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(54) TURBINE CONTROL SYSTEM

(71) We, GENERAL ELECTRIC COMPANY, a corporation organized and existing under the laws of the State of New York, United States of America, of 1 River Road, Schenectady 12305, State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates generally to turbine control systems; and, in particular, this invention is applicable to marine steam turbine control systems.

During startup and shutdown of a marine steam turbine there is a danger that the turbine rotor may become distorted if allowed to cool or heat up nonuniformly. To prevent this thermal distortion, the shaft must be rotated at low speeds until sufficiently heated or cooled. This may be done by turning gear or by manual actuation of the steam valve control whenever the shaft speed approaches zero-speed. Zero-shaft speed may be defined as less than one-half shaft revolution per minute.

While the foregoing procedures may be adequate to prevent shaft distortion, the turning gear solution has a disadvantage because of the time it takes to convert from turning gear operation to steam operation. This delay could be critical in the case of modern super tankers which may be required to leave an offshore unloading area quickly under the threat of fire. In the instance of manual operation, the required observation is tedious and subject to operator error.

It is the object of the present invention to provide a turbine control system which provides automatic shaft rollover upon detection of zero-speed condition, a condition which may be detected both during start-up and shut-down, and may be applied to advantage to delay both heating-up of the tur-

bine during start-up and its cooling down on shut-down.

The present invention provides a turbine control system for rolling a turbine rotor when the throttle control is set either to stop, or to start; as required, including a main steam valve position control circuit for controlling the flow of a motive fluid to at least one turbine; an automatic rollover circuit for providing a valve position set command signal to the valve position control circuit in response to a turbine shaft zero-speed condition (as hereinbefore defined), the automatic rollover circuit comprising:

at least one shaft speed signal input; means responsive to the shaft speed signal input for detecting a zero-speed condition of the turbine shaft;

a valve position set circuit for providing a valve position set command signal in response to a signal from the zero-speed detection means; and

means responsive to the shaft speed signal input for detecting turbine shaft rollover; the rollover detection means output signal providing a reset signal to the zero-speed detection means and the valve position set circuit upon detection of turbine shaft rollover.

The input shaft speed signal is preferably watched by the zero-speed detection circuit and the rollover detection circuit connected in parallel. If a zero-speed condition is detected, a delayed signal activates the valve position set circuit, which provides a valve position set command to the turbine valve position control circuit. An ahead/astern logic circuit preferably controls the polarity of the valve position set command so that the turbine is alternately rolled in the ahead or astern direction. If the rollover attempt fails, the zero-speed detection circuit and valve position set circuit are preferably reset by a valve open timer and another attempt to roll the turbine is made in an

opposite direction. Meanwhile a shaft-stopped alarm may be sounded. If the rollover is successful, the zero-speed detection circuit, the valve position set circuit, and valve open timer are re-set by the roll-over detection circuit to await the next zero-speed condition. A rollover trip circuit may also be enabled by a signal from the valve position set circuit.

In order that the invention may be clearly understood, a preferred embodiment thereof will now be described by way of example only with reference to the accompanying drawings, in which:—

Figure 1 is a schematic diagram of a marine turbine control system from throttle to turbine incorporating the automatic rollover circuit according to the preferred embodiment of the invention;

Figure 2 is a schematic diagram of the automatic rollover circuit including a shaft speed input and a valve position set command output;

Figure 3 is a schematic diagram of the zero-speed detection circuit and valve set delay timer;

Figure 4 is a schematic diagram of one embodiment of a timer device useful in the present invention; and

Figure 5 is a diagrammatic representation of the rollover detection circuit.

