** to turn the propeller in the astern direction. The application of steam to the astern section of the turbine in this manner is termed bursting. The astern steam valve **111** is then closed. Momentum will continue to carry the ship forward in the water, causing the propeller **131** to rotate in a forward direction due to the drag of the water. The speed feedback tachometer **127** applies a signal back causing the astern steam valve **111** to open again for a short period of time rotating the propeller in the astern direction. The throttle lever **73** remains in the stop position and an error signal from the comparison of the speed feedback signal from the tachometer **127** and the function generator **79** closes the astern steam valve **111**. This continues until the ship's momentum in the water is reduced so that the propeller **131** will not rotate due to drag.

The control of the steam valves **89** and **111** may be removed from automatic control by closing contacts **97** and **115** and opening contacts **99** and **117**. The pilot motors may be directly operated then by signals applied directly to the pilot motors **87** and **107**.

The automatic control of the throttles may be transferred between the bridge and engine room by closing the appropriate contacts **75** and **77**.

A pressure transducer is used to measure the steam pressure of the steam turbine. If the pressure in the steam turbine **93** falls below a safe level, the low pressure amplifier **143** applies a signal to the ahead summing amplifier **81** and the astern summing amplifier **101** to limit the signal from these amplifiers and thus limit how far the ahead steam valve **89** and the astern steam valve **111** opened. If the steam pressure continues to fall, the low pressure signal amplifier **143** overrides the signals from the function generator **79** and the feedback signals to close the ahead steam valve **89** and the astern steam valve **111**.

Throttle transfer control

Refer now to FIGURE 4 for a description of the throttle transfer control. Assume that the engine room is transferring the control of the turbine to the bridge. To accomplish this, transfer switch contact **201** and **203** must be closed. An alarm bell **205** is energized through normally closed contact **207A** of the bridge control auxiliary relay. To stop the alarm the bridge operator must depress the acknowledge pushbutton **209**, which allows current to flow from the common bus **211** through transfer switch contact **201**, through normally closed contact **213A** of the throttle match relay, through coil **207** of the bridge control auxiliary relay, and through coil **215** of the bridge control relay, into negative bus **212**. The bridge control relay and the bridge control auxiliary relays now pick up and normally closed contact **207A** now opens and disconnects the alarm bell from the circuit. Normally open contact **207B** of the bridge control auxiliary relay closes as the relay picks up and allows current to continue to pass through bridge-control auxiliary relay coil **207** after acknowledge pushbutton **209** has been released, thus sealing the relay in. Normally open contact **207C** of the bridge control auxiliary relay is now closed and allows the alarm bell to be energized when one of the following conditions exists: (1) when normally open contact **439A** of the shaft stop relay **439** is closed due to the propeller shaft NOT having been rotated for three minutes, and (2) when the bridge engine order telegraph is moved from its standby or bridge control position, which causes contact **219A** to close.

Throttle malfunction of the bridge throttle assembly causes normally open contact **221A** of the throttle failure relay to close, thus completing the circuit to the alarm bell **205**, energizing the bell.

The transfer from the engine room to the bridge cannot take place when the engine room throttle position and the bridge throttle position do not match. Indicating meters may be used instead of the described interlocking. In FIGURE 5 potentiometer **301**, which is mounted on the engine room throttle lever assembly, is connected at one side to negative 50 volt bus **303** and on the other side to positive 50 volt bus **305**. Point A which is a center tap of the potentiometer is connected to the common bus **211**, thereby stabilizing point A at zero volt potential with respect to the 50 volt positive and negative busses **305** and **303** respectively.

The potentiometer wiper connection **307** is connected to one side of potentiometer **309**.

The bridge potentiometer **311** is connected in a similar manner as described above with the positive and negative busses **305** and **303** respectively connected to either side of the potentiometer and a center tap, point B, connected to the common bus **211** to stabilize point B at zero volt potential with respect to the positive and negative busses **205** and **303** respectively. The bridge potentiometer wiper connection **313** is connected to the other side of potentiometer **309**. Potentiometer **309** acts as a voltage divider, balancing a voltage from potentiometer **301** against an equal voltage from potentiometer **311**.

