

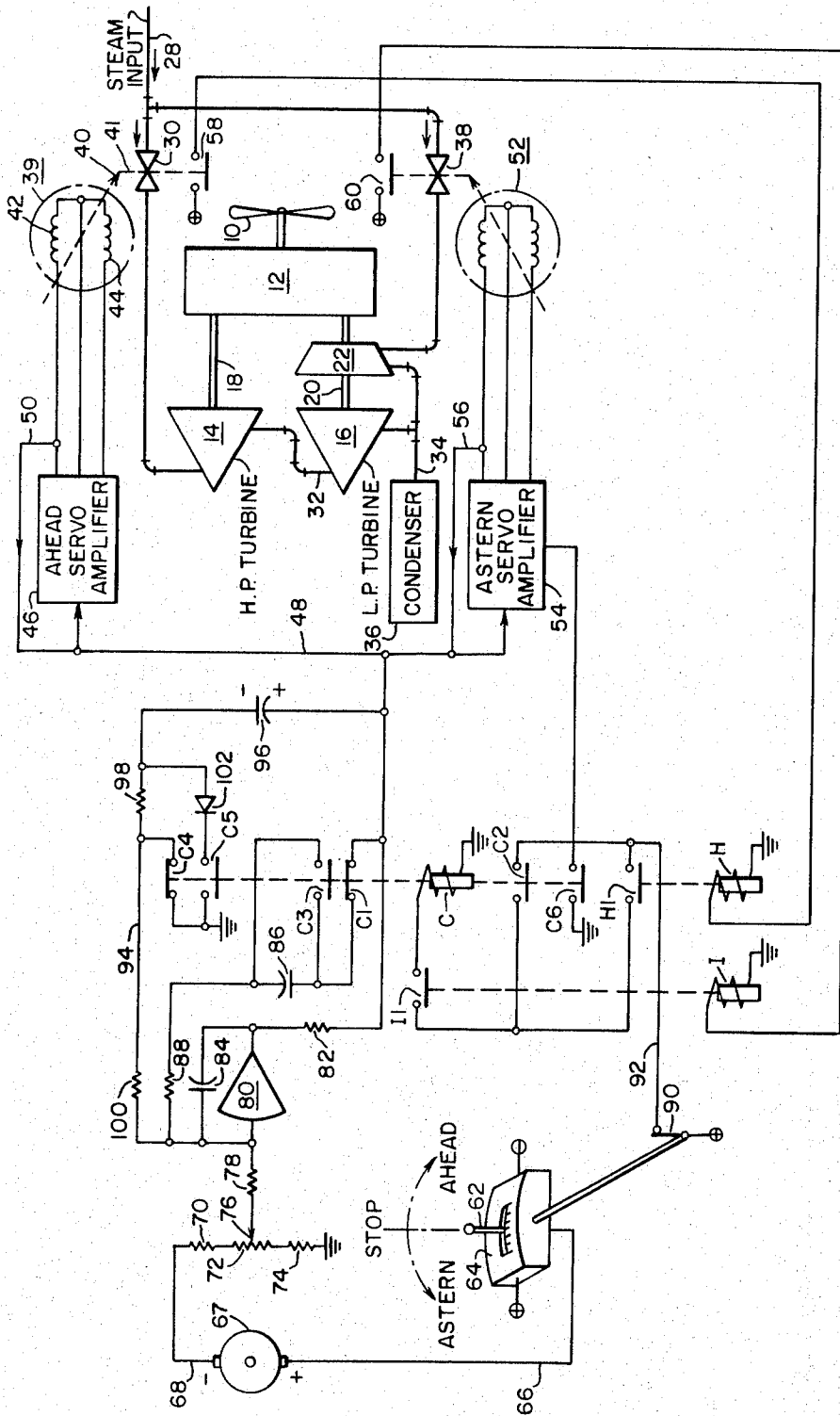
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STAND-BY CONTROL FOR STEAM TURBINES