Referring to Figure 1, the throttle control is set to produce both a valve position reference signal and a speed reference signal. In summing junction A, the valve position reference is added to the actual valve position (feedback) to provide a valve position error signal. In summing junction B, the speed reference signal is added with the actual speed signal to provide a speed error signal. In summing junction C, the valve position error signal and the speed error signal are added to provide a valve position command which reflects both the valve position error signal and the speed error signal. During normal operations, the automatic rollover circuit is disabled and hence its output signal (valve position set command) is zero. The valve position command (summation of the valve position error and speed error) is input into a fourth summing junction D which determines flow from a variable displacement pump used for actuating the turbine valves. The variable displacement pump, or valve actuating system provides means for controlling a pair of valves to open and closed positions respectively. These can be primary valves, or they can be secondary, or relay (or relief) valves which control primary valves. In the summary passage which follows the valves therein referred to may be read as constituting the actual turbine valves of the present application.

The valve actuating system comprises a pair of valves spring-biased to their closed

positions, a pair of hydraulic actuators (the variable displacement pump), each controlling one of the valves, and means for introducing pressurized fluid into the actuators. The actuators are so arranged that when pressurized fluid is introduced into the actuators, the valves are sequentially moved in opposite directions, thus closing one valve and opening the other. The pressure sources for actuation of the valves, a pair of solenoid valves and hydraulic circuitry, are all interconnected, so that fluid can be introduced from either pressure source. Emergency and fail-safe closure of the valves is also provided by biasing the valves to their closed positions.

Referring to Figure 2, an automatic rollover control circuit is shown in more detail. Redundant pickup speed signals HPS1 and HPS2 are provided from the high-pressure turbine shaft by means of a toothed wheel and magnetic pickup. The speed signals are in the form of digital pulse trains whose repetition rate is proportional to turbine shaft speed. The redundant speed signals are input into an Automatic Switching Input Check Circuit which produces a single speed signal output. The Automatic Switching Input Check Circuit uses HPS1 as the primary control signal, but if this should fail, it disables HPS1 as an input and automatically switches to HPS2 as the control signal.

The Automatic Switching Input Check Circuit output speed signal is input to a Zero-Speed Detection Circuit and Rollover Detection Circuit, both of which are in parallel. The Zero-Speed Detection Circuit is an asynchronous digital circuit which enables a Valve Set Delay Timer if there is a zero-speed detection. Zero-speed has already been defined as a shaft speed of less than one-half revolution per minute. The Valve Set Delay Timer has an adjustable delay setting which is usually set for one-minute delay. At the end of the one-minute delay, a signal from the timer activates a Valve Position Set Circuit which has been preset to the amount of valve opening in the turbine control valves. The output signal of the Valve Position Set Circuit is further modified by an Ahead-Astern Direction Control (a flip-flop device) which then either causes the ahead or the astern turbine valves to open in the amount preset in the Valve Position Set Circuit. Hence, returning to Figure 1, it is seen that a speed input signal to the Automatic Rollover Circuit, which is identified as a zero-speed signal, results in an output signal from the Automatic Rollover Circuit which is a valve position set command. The valve position set command is a reference input to the valve position control circuit and hence sets (opens) the turbine valves.

Returning to Figure 2, if rollover is accom-

plished, it is sensed by a Rollover Detection Circuit. The Rollover Detection Circuit is set so that it is activated by the digital pulse train speed signal input where the pulse interval is less than that corresponding to one-half shaft revolution per minute. Activation of the Rollover Detection Circuit resets the Zero-Speed Detection Circuit (to await the next zero-speed condition) and resets the Valve Position Set Circuit, closing the turbine valves.

The Valve Position Set Circuit also activates a Valve Open Timer which is a delay timer with a nominal delay of one minute. If a zero-speed condition is sensed and thereafter the turbine shaft is rolled, the Valve Open Timer is reset by the Rollover Detection Circuit. If there is no rollover, the timer activates a shaft-stopped alarm and resets the Zero-Speed Detection Circuit and the Valve Position Set Circuit so that rollover is then attempted in the opposite direction.

The Valve Position Set Circuit also resets the Valve Set Delay Timer and enables a Rollover Trip Circuit.