During installation the wiper of potentiometer **309** is adjusted so that the potential of the wiper connection **313** is at zero volts with respect to the positive and negative busses **305** and **303** respectively, and throttle match relay coils **223** and **225** remain dropped out in their normal positions. If, however, the engine room throttle position is different from the bridge throttle position at the time when the transfer is to be made, the voltages from potentiometers **301** and **311**, as applied to potentiometer **309**, are different. This causes a current to flow from the wiper connection **313** of potentiometer **309**, through adjustable resistor **315**, and energize one of the throttle match relay coils **223** or **225**, depending on the polarity of the current which is applied. If, for example, the current is positive with respect to the common bus **211**, relay coil **225** will be energized and normally open contact **225A**, in FIGURE 4, will close, energizing coil **213** of the throttle match auxiliary relay, and opening normally closed contact **213A**. This prevents the transfer from being made. Similarly, if the current from potentiometer **309** is negative, the throttle match relay coil **223** is energized and normally open contact **223A** of the throttle match relay will close, causing coil **213** of the throttle match auxiliary relay to be energized and open normally closed contact **213A**, and thereby preventing the transfer from being made.

With the engine room in control of the turbine, the bridge throttle control lever assembly must be oriented in the OFF position and cam switch contact **227** is then open. However, if the bridge throttle lever is moved away from the OFF position, either in the ahead or in the astern direction, cam switch contact **227** closes and allows current to flow through normally closed contact **207A** and energize the alarm bell **205**.

Normal and maneuvering mode control

The mode selector switch, located on the engine room console, is used to select the normal or maneuvering modes of operation. As the name implies, the normal mode usually will be used when steaming at sea. In the normal mode, the sea scoop is open, the circulating pump is stopped, the astern guard valve is closed and there is no speed feedback error signal applied to the throttle control regulator. The maneuvering mode is used for slow, stop or astern operations, or where speed feedback error signals are necessary.

In going to maneuvering mode the mode selector switch is turned to the maneuvering mode position, closing contact **235** in FIGURE 4 and energizing the closing coil **239** of the maneuvering mode relay. This closes normally open contact **239A**, which energizes coil **241** of the auxiliary maneuvering mode time delay relay and coil **243** of the auxiliary maneuvering mode relay through normally closed contact **249B** of the automatic maneuvering mode relay. Normally open contacts **243A**, **243B**, and **243C** now close for a period of one second to start the main circulating pump (not shown), to open the sea water inlet valve (not shown), to open the astern guard valve (not shown). The auxiliary maneuvering mode time delay relay times out after one second, which causes contact **241A** to open and de-energize auxiliary maneuvering relay coil **243**, opening contacts **243A**, **243B**, and **243C**.

When closing, coil **239** of the maneuvering mode relay is energized, normally open contact **239B** is closed and energizes the coil **245** of the speed feedback relay.

Automatic switching to the maneuvering mode occurs when the throttle lever is moved to the stop or astern position while the mode selector switch is in the normal position. Cam switch **247** closes in these positions and closing coil **249** of the automatic maneuvering mode relay is energized. This closes normally open contact **249A** and energizes coil **239** of the maneuvering relay, which results in an operation in a similar manner as described previously. When cam switch **247** closes, coil **251** of the auxiliary automatic maneuvering relay is energized and closes normally open contact **251A**, allowing coils **241** and **243** to be energized while normally closed contact **249B** of the automatic maneuvering mode relay is open.

When automatic switching occurs and coil **249** of the automatic maneuvering mode relay is energized, the relay is latched in the energized position by mechanical means and can not be reset until the mode selector switch contact **233** is closed by selection of the maneuvering mode of the mode selector switch. When this selection is made and contact **233** closes, current will pass from the common bus **211** through contact **233** and through normally open contact **249C** of the automatic maneuvering mode relay and energize trip coil **250**, thus resetting the automatic maneuvering relay.