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1

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STAND-BY CONTROL FOR STEAM TURBINES
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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 driven by an operational amplifier whose input responds to a summation of signals representing actual and desired propeller speeds. A speed controller in the stop position applies a low value "ahead" signal to the operational amplifier, and the ahead valve is alternately opened and closed in response to see-saw of dominance between the ahead and the speed feedback signals. Thus the turbine is cyclically started-stopped-started-stopped, and so on to prevent bowing of the turbine rotor. With the speed controller in the stop position, the operational amplifier has a negative feedback circuit that is operative when the input to the amplifier is in the ahead sense and inoperative when the input to the amplifier is in the opposite sense.

This invention relates to control systems for steam turbines and the like, and more particularly to a stand-by control for marine steam turbines wherein the turbine is stopped and started periodically while the ship is not moving to maintain turbine rotor straightness.

When steam turbines used in marine propulsion systems are at rest, uneven heating of the turbine parts ensues. This uneven heating, if not prevented, will cause the turbine rotor to become bowed, a condition which obviously cannot be tolerated. Accordingly, it becomes necessary to start and stop the turbine every few moments to intermittently rotate the rotor and maintain its straightness.

As an overall object, the present invention seeks to provide apparatus for automatically starting and stopping a steam turbine periodically in order to maintain straightness of the turbine rotor.

More specifically, an object of the invention is to provide stand-by control for a marine propulsion system wherein a steam valve controlling admission of steam to a turbine is periodically opened just wide enough and long enough to start the turbine rotor turning, and then shut long enough for the rotor to coast to a stop and remain stopped until the cycle is repeated in a short time.

The above and other objects and features of the invention will become apparent from the following detailed description taken in connection with the accompanying single figure drawing which schematically illustrates one embodiment of the invention.

The steam propulsion control system as shown herein is described in detail in copending application Ser. No. 540,566 (Westinghouse Electric Corporation) filed concurrently herewith and assigned to the assignee of the present application. For a full and detailed description of the overall control system, reference may be had to that application, the present description being limited to those elements which effect stand-by operation of the turbine to maintain rotor straightness.

With reference now to the drawing, 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.

2

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 boiler, not shown, 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.

The main ahead valve 30, for example, is controlled by means of a servomotor, schematically illustrated at 39 and described in detail in the aforesaid copending application Serial No. 540,566. For purposes of the present application, however, it will be sufficient to state that the servomotor includes a magnetically permeable core, schematically illustrated by the arrow 40, which can be rotated about a center point in one direction or the other by means of two windings 42 and 44 connected to the output of an ahead servo amplifier 46 in a push-pull arrangement. The input to the servo amplifier 46 on lead 48, comprising a speed control, will cause the servo amplifier to rotate the core 40 in one direction and open valve 30 when the control voltage on lead 48 is of negative polarity and increasing magnitude. When the control voltage on lead 48 is still of negative polarity but decreasing in magnitude, the core will rotate in the opposite direction to close valve 30. Whenever the control voltage on lead 48 is not changing, the output from the servo amplifier 46 will remain constant while the core 40 and valve 30 remain in their previously-established position by virtue of a negative feedback path 50 around the amplifier 46 providing a conventional servo loop. The servomotor 39 is mechanically connected to the valve 30 by means of a conventional servomechanism, schematically illustrated by the broken line 41.

The astern valve 38 is controlled by a similar servomotor 52 connected to the output of an astern servo amplifier 54, also provided with a negative feedback path 56. Whereas the ahead servo amplifier 46 and servomotor 39 respond to negative control voltages on lead 48, the astern servo amplifier 54 and servomotor 52 respond to positive control voltages. In this respect, when a positive control voltage on lead 48 is increasing in magnitude, the servomotor 52 will cause the valve 38 to open further; whereas a positive control voltage on lead 48 of decreasing magnitude will cause the servomotor 52 to close the astern valve 38.