The Rollover Trip Circuit includes a digital speed signal input LPS1 taken from the low-pressure turbine. If the speed signal indicates a turbine speed of greater than 15% of rated turbine speed, then a signal output from the Rollover Trip Circuit (Malfunction Trip) is gated with the valve position control circuit output to assure that the 15% speed signal is due to an Automatic Rollover Circuit Malfunction and not any other control mode. The trip is hydraulic and is known in the prior art. Additionally, this trip is interlocked with the throttle control which must be set at zero to operate the Automatic Rollover Control Circuit.

Referring now to Figure 3, in conjunction with the aforementioned Figures 1 and 2, the zero-speed detection circuit is a combination of a retriggerable monostable multivibrator P1 and flip-flop circuits employing NAND gates. The retriggerable monostable multivibrator may be of the type known as a Fairchild 9601 having a fixed timed output signal set by an RC time constant (T). The speed signal input is a digital pulse train whose repetition rate is proportional to shaft speed. If the repetition rate of the speed pulses is such that the time between speed pulses exceeds T, then the 1 output of P1 will be high. If the time between speed pulses is less than T, then the 1 output of P1 goes low and sets FF1 (flip-flop). The T constant of P1 corresponds to the time delay between arriving speed pulses representing a shaft speed of $\frac{1}{2}$ RPM.

Flip-flop circuit FF1 is made up of two, 2 input NAND gates (Fairchild 9949). A set or reset command is a logic low signal. A logic low input to S will cause the 1 output

to be high and the 0 output to be low. A low input to R will cause the 1 output to be low and the 0 output to be high. Operation is asynchronous.

After FF1 is set, its output signal (1) is gated in a NAND gate with the 0 output of FF2. This is an interlock which means that the circuits must be in the reset mode (the 1 output low, the 0 output high) for proper operation. This insures that once a valve set command has been initiated it will not be disrupted by the zero-speed detection circuit. This is important when the shaft is forced to zero and rotated in the opposite direction.

The signal will now set the timer which until this time is being held in reset by using a NAND gate as a logical inverter from the set signal to the reset line. This insures that the set reset operation of the timer control is mutually exclusive. The timer represents the valve set delay timer. When it times itself out, it emits a high pulse that is logically inverted by another NAND gate to set FF2 and the 1 output thereof sets the valve position set circuit. Another zero-speed condition can only be detected after both FF1 and FF2 have been reset. The reset signal will come either from the Rollover Detection Circuit or the Valve Open Timer.

Referring to Figure 4, an example of a timer device is shown. When the timer is in the reset mode a switch connects the 741 operational amplifier (connected as an integrator) inverting input to a negative reference voltage through an input resistor. The 741 operational amplifier is held in positive saturation, about 12 V, DC. The compactor C is set to trigger on a negative voltage.

The timer is started by switching the 741 input to a positive reference voltage (adjustable by means of a potentiometer). The 741 amplifier then starts to integrate negatively as a function of $R_1 C_1$, the voltage at the slider of PR₁. When this voltage reaches the set point of comparator C, set by potentiometer PR₂, the comparator fires and a logic compatible signal is output. The time delay is controlled by the reference voltage at PR₁ and the comparator set point, determined by PR₂. To reset the timer the switch position is reversed and the 741 amplifier will have a negative reference voltage. The reset mode is faster than the timer mode by making the time constant $R_2 C_1$ much smaller than time constant $R_1 C_1$. Also the negative reference voltage is much greater. The analog switches are controlled by a flip-flop. A set signal to the flip-flop closes S₂ and opens S₁, thereby starting the timer. A reset signal to the flip-flop closes S₁ and opens S₂.