Cam switch **248** on the bridge throttle lever operates in a similar manner as described above and is placed in the circuit by energizing the bridge control relay coil **207** which then opens contact **207D** and closes contact **207E**, as described in the throttle transfer control portion of this description.

Direction relays

Normally open contact **207F** and normally closed contact **207G** of the bridge control auxiliary relay in FIGURE 4 change state when the responsibility of the turbine is transferred from the engine room to the bridge. With normally closed contact **207G** closed, the engine room throttle is in command; and when the throttle lever is moved in the ahead direction, contact **263** closes and allows current to pass from the common bus **211** through normally closed contact **207G** of the bridge control auxiliary relay through normally closed contact **255D** of the astern direction relay and energize the coil **259** of the ahead direction relay which then picks up and opens normally closed contact **259D**, preventing the accidental completion of the astern direction relay coil **255**.

Similar action results from moving the throttle in the astern direction, in which case throttle lever contact **265** closes and permits current to pass from the common bus **211** through normally closed contact **207G**, through normally closed contact **259D** and energize astern direction coil **255**, which picks up and opens normally closed contact **255D**, thus preventing accidental pickup of the ahead direction relay coil **259**.

Both the astern and ahead direction relays have additional normally closed contacts in the speed feedback circuit, where their functions are described under "Speed Feedback Control."

Zero shaft speed detector

In FIGURE 6, terminal B of static limit switch **401** is connected to the negative 18 volt bus **18N** and to the one side of timer relay contact **403**, having motor **405** close contact **403** once during each one minute cycle. Terminal R of static limit switch **401** is connected to the positive 6 volt bus **6P** and to terminal F of AND/NOT circuit **409**. This positive voltage as applied to the AND/NOT circuit **409** is equivalent to a ZERO signal.

Terminal W of static limit switch **401** is connected through resistor **407** to negative voltage bus **18N** and to terminal K of AND/NOT circuit **409**. The static limit switch operates in such a manner that when a metal object passes within its proximity its terminal W is temporarily connected to terminal B, which thus acquires a negative polarity of −18 volts, changing the signal applied to terminal K of the AND/NOT circuit **409** from a ZERO to a ONE.

The ZERO signal, which is produced from output terminal E of AND/NOT circuit **409**, changes to a ONE signal when ZERO signals are applied to both input terminals K and F. The change, however, may not be abrupt enough to be applied to the counter circuit **413** and is therefore first applied to trigger circuit **411**, terminal Y. When the ONE signal is applied to terminal Y of trigger circuit **411**, a ZERO signal is produced from its output terminal W and applied to the PUL terminal of counter bit **413**. This positive going pulse causes the counter bit **413** to change its state so that a ZERO signal is now produced from terminal E. As the output from terminal E of counter **413** changes from a ONE signal to a ZERO signal and is applied to the PUL terminal of counter bit **415** as a positive going pulse, the state of counter bit **415** also changes and now produces a ONE signal from terminal W which is applied to terminal X of AND/NOT circuit **417**.

The next operation of static limit switch **401** again causes the output terminal E of AND/NOT circuit **409** to produce a positive going pulse which is applied to the PUL terminal of counter bit **413**, again changing its state. Terminal L now produces a ZERO signal which is applied to terminal Y of AND/NOT circuit **417**. With the next pulse, counter bit **413** again changes its state, which causes a positive going pulse to be applied to the PUL terminal of counter bit **415**, causing it to change its state and produce a ZERO signal from its output terminal W which is applied to terminal X of AND/NOT circuit **417**. When counter bit **413** changed state, its ZERO signal from output terminal L changed to a ONE signal, which again changes to a ZERO signal with the next pulse from the static limit switch. AND/NOT circuit **417** now has two ZERO signals applied to its input terminals X and Y, which causes AND/NOT circuit **417** to produce a ONE signal from its output terminal Z. This negative going pulse is applied to terminal R of ONE SHOT circuit **419**, which produces a momentary ONE signal from its output terminal P.