Connected to the main ahead valve 30 is a limit switch 58 which is closed when the ahead valve is completely closed (i.e., shut). In a similar manner, a second limit switch 60 becomes closed when the astern valve 38 is completely closed. When valve 30 is completely closed and limit switch 58 closed, relay H becomes energized to close its normally open contacts H1. Similarly, when the astern valve 38 is completely closed, closure of limit switch 60 causes energization of relay I to close its contacts I1.

The main control for the propulsion system comprises a throttle control lever 62 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 62 is connected to a

reference divider or potentiometer 64 such that the output of a movable tap on the potentiometer appearing on lead 66 will have a polarity dependent upon whether the throttle lever 62 is moved to an ahead position or an astern position, and a magnitude dependent upon the amount of movement of the throttle lever in either direction from its center or stop position. In the particular control system shown herein, the output on lead 66 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, 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 66 is proportional to desired speed and its polarity indicative of the desired direction of movement of the ship. Hence, the signal on lead 66 can be referred to as a "desired speed signal."

The desired speed signal on lead 66 is added in series with the output of a tachometer generator 67 which is mechanically connected to the propeller 10 of the ship by suitable means, not shown herein. Hence, the output of the tachometer generator 67 is proportional to the actual speed of the propeller, and the polarity of the signal across the output terminals of generator 67 is indicative of the direction of actual movement, either astern or ahead. Hence, the output of tachometer generator 67 can be referred to as the "actual speed signal."

The actual speed signal across tachometer generator 67 normally has a polarity opposing that on lead 66 whenever the lever 62 is moved from a previously established position. Whenever the actual speed of the ship coincides with the desired speed as determined by the position of throttle lever 62, the output of reference divider 64 comprising the desired speed signal will be equal to, and opposite in polarity to, the actual speed signal produced by tachometer generator 67 such that the voltage between lead 68 and ground will be zero. However, whenever the desired speed signal differs from the actual speed signal, a speed error signal or voltage will be produced between lead 68 and ground. This voltage is applied across a voltage divider comprising resistors 70, 72 and 74 in series. The resistor 72 is provided with a movable tap 76 which is connected through resistor 73 to the input of an operational amplifier 80, the output of amplifier 80 being applied through resistor 82 to the lead 48. Hence, the output of the operational amplifier comprises the aforesaid speed control voltage which is applied to amplifiers 46 and 54 and which is effective, when negative, to actuate the servomotor 39 and effective, when positive, to actuate the servomotor 52.

The operational amplifier 80 is provided with a first feedback path including a capacitor 84 which filters out any ripple appearing in the input direct current control voltage. A second feedback path includes capacitor 86 and resistor 88 in series with normally closed contacts C1 of a relay C. This second feedback path including capacitor 86 and resistor 88 provides proportional plus integral control action. That is, in response to an abrupt change in the voltage on lead 68, there will be a step output or abrupt increase in voltage on lead 48, followed by a gradual change. As an example, assume a sudden speed error of one propeller revolution per minute. This will produce an error voltage on lead 68; and almost immediately after the appearance of the error voltage, the output of amplifier 80 on lead 48 will change abruptly. However, after this abrupt change in output, the integral action of the amplifier will cause the output to continue to change after the transient step change resulting from the proportional response to the sudden error.

The throttle control lever 62 has connected thereto a wiper brush 90 which energizes lead 92 when, and only when, the throttle lever 62 is in its central or stop posi-

tion. Thus, whenever the ship is at rest, the lead 92 will be energized. Assuming that both the ahead valve 30 and astern valve 38 are closed, relays H and I will be energized to close contacts H1 and I1. Consequently, relay C will now become energized and will remain energized through contacts C2 even though the ahead valve 30 opens and relay H becomes deenergized. Thus, once the relay C becomes energized, it will remain energized until the throttle lever 62 is moved from its central or stop position, or until the astern valve 38 opens to deenergize relay I.