Figure 5 is a diagrammatic representation of the rollover detection circuit. Two retriggerable monostable multivibrators P₁ and P₂ have different time constants T₂ and T₁ wherein T₂ is greater than T₁. P₂ is used as

a delay device whereas P_2 is the primary de-
 tection device. The digital speed signal trig-
 gers P_2 and as long as the time delay between
 arriving speed pulses is greater than T_2 of
 P_2 , P_2 will have pulsed outputs. The 0 output
 of P_2 is used to trigger P_3 . Two NAND
 gates in series are used to delay the 1 output
 of P_2 before it is gated with the 0 output of
 P_3 . The NAND gates in series compensate
 for the propagation delay incurred when
 triggering P_3 . When the time between arriv-
 ing speed pulses is less than T_2 of P_2 (T_2 is
 set such that it is equal to the time between
 speed pulses that would correspond to a
 shaft speed slightly greater than $\frac{1}{2}$ RPM),
 the output of P_2 1 stays high. P_3 is then no
 longer being triggered and times itself out,
 and its 0 output will go high. The P_2 1 out-
 put is gated with the P_3 0 output (both
 high) providing a rollover detection signal.

The rollover trip circuit is similar to the
 aforementioned rollover detection circuit and
 therefore would be obvious to one of ordi-
 nary skill in the art to derive the roller trip
 circuit from the teachings of Figure 5 and
 the foregoing explanation.

The operation of the Automatic Rollover
 Circuit is as follows. When the throttle
 control is set to zero, it is still desirable to
 keep the shaft rotating to prevent distortion
 of the shaft. This is the function of the Auto-
 matic Rollover Circuit which provides a
 valve position set command when a zero-
 speed condition is detected. The valve posi-
 tion set command is introduced into the
 valve position control circuit shown in Fig.
 1 and operates the turbine control valves.
 Again, it is emphasized that during the
 operation of the Automatic Rollover Circuit,
 the throttle is set at zero and an interlock
 between the Automatic Rollover Circuit and
 the throttle control is provided for this pur-
 pose.

Redundant high-pressure turbine speed
 signals are introduced into the Automatic
 Rollover Circuit into an asynchronous
 switching circuit which can detect failure of
 one of the input signals and which then can
 utilize the working signal for control. The
 input speed signal is ignored allowing the tur-
 bine to coast until such time as a zero-speed
 condition exists. This condition is detected
 by a Zero-Speed Detection Circuit (an asyn-
 chronous digital circuit which looks at the
 time interval between speed pulses) which
 activates a Valve Position Set Circuit after
 a nominal delay set by the Valve Set Delay
 Timer. The Valve Position Set Circuit and
 the Ahead/Astern Direction Control direct
 the Marine Turbine Control to open either
 the Ahead or Astern valves and sets the
 amount (position) of the valve opening.
 Simultaneously, with this signal to the tur-
 bine control, the Valve Set Delay Timer is
 reset; the Valve Open Timer is set and the

Rollover Trip Circuit is set. If the turbine
 shaft is rolled, this is detected by the Roll-
 over Detection Circuit which resets the Zero-
 Speed Detection Circuit; resets (closes) the
 Valve Position Set Circuit and resets the
 Valve Open Timer. The turbine shaft then
 coasts until the next zero-speed condition is
 detected.

If within the one-minute delay of the
 Valve Open Timer, the shaft does not roll,
 a signal from the timer activates a shaft-
 stopped alarm and resets the Zero-Speed
 Detection Circuit and Valve Position Set
 Circuit. Thereafter the zero-speed is again
 detected and a valve position set command
 is activated for turning the shaft in the other
 direction. If, in the course of Automatic
 Rollover Circuit control, the turbine speed
 exceeds 15% of rated speed (as detected
 from an alternative turbine speed pickup)
 then a signal (malfunction trip) is gated with
 the valve position control output signal to
 shut down the turbine.

Similar conditions will apply on start-up,
 the only difference being that the throttle
 control is set off-zero to initiate the start.
 Thereafter, the rollover control functions as
 before, to maintain rollover of the turbine
 shaft at near zero speed until a faster speed
 is warranted.

