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RELAY FOR LOW-SPEED SENSING SYSTEM

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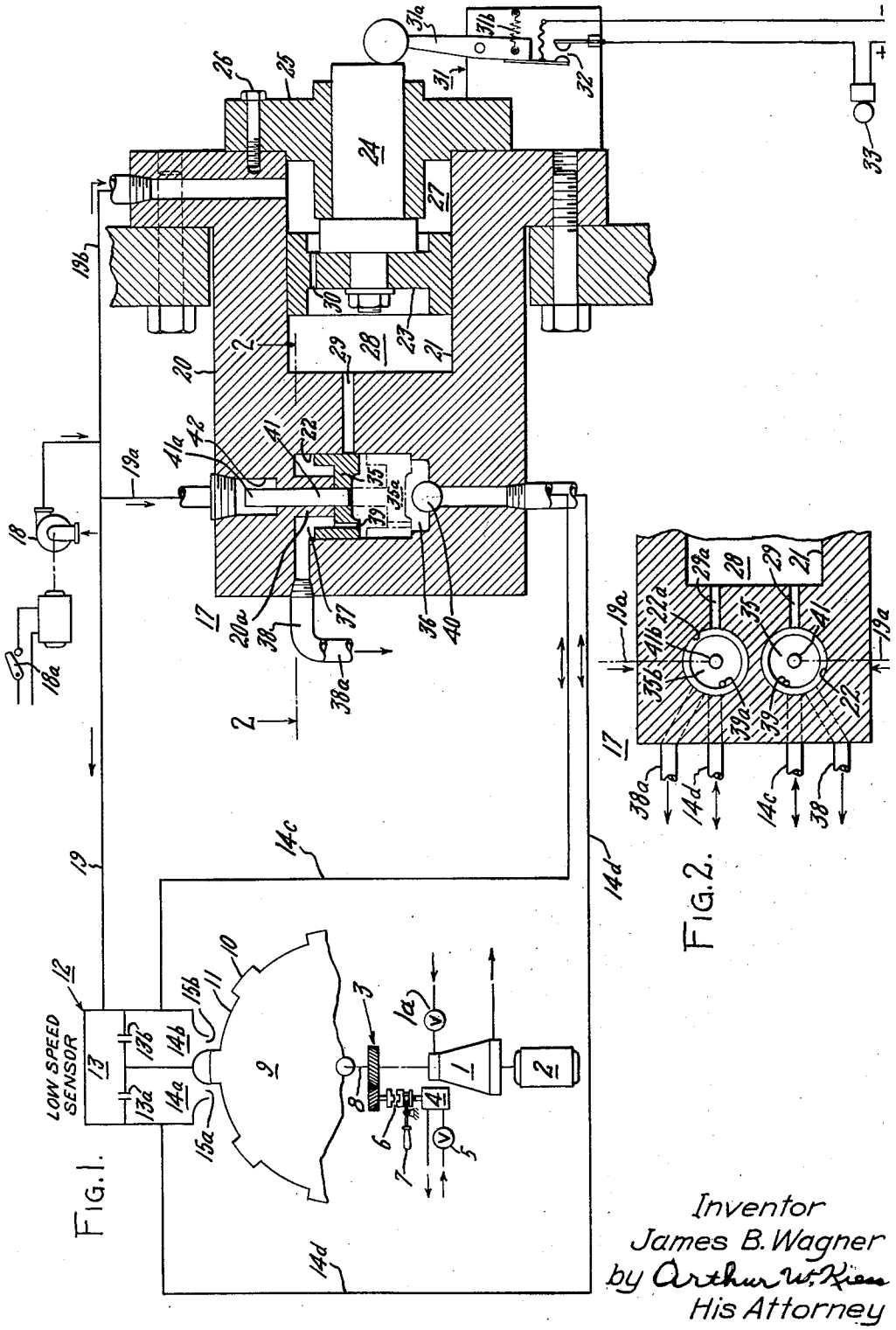


FIG. 1.

FIG. 2.

Inventor
James B. Wagner
by Arthur W. Kiess
His Attorney

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RELAY FOR LOW-SPEED SENSING SYSTEM

James B. Wagner, Lynnfield, Mass., assignor to General Electric Company, a corporation of New York

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This invention relates to speed responsive systems for indicating the occurrence of a predetermined low-speed (or zero speed) condition, particularly to an improved hydraulic relay for use in connection with a low-speed sensor for determining when the rotor of a steam or gas turbine has substantially come to rest, so that it is safe to engage the "turning gear" mechanism which rotates the turbine rotor slowly during the cooling cycle, after shutdown.

As is well known in thermal turbine design practice, it is customary after a turbine is shut down to cause the rotor to turn slowly, at a speed perhaps on the order of 1 to 3 r.p.m., so that the cooling process will not produce uneven temperatures in the rotor, which might otherwise cause it to assume a bowed condition. The turning gear mechanism ordinarily comprises a suitable motor connected by a mechanical jaw clutch to drive the rotor of the turbine. It is not safe to engage such a mechanical clutch unless the turbine rotor is either at rest or turning at some very low speed, perhaps on the order of 1 r.p.m. or less.

It has previously been suggested that the low-speed sensor comprise a pair of spaced nozzles discharging hydraulic fluid against or through a disk member rotating with the turbine shaft, a suitable hydraulic relay device being associated with the disk-nozzle system so that a pressure signal generated by the low-speed sensor actuates the hydraulic relay when the desired low-speed condition is reached. One such low-speed sensing system is disclosed in the U.S. Patent to Le Gates et al.—2,982,902. Such speed sensing systems require an accurate, positively-operating hydraulic relay for converting the pressure signal from the speed sensor device into an output signal which can be used to actuate suitable indicators or automatic servo devices.