When relay C becomes energized, contacts C1 open to thereby interrupt the feedback path comprising capacitor 86 and resistor 88 in series. At the same time, closure of contacts C3 short out capacitor 86 and remove any residual charge thereon. This insures that once the throttle lever 62 is moved from its stop position and relay C becomes deenergized, no residual charge will exist on the capacitor 86 to impede the response characteristics of the system.

In addition to the two feedback paths previously described, there is a third feedback path 94 comprising capacitor 96 in series with resistors 98 and 100. When the throttle lever 62 is not in its central or stop position and the relay C is deenergized, contacts C4 will be closed, thereby grounding feedback path 94. When, however, the relay C becomes energized with the ship at rest and valves 30 and 38 closed, the contacts C4 will open and contacts C5 will close, thereby connecting the junction of capacitor 96 and resistor 98 to ground through diode 102.

When the throttle lever 62 is placed in the stop position, the maneuvering valve 30 or 38 which has been open will close. Once both the ahead and astern valves 30 and 38, respectively, are closed as sensed by limit switches 32 and 60, the relay C is energized and remains energized so long as the throttle lever is left in the stop position. As mentioned above, relay C disconnects the normal feedback circuit around the amplifier 80 by virtue of contacts C1, which now open, and connects the higher gain feedback path 94 between the input and output of amplifier 80. When the throttle lever 62 is in its center or stop position, a slight positive voltage is produced on lead 66 as is more fully explained in the aforesaid pending application Ser. No. 540,566. That is, at this time, the lead 66 is not grounded but, rather, is slightly positive with respect to ground. This positive voltage, when applied to the amplifier 80, causes its output on lead 48 to integrate slowly from positive to negative polarity. When the voltage on lead 48 is sufficiently negative, the servomotor 39 opens steam valve 30. During this process, capacitor 96 changes its charge from the polarity shown to opposite polarity.

Once the valve 30 is opened, the propeller 10 rotates in the forward direction, thereby causing the tachometer generator 67 to produce a voltage with the polarity shown on the drawing. This voltage, applied to amplifier 80, causes the negative output on lead 48 to swing fully positive abruptly, because diode 102 discharges capacitor 96 to ground (via contact C3) and thereby effectively prevents the high gain feedback path through resistors 98 and 100 from acting as a result the ahead valve 30 is closed. This positive voltage on lead 48, however, cannot actuate the astern servomotor 52 for the reason that the output of amplifier 54 is now grounded via contacts C6 which are now closed. After the valve 30 closes, the propeller 10 stops, and the voltage output of the tachometer 67 drops to zero, whereupon the slight positive voltage on lead 66 will cause the aforesaid cycle to repeat.

Thus, by the action of the circuit, valve 30 is opened just long enough for the propeller 10 to be accelerated to some value ordinarily less than three revolutions per minute. At this point, the speed of the propeller is quickly sensed by the tachometer 67 with the output of amplifier 80 on lead 48 quickly changing from a negative voltage

necessary for opening the ahead valve 30 to a positive voltage causing "hard closing" of the ahead valve. If the ship has no headway, the turbine speed will gradually reduce to zero and the amplifier 80 with feedback path 94 will begin to integrate from the positive "hard closed" region back into the negative region necessary for the next steam pulse.

It can be seen, therefore, that the present invention provides a means for periodically rotating the rotor of a steam turbine while it is at rest to prevent uneven heating of the rotor and to maintain its straightness. Although 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.