The above shows that three pulses produced by the static limit switch will produce one pulse from the ONE SHOT **419**. This is to accommodate the gear ratio between the ship's propeller shaft and the tachometer which supports the actuator for the static limit switch and produces three pulses for each revolution of the propeller shaft.

Timer motor **405** causes contact **405** to close momentarily once per minute, thus applying a ONE signal to input terminal H of trigger circuit **421**, which produces a positive going pulse from its output terminal L and applies this to terminal M of ONE SHOT circuit **423**. ONE SHOT circuit **423** then produces a ONE pulse from terminal E and applies this to terminal M of AND/NOT circuit **425**.

Assuming now that counter bit **427** and counter bit **429** have been reset, then the output from terminals L and W of counter bits **427** and **429** are both ONE and applied to input terminals X and Y of AND/NOT circuit **431**, causing AND/NOT circuit **431** to produce a ZERO signal, which is applied to terminal N of AND/NOT circuit **425**.

When the output of terminal E of ONE SHOT **423** momentarily changes from a ZERO to a ONE and back, it causes AND/NOT circuit to change its output from terminal L from a One to a ZERO. This positive going pulse is applied to the PUL terminal of counter bit **427**, changing its state, so that the output from terminal E is now a ONE and the output from terminal L changes to a ZERO, which is applied to terminal Y of AND/NOT circuit **431**.

The next pulse from trigger **421**, as caused by the closing of contact **403**, again causes the ONE SHOT **423** to fire and AND/NOT circuit **425** to produce a positive going pulse, which is applied to counter bit **427** causing it to change state. When the output of terminal E changes from a ONE to a ZERO and applies this positive going pulse to the PUL terminal of counter bit **429**, counter bit **429** changes state and applies a ONE signal from terminal P to the input terminal L of amplifier **432**. This causes alarm relay **435** to pick up and close contact **435A** in FIGURE 4, which then allows power to be supplied to shaft stop indicating light **229**.

In FIGURE 6, contact **403** closes again one minute later and causes through the trigger **421**, ONE SHOT **423**, and AND/NOT circuit **425**, a positive pulse to be applied to counter bit **427** which changes state and causes the output of terminal L to change from a ONE to a ZERO, which is applied to terminal Y of AND/NOT circuit **431**. With two ZERO signals applied to input terminals X and Y, AND/NOT circuit **431** produces a ONE signal from its output terminal W which is applied to amplifier **437**, causing shaft stop relay **439** to pick up and close contact **439A** in FIGURE 4, causing the alarm bell **205** to ring.

The ONE signal is also applied to terminal N of AND/NOT circuit **425**, and thus prevents future pulses to be applied to counter **427**, and thus prevents counter **427** from changing its state.

However, if the propeller shaft is rotated at least one revolution per minute, the positive going pulses from ONE SHOT **419** applied to terminals RST of counter bits **427** and **429** will reset the counters once each minute, and thus counteract the pulses applied to the PUL terminals of the counters **427** and **429** and prevent them from changing state, and consequently preventing the relays **435** and **439** from picking up.

Speed-feedback control

Throttle lever potentiometers **501** and **503** (in FIGURE 7) located in the engine room and on the bridge respectively, are connected on either end to the positive and negative 50 volt busses **305** and **303**, respectively. A center tap C and D of each of the potentiometers is connected to the common bus **211**, thereby stabilizing points C and D at zero volt potential with respect to the 50 volt positive and negative busses. The potentiometer wiper connection of the engine room potentiometer **501** is connected to normally closed contact **215A** of the bridge control relay while the wiper connection of the bridge throttle potentiometer **503** is connected to the normally closed contact **215B** of the bridge control relay.

The bridge control relay, which is energized when control responsibility of the turbine is transferred from the engine room to the bridge, connects either the engine room throttle **501** or the bridge throttle potentiometer **503** in the circuit. Normally closed contact **215A** of the bridge control relay is connected to the input terminal R of the function generator **502** and through resistor **504** to rheostat **525**, applying the reference signal to the speed feedback amplifier **511**. Tachometer **505** is connected to one side of each of potentiometers **507** and **509** of which the other sides are connected to the common bus **211**. Each of the potentiometers **507** and **509** acts as a voltage divider and provides an adjustable voltage input to the ahead and astern speed feedback amplifiers **511** and **513**, respectively.