WHAT WE CLAIM IS:—

1. A turbine control system for rolling
 a turbine rotor when the throttle control is
 set either to stop, or to start, as required,
 including a main steam valve position control
 circuit for controlling the flow of a motive
 fluid to at least one turbine; an automatic
 rollover circuit for providing a valve position
 set command signal to the valve position
 control circuit in response to a turbine shaft
 zero-speed condition (as hereinbefore de-
 fined), the automatic rollover circuit com-
 prising:

at least one shaft speed signal input;
 means responsive to the shaft speed sig-
 nal input for detecting a zero-speed condi-
 tion of the turbine shaft;

a valve position set circuit for providing
 a valve position set command signal in re-
 sponse to a signal from the shaft zero-
 speed detection means; and

means responsive to the shaft speed sig-
 nal input for detecting turbine shaft roll-
 over; the rollover detection means output
 signal providing a reset signal to the zero-
 speed detection means and the valve posi-
 tion set circuit upon detection of turbine
 shaft rollover.

2. A turbine control system as claimed in
 claim 1, wherein the zero-speed detection
 means and the shaft rollover detection means
 are connected in parallel and are responsive
 to the shaft speed signal input.

3. A turbine control system as claimed

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a delay device whereas P_2 is the primary detection device. The digital speed signal triggers P_2 and as long as the time delay between arriving speed pulses is greater than T_2 of P_2 , P_2 will have pulsed outputs. The 0 output of P_2 is used to trigger P_3 . Two NAND gates in series are used to delay the 1 output of P_2 before it is gated with the 0 output of P_3 . The NAND gates in series compensate for the propagation delay incurred when triggering P_3 . When the time between arriving speed pulses is less than T_2 of P_2 (T_2 is set such that it is equal to the time between speed pulses that would correspond to a shaft speed slightly greater than $\frac{1}{2}$ RPM), the output of P_2 1 stays high. P_3 is then no longer being triggered and times itself out, and its 0 output will go high. The P_2 1 output is gated with the P_3 0 output (both high) providing a rollover detection signal.

The rollover trip circuit is similar to the aforementioned rollover detection circuit and therefore would be obvious to one of ordinary skill in the art to derive the roller trip circuit from the teachings of Figure 5 and the foregoing explanation.

The operation of the Automatic Rollover Circuit is as follows. When the throttle control is set to zero, it is still desirable to keep the shaft rotating to prevent distortion of the shaft. This is the function of the Automatic Rollover Circuit which provides a valve position set command when a zero-speed condition is detected. The valve position set command is introduced into the valve position control circuit shown in Fig. 1 and operates the turbine control valves. Again, it is emphasized that during the operation of the Automatic Rollover Circuit, the throttle is set at zero and an interlock between the Automatic Rollover Circuit and the throttle control is provided for this purpose.

Redundant high-pressure turbine speed signals are introduced into the Automatic Rollover Circuit into an asynchronous switching circuit which can detect failure of one of the input signals and which then can utilize the working signal for control. The input speed signal is ignored allowing the turbine to coast until such time as a zero-speed condition exists. This condition is detected by a Zero-Speed Detection Circuit (an asynchronous digital circuit which looks at the time interval between speed pulses) which activates a Valve Position Set Circuit after a nominal delay set by the Valve Set Delay Timer. The Valve Position Set Circuit and the Ahead/Astern Direction Control direct the Marine Turbine Control to open either the Ahead or Astern valves and sets the amount (position) of the valve opening. Simultaneously, with this signal to the turbine control, the Valve Set Delay Timer is reset; the Valve Open Timer is Set and the

Rollover Trip Circuit is set. If the turbine shaft is rolled, this is detected by the Rollover Detection Circuit which resets the Zero-Speed Detection Circuit; resets (closes) the Valve Position Set Circuit and resets the Valve Open Timer. The turbine shaft then coasts until the next zero-speed condition is detected.