I claim as my invention:

1. In control apparatus for a ship propulsion system including a valve for admitting fluid under pressure to turbine means having a rotor mechanically coupled to the ship's propeller; the combination of means for intermittently rotating said rotor and propeller while the ship is stopped, comprising servomotor means for opening and closing said valve, tachometer generator means coupled to said propeller and adapted to produce a direct current voltage when said rotor and propeller rotate, a source of direct current voltage in series with said tachometer generator means and having a polarity opposing the direct current voltage produced by the tachometer generator means when said valve is open, operational amplifier means operable in response to the voltage resulting from the series addition of said direct current voltages and having its output connected to said servomotor means, and a negative feedback path for said operational amplifier means such that said source of direct current voltage will cause the operational amplifier means to produce an output voltage which opens said valve, the valve remaining open until the rotor and propeller accelerate to the point where the voltage produced by the tachometer generator means overrides said source of direct current voltage and causes said valve to close, and means operable only when the tachometer generator voltage overrides said source of direct current voltage for reducing the effectiveness of said negative feedback path whereby to increase the gain of the amplifier means and thus accelerate the closing of said valve.

2. The combination of claim 1 wherein the output of said operational amplifier means is applied to said servomotor means through a servo amplifier having a negative feedback path.

3. The combination of claim 2 wherein said servomotor means will open said valve when the output of the operational amplifier means is of one polarity and increasing in magnitude, and wherein the servomotor means will cause said valve to close when the output of the operational amplifier means is of said one polarity and decreasing in magnitude.

4. The combination of claim 1 wherein said valve comprises an ahead valve which causes the ship to move in the ahead direction when it is opened, the ship propulsion system also including an astern valve for admitting fluid under pressure to the turbine means to rotate the propeller such that the ship moves in the astern direction, servomotor means for actuating said astern valve, and means initially responsive to said ahead valve being in closed position for disabling said latter-mentioned servomotor means when the ship is stopped and for maintaining said disablement even after said ahead valve is opened to initiate said intermittent operation.

5. The combination of claim 1 wherein said operational

amplifier means includes a second feedback path including a capacitor and a resistance element, which second feedback path causes the amplifier to operate as a proportional plus integral controller, means for interrupting said second feedback path when the ship is stopped, and means for disabling said first-mentioned feedback path when the ship is moving.

6. The combination of claim 1 wherein said feedback path includes a capacitor in series with a resistance element, and a unidirectional current device connecting the junction of said capacitor and resistance element to ground.

7. In control apparatus for a ship propulsion system including a valve for admitting fluid under pressure to turbine means having a rotor mechanically coupled to the ship's propeller; the combination of means for intermittently rotating said rotor and propeller while the ship is stopped comprising operational amplifier means having a negative feedback path, means responsive to the output of said amplifier means for controlling said valve, means for applying a voltage of one polarity to said amplifier means to cause said valve to open, means operable when said propeller rotates for applying a voltage of the other polarity to said amplifier means to cause said valve to close, and means operable only when the voltage of said other polarity is applied to said amplifier means for reducing the effectiveness of said negative feedback path whereby to increase the gain of the amplifier means thus to accelerate the closing of said valve.

8. The combination of claim 7 wherein said feedback path includes a capacitor, and said means for reducing the effectiveness of said feedback path comprises means for discharging said capacitor.

9. The combination of claim 7 wherein said valve comprises an ahead valve which causes the ship to move in the ahead direction when it is opened, the ship propulsion system also including an astern valve for admitting fluid under pressure to the turbine means to rotate the propeller such that the ship moves in the astern direction, servomotor means for actuating said astern valve, and means initially responsive to said ahead valve being in closed position for disabling said latter-mentioned servomotor means when the ship is stopped and for maintaining said disablement even after said ahead valve is opened to initiate said intermittent operation.

10. The combination of claim 7 wherein said operational amplifier means includes a second feedback path including a capacitor and a resistance element, which second feedback path causes the amplifier to operate as a proportional plus integral controller, means for interrupting said second feedback path when the ship is stopped, and means for disabling said first-mentioned feedback path when the ship is moving.

11. The combination of claim 7 wherein said feedback path includes a capacitor in series with a resistance element, and said means for reducing the effectiveness of said feedback path comprises a unidirectional current device connecting the junction of said capacitor and resistance element to ground.

12. The combination of claim 1 wherein said feedback path includes a capacitor, and said means for reducing the effectiveness of said feedback path comprises means for discharging said capacitor.

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