The slider connection of potentiometer **507** is connected to normally closed contact **259A** of the ahead direction relay and is connected through resistor **521** to rheostat **523**. Normally closed contact **259A** of the ahead direction relay is connected through normally closed contact **255A** of the astern direction relay to one side of resistor **519**. Rheostats **525** and **523** and resistor **519** are on one side connected together, and to terminal R of speed-feedback amplifier **511**, and through resistor **527** to one side of rheostat **529**. Terminals A, E and C of speed feedback amplifier **511** are connected to the 50 volt positive bus **305**, common bus **211** and 50 volt negative bus **303**, respectively.

The speed feedback amplifier **511** is an operational amplifier and operates in a manner which is well-known to those skilled in the art. In the operation involved here, the output of throttle potentiometer **501**, through resistor **504**, and rheostat **525**, is applied to the input of the operational amplifier **511** as a reference signal, where it is compared to the signal produced by the feedback output of the tachometer **505**. The resultant of this comparison is fed through resistor **527** and then through rheostat **529** as an output of the operational amplifier. The signal is applied to normally open contact **245A** of the speed feedback relay which is energized when the maneuvering relay coil **239** (FIGURE 4) is energized. Normally open contact **245A** of the speed feedback relay is connected to normally closed contact **255B** of the astern direction relay and to normally open contact **535** of the astern valve closed limit relay.

The astern valve closed limit relay is energized when the astern valve is closed, and consequently normally open contact **535** of the astern valve closed limit relay closes when the astern valve is closed, and thus provides for completion of the circuit between the ahead speed feedback amplifier **511** and the ahead summing amplifier (operation shown later).

The astern direction relay contact **255B** closes when the throttle lever is moved to the stop position, as described above.

The astern speed feedback amplifier circuit operates in a similar manner to the ahead speed feedback circuit with throttle lever potentiometer **501**, establishing the reference signal, which is applied through resistor **551** to rheostat **553**, and with tachometer **505** applying the feedback signal to one side of potentiometer **509**, which is on the other side connected to the common bus **211**. The slider connection of potentiometer is connected through resistor **547** to rheostat **549** and to normally closed contact **259C** of the ahead direction relay which is connected to normally closed contact **255C** of the astern direction relay, which in turn is connected to resistor **545**. The other side of rheostats **553** and **549** and of resistor **545** are connected together and to the input terminal R of the astern speed feedback amplifier **513** and through resistor **555** to rheostat **557**.

Terminals A, E, and C of speed feedback amplifier are connected to the 50 volt positive bus **305**, the common bus **211** and the 50 volt negative bus **303**, respectively. The output of the operational amplifier from terminal J is applied to the normally open contact **245B** of the speed feedback relay and to resistor **559**, which are connected together and to the common bus **211**.

Normally open contact **561** of the ahead valve closed limit relay is closed when the ahead steam valve is closed and completes the circuit between the astern speed feedback amplifier and the astern summing amplifier. The ahead direction relay contact **259B** closes when the throttle lever is moved to the stop position, allowing the signal from the speed feedback amplifier to be applied to the summing amplifier.

Sensitivity of the speed feedback amplifier is greatly increased when the throttle lever is moved to the stop position. Under this condition the ahead and astern direction relays are de-energized and normally closed contacts **259A** and **255A** of the ahead and astern direction relays, respectively, are closed and pass current through resistor **519**, thus setting up a parallel resistance path, which has a ratio of approximately 30:1 with the resistance path consisting of resistor **521** and rheostat **523**.

The reference input to the speed feedback amplifier is at ZERO due to the position of the throttle, and a large current from the speed feedback tachometer is now applied to the speed feedback amplifier as a positive feedback signal. The speed feedback amplifier compares these signals and produces a negative error signal which is applied to the summing amplifier and which causes the ahead steam valve to close.