If within the one-minute delay of the Valve Open Timer, the shaft does not roll, a signal from the timer activates a shaft-stopped alarm and resets the Zero-Speed Detection Circuit and Valve Position Set Circuit. Thereafter the zero-speed is again detected and a valve position set command is activated for turning the shaft in the other direction. If, in the course of Automatic Rollover Circuit control, the turbine speed exceeds 15% of rated speed (as detected from an alternative turbine speed pickup) then a signal (malfunction trip) is gated with the valve position control output signal to shut down the turbine.

Similar conditions will apply on start-up, the only difference being that the throttle control is set off-zero to initiate the start. Thereafter, the rollover control functions as before, to maintain rollover of the turbine shaft at near zero speed until a faster speed is warranted.

WHAT WE CLAIM IS:—

1. A turbine control system for rolling a turbine rotor when the throttle control is set either to stop, or to start, as required, including a main steam valve position control circuit for controlling the flow of a motive fluid to at least one turbine; an automatic rollover circuit for providing a valve position set command signal to the valve position control circuit in response to a turbine shaft zero-speed condition (as hereinbefore defined), the automatic rollover circuit comprising:
 - at least one shaft speed signal input; means responsive to the shaft speed signal input for detecting a zero-speed condition of the turbine shaft;
 - a valve position set circuit for providing a valve position set command signal in response to a signal from the shaft zero-speed detection means; and
 - means responsive to the shaft speed signal input for detecting turbine shaft rollover; the rollover detection means output signal providing a reset signal to the zero-speed detection means and the valve position set circuit upon detection of turbine shaft rollover.
2. A turbine control system as claimed in claim 1, wherein the zero-speed detection means and the shaft rollover detection means are connected in parallel and are responsive to the shaft speed signal input.
3. A turbine control system as claimed

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in claim 1 or claim 2, wherein the shaft speed input signal is a digital pulse train whose repetition rate is proportional to shaft speed, and wherein the zero-speed detection means includes a retriggerable monostable multivibrator having a time constant corresponding to a digital pulse train repetition rate representing a shaft speed of one-half revolution per minute.

4. A turbine control system as claimed in any one of Claims 1—3, further comprising

a first signal delay means between the zero-speed detection means output and the valve position set circuit input, the first signal delay means being reset by the valve position set circuit output; and

a second signal delay means set by the valve position set circuit for resetting the zero-speed detection means and valve position set circuit, the second signal delay means being reset by a signal from the rollover detection means.

5. A turbine control system as claimed in claim 3 or 4, wherein said rollover detection means comprises first and second retriggerable monostable multivibrators having respective time constants of which that for the second multivibrator is greater than that for the first; said first multivibrator receiving said shaft speed input signal digital pulse train, and having a time constant corresponding to a digital pulse train repetition rate representing a predetermined shaft speed slightly greater than one-half revolution per minute; said first multivibrator triggering said second multivibrator constantly while said shaft speed is below said predetermined speed; both said multivibrators combining their outputs after a predetermined delay to deliver a rollover detection output for speeds exceeding said predetermined speed.

6. A turbine control system as claimed in any one of the preceding claims, further including a rollover trip circuit, the rollover trip circuit being enabled by a signal from the valve position set circuit; the rollover trip circuit further comprising:

a second shaft speed signal input comprising a digital pulse train whose repetition rate is proportional to shaft speed; and

at least one retriggerable monostable multivibrator receiving the second shaft speed signal input, the retriggerable monostable multivibrator having a time constant corresponding to a digital pulse train repetition rate of a selected percent of turbine rated speed.

7. A turbine control system as claimed in claim 6, wherein the rollover trip circuit output signal is gated with the valve position control circuit output signal.

8. A turbine control system as claimed in any one of the preceding claims, further including means for directing the valve position set command signal alternatively in an ahead and astern direction, the said means being interposed between the valve position set circuit and the valve position control circuit.

9. A turbine control system as claimed in any one of the preceding claims, wherein the zero-speed detection means and the rollover detection means are asynchronous digital circuits.

10. A turbine control system substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

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