When the ahead steam valve is closed normally open contact **561** of the ahead valve closed limit relay is also closed and allows a signal from the astern speed feedback amplifier to be applied to the astern summing amplifier. This signal is caused by the propeller which is still rotating in the ahead direction due to drag in the water caused by the momentum of the ship. As the propeller rotates, so does the speed feedback tachometer **505** which then produces a positive signal through rheostat **509**, normally closed contacts **259C** and **255C** of the ahead and astern direction relays, respectively, and through resistor **545**, and applies this signal to astern speed feedback amplifier, which in turn produces a negative signal which is applied to the astern summing amplifier, causing the astern steam valve to open. This causes the propeller to stop, at which point the tachometer signal is reduced to zero; and consequently the signal from the speed feedback amplifier is reduced to zero. The circuitry of the summing amplifier is so that a zero signal from the speed feedback amplifier will cause the astern steam valve to close, as is discussed later.

If the momentum of the ship is such that the propeller will again begin to rotate, an error signal is again produced by the speed feedback tachometer which will cause the astern steam valve to open and repeat the process until the ship has come to a complete standstill.

Summing amplifiers

In FIGURE 1, the ahead summing amplifiers **81** and the astern summing amplifier **101** accept signals from the function generator **179**, the ahead and astern speed feedback amplifiers **129** and **130**, the ahead and astern steam valve position sensors **35** and **103**, and the low steam pressure amplifier **143**. The sum of these signals, considering positive and negative values, determines the output voltage of the summing amplifiers **81** and **101**. The summing amplifiers invert the sum of the applied signals; and therefore if the sum of the applied signals is positive, the output of the amplifier will be negative.

A negative output of the ahead summing amplifier tends to open the ahead steam valve while a positive output tends to close it. The opposite is true of the astern amplifier where a positive output from the amplifier tends to open the astern steam valve while a negative output tends to close it.

The zero adjust function positions the steam valves near the crack point, which is that position of the steam valve where all the mechanical tolerances have been taken up; and if the valve is opened a fraction farther, steam will be allowed to flow into the turbine. Zero adjust occurs when the throttle lever is off the stop position, producing either a positive or negative signal which is summed with the valve position feedback voltage.

The steam valve close adjustment positions the steam valve well into the closed position, when the throttle lever is in the stop position or in the position calling for the opposite valve to open.

The low steam pressure signal applied to the ahead summing amplifier is a negative signal supplied by the low steam pressure amplifier (not shown) which must cancel out the positive voltage of the function generator which causes the negative signal from the valve position sensor to be the only effective input to the ahead summing amplifier. This negative signal is inverted and is applied to the steam valve circuitry as a positive signal, causing the ahead steam valve to close.

If the low steam pressure signal does not call for a complete valve closing, its negative voltage will cancel only part of the function generator's positive signal while the remainder of the function generator signal is canceled out by the negative signal from the valve position sensor, which means that the steam valve will position itself somewhere between fully open and totally closed, depending on the relative magnitude of the low steam pressure signal.

The low pressure signal which is applied to the astern summing amplifier operates in a similar manner except that the signal from the low steam pressure amplifier is now a positive signal so that it may cancel out the negative voltage signal produced by the function generator, which causes the positive symbol of the astern steam valve position sensor to be the only effective input to the astern summing amplifier. This positive symbol is inverted by the summing amplifier and applied to the astern steam valve circuitry (not shown) and causes the astern steam valve to close.

If the low steam pressure signal is not calling for a complete valve closing, its positive voltage will cancel only part of the function generator's negative signal while the remainder of the function generator signal is canceled out by the positive signal from the astern valve position sensor, which means that the valve will position itself somewhere between fully open and totally closed, depending on the relative magnitude of the low steam pressure signal.

Function generator

In FIGURE 8, the throttle lever potentiometer **603** represents both the engine room and the bridge throttle potentiometers.

The wiper connection **601** of throttle potentiometer **603** is connected to point E, which in turn is the junction point of the cathodes of diodes **605** and **607** and the anode of diode **609**.

The cathode of diode **609** is connected through rheostat **611** to the negative 50 volt bus **50N** and to resistor **613** and the cathode of diode **615**. The anode of diode **615** is connected through rheostat **617** to junction point F, which is the junction point for the connections to rheostats **618–627** and connects to the input terminal R of operational amplifier **629**.

This high gain operational amplifier is used for signal amplification. When analyzing the electrical characteristics of operational amplifier **629**, it is sufficiently accurate to assume that the input signal voltage (the voltage at point F and terminal R) of the operational amplifier never deviates from zero volts with respect to common bus **211**. Thus, the gain of the amplifier is determined directly by the ratio of the feedback resistance to the input resistance.

The operational characteristics of the function generator for the ahead direction is described as follows. Assume that the throttle lever is initially in the STOP position so that no voltage signal is applied to the function generator. When the throttle lever is moved slightly in the ahead direction, the reference output voltage of the throttle lever potentiometer which is applied to point E becomes negative with respect to common bus **211**. Current now flows from the operation **1** amplifier input terminal R, through junction point F, rheostat **617** and diode **615** to point G, and the negative 50 volt bus **50N**. This current produces a positive voltage output from the operational amplifier **629**, which in magnitude is directly proportional to the increasing negative reference voltage from the throttle lever potentiometer, thus establishing the first slope of the function generator characteristic.

The constant current circuit consists of resistor **613** connected in series with series connected potentiometers **631–637**. Potentiometer **637** is connected through resistor **641** to the collector of transistor **643** of which the emitter is connected to rheostat **645**, which is connected to the positive 50 volt bus **50P**.

Zener diode **647** connected to the anode of diode **649** has its cathode connected to the positive 50 volt bus **50P**. The cathode of diode **649** is connected to the base of transistor **643** and through resistor **651** to the common bus **211**, thus forming the firing circuit for transistor **643**, which then passes one milliamp constant current through potentiometers **631–637** and resistor **613**, and in doing so establishes a fixed voltage drop across each of the potentiometers **631–637**.

As the reference voltage increases, due to repositioning of the throttle lever potentiometer, in the negative direction, a point is reached where the voltage level of point H goes negative with respect to the input terminal R of the operational amplifier **629**, causing additional current to flow through point H in the second path, consisting of rheostat **618** connected in series with diode **653**, the cathode of which is connected to the wiper connection of potentiometer **631**. There are now two parallel paths for the input current, causing a change in the ratio of feedback resistance to input resistance and thus establishing a new slope in the function generator output.

As the reference voltage increases farther in the negative direction, a third parallel path through rheostat **619** and diode **655** which has its cathode connected to the wiper connection of potentiometer **632**, allowing additional current to pass through points I and H which again change the ratio of the feedback resistance to the input resistance thus establishing a third slope for the characteristics of the function generator. FIGURE 9 is a graphic representation of these characteristics of the function generator showing the slopes represented by the odd numbers and the breakover points represented by the even numbers. Thus, slope **701** is established by the ratio of the feedback resistance of rheostat **617** (in FIGURE 8) when at point **702** (in FIGURE 9) the second current path is established through rheostat **618** and diode **653** (in FIGURE 8) which changes the slope of curve to **703** (in FIGURE 9).

As the throttle lever is moved farther in the ahead direction, causing the reference voltage to constantly increase in the negative direction, the slope changes with each consecutive breakover point until the throttle lever is in the full ahead position, at which point all the rest of the parallel circuits consisting of rheostat **620** connected to the anode of diode **657** which has its cathode connected to the wiper connection of potentiometer **633**, parallel circuit with rheostat **621** connected to the anode of diode **659** which has its cathode connected to the wiper connection of potentiometer **634**, parallel circuit with rheostat **622** connected to the anode of diode **661** which has its cathode connected to the wiper connection of potentiometer **635**, parallel circuit with rheostat **623** connected to the anode of diode **663** which has its cathode connected to the wiper connection of potentiometer **636**, and parallel circuit with rheostat **624** connected to the anode of diode **665** which has its cathode connected to the wiper connection of potentiometer **637**, are connected in the feedback circuit.

In FIGURE 9, point **704** is the breakover point when the fourth parallel circuit establishes slope **705**, until at point **706** the fifth parallel circuit establishes slope **707**, and at point **708** the sixth parallel circuit establishes slope **709**, and at point **710** slope **711** is established by the seventh parallel circuit, when finally at point **712** slope **713** is established by the eighth parallel circuit. Thus, the breakover points are determined by the setting of potentiometers **631–637** and the slope of gain of the function generator beyond each breakover point is determined by the setting of the associated rheostats **617–624**.

The astern characteristic is established whenever the throttle lever is moved in the astern direction, thus producing a positive reference signal which is similar to those of the ahead characteristics, and as in the ahead direction slopes and breakover points are established by the various parallel paths of the feedback circuits. Thus, the parallel circuit consisting of potentiometer **638** which has its wiper connection connected to the anode of diode **667** of which the cathode is connected to rheostat **625** (in FIGURE 8) produces slopes **721** (in FIGURE 9) when the throttle lever is slightly moved in the astern direction. As the throttle is continued to be moved in the astern direction, point P becomes positive with respect to the positive voltage of the input terminal R of the operational amplifiers **629**, causing a second parallel circuit to be established. The new circuit consists of potentiometer **639** with its wiper connected to the anode of diode **669**, which has its cathode connected to rheostat **626**.

In FIGURE 9, the breakover to the second parallel circuit is represented by point **722**, at which time slope **723** is established. Breakover point **724** indicates the establishment of slope **725** which is caused by the third parallel circuit consisting of potentiometer **640** with its wiper connection connected to the anode of diode **671** which has its cathode connected to rheostat **627** in FIGURE 8. The astern constant current circuit consists of rheostat **673**, which on one side is connected to the positive 50 volt bus **50P** and on the other side is connected to the anode of diode **605** and the anode of diode **607** and through resistor **675** to the series connected potentiometer **638**, **639** and **640**, which are connected to one side of resistor **677**. The other side of resistor **677** is connected to the collector of transistor **679** of which the emitter is connected through resistor **681** to the negative 50 volt bus **50N**. The common bus **211** is connected through resistor **687** to the base of transistor **679** and to the anode of diode **685** of which the cathode is connected to the cathode of the Zener diode **683**. The negative 50 volt bus is connected to the anode of Zener diode **683**.

Rheostat **681** is set so that a consant current of one milliamp passes through the constant current circuit. The slopes or gain of the function generator can be changed so that the function need not be a cube, which is the case with the astern direction.

While the invention has been explained and described with the aid of particular embodiments thereof, it will be understood that the invention is not limited thereby and that many modifications restaining and utilizing the spirit thereof without departing essentially therefrom will occur to those skilled in the art in applying the invention to specific operating environments and conditions. It is therefore contemplated by the appended claims to cover all such modifications as fall within the scope and spirit of the invention.

What is claimed is:

1. A ship comprising a propeller, a propulsion unit connected to said propeller for rotating said propeller and providing power for said ship, means for presetting a reference power response for said propulsion unit, means for measuring the speed of rotation of said propeller to indicate the power response of said propulsion unit, means for comparing the measured and reference power response of said propulsion unit, means responsive to a predetermined power response reference and said measuring means for reversing the power response of said propulsion unit for a predetermined period of time to reverse the direction of rotation of said propeller.

2. A ship having a steam turbine as a propulsion unit for said ship, a propeller connected to said steam turbine, means for presetting a reference propeller speed for said steam turbine, means for measuring the speed of rotation of said propeller, means for comparing the speed of rotation of said propeller and the reference propeller speed, means responsive to said comparing means for controlling said steam turbine to bring the speed of rotation of said propeller towards the reference power response, means for removing said reference propeller speed, and means responsive to the removal of said reference propeller speed and said speed of rotation of said propeller to apply reverse torque to said propeller.

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