Accordingly, the primary object of the present invention is to provide an improved actuating relay for use in connection with hydraulic low-speed sensor devices of the type described.

A further object is to provide a hydraulic speed sensing relay which requires no mechanical springs but instead employs all hydraulically-balanced elements.

A further object is to provide a speed sensing hydraulic relay in which the critical operating parameters are all designed into the hydraulic system so there is nothing to get out of adjustment, the operating characteristics of the relay depending entirely on the effective areas of pistons and orifices, which can be very carefully constructed to provide precisely the operating characteristics desired, without resort to mechanical springs subject to failure, maladjustment, or change of characteristics over the life of the equipment.

A still further object is to provide a hydraulic speed sensing relay which is relatively insensitive to change in hydraulic fluid supply pressure, and capable of sensing speeds as low as perhaps ¼ r.p.m.

Other objects and advantages will become apparent from the following description taken in connection with the accompanying drawing, in which FIG. 1 represents diagrammatically a steam turbine with its associated turning gear and low-speed sensor device, with a hydraulic relay in accordance with the invention shown in section, and FIG. 2 is a sectional detail view taken on the plane 2—2 in FIG. 1.

Generally stated, the invention is practiced by providing an actuating piston and a frequency relay cylinder having a drain port adapted to be blocked by a timing relay piston during normal operation, the timing piston acting to uncover the drain port and permit movement of the actuating piston when the hydraulic signal received from the low-speed sensor reaches a predetermined minimum condition, for instance representing the safe speed at which the turbine turning gear may be engaged.

Referring now more particularly to the drawing, the invention is shown as applied to a steam turbine **1**, connected to drive a load device **2**, and having a turning gear shown generally at **3** for causing the turbine rotor to turn slowly during the cooling process after shutdown. The turning gear is illustrated diagrammatically as representing a hydraulic motor **4** supplied with operating fluid by valve **5** and a jaw clutch **6** adapted to be engaged by an operating lever **7** when the turbine rotor **8** reaches a preselected speed at which the mechanical clutch **6** may be safely engaged.

Low-Speed Sensor

The low-speed sensor device is illustrated diagrammatically as a toothed disk **9** carried on the turbine rotor **8** and having a rim portion defining alternate lands or teeth **10** separated by recesses, grooves, or openings **11**. Adjacent the disk **9** is a nozzle assembly comprising a housing **12** defining an inlet chamber **13** supplying actuating fluid through parallel orifices **13***a*, **13***b* to a pair of nozzle chambers **14***a*, **14***b*, which in turn supply fluid to a pair of circumferentially spaced nozzles **15***a*, **15***b*.

Nozzles **15***a*, **15***b* are disposed to form close clearances with the periphery of the teeth or lands **10**. This clearance may for instance be of the order of .01 inch. It will thus be apparent that each time a tooth **10** passes one of the nozzles, the discharge of fluid therefrom is substantially restricted so that a pressure is built up in the respective nozzle chamber **14***a* or **14***b*. Conversely, when a recess **11** is disposed opposite the nozzle, the discharge of fluid therefrom is substantially unrestricted and the pressure in the nozzle chamber rapidily drops. In this connection, it is to be noted that the diameter of the supply orifices **13***a*, **13***b* is roughly half the diameter of the discharge nozzles **15***a*, **15***b*.

It should also be noted that the circumferential extent of the teeth **10** is such that a single tooth will just extend from nozzle **15***a* to nozzle **15***b*, with both nozzles unlocked, as shown in the drawing. Likewise, the circumferential extent of each recess **11** is such that it will "straddle" both nozzles, with both unblocked. With this configuration of the toothed wheel **9** relative to the circumferential spacing of nozzles **15***a*, **15***b*, the result is that one or both of the nozzles will at all times be opposite a recess **11**. This arrangement makes it impossible for the rotor **9** to stop in any position where both nozzles are blocked.

The hydraulic signal pressure chambers **14***a*, **14***b* are connected respectively to two identical hydraulic actuating relay cylinders, as shown in FIG. 2, both being connected to a single actuating cylinder.

Hydraulic Actuating Relay

Turning now to the details of the hydraulic actuating relay which comprises the present invention, relay **17** is illustrated as being supplied at all times during normal operation with hydraulic operating fluid by a motor-driven pump **18**. Discharge pressure of the pump **18** may for instance be on the order of 25 pounds per square inch. Pump **18** may be the lubricating pump which also supplies oil to the bearings of turbine **1**, as is necessary before the operation of the turbine may be initiated. Pump **18** also supplies operating fluid to the nozzle supply chamber **13** by way of conduit **19**.

The speed sensing relay 17 comprises a housing 20 defining an actuating piston cylinder 21 and a pair of timing piston relay cylinders, one of which is identified 22 in FIG. 1. The cylinder 21 contains an actuating piston 23 secured to a large diameter piston rod 24, slidably disposed in an end cap 25 secured by bolts 26 to the housing 20. The right-hand side of piston 23 cooperates with cylinder 21 and end cap 25 to define an inlet pressure chamber 27 supplied with operating fluid from pump 18 by way of conduit 19*b*. The left-hand side of piston 23 forms an outlet chamber 28 communicating with a drain port 29 in housing 20. Because of the large diameter of piston rod 24, the effective area of piston 23 exposed to the inlet pressure in chamber 27 is roughly half the effective area of the left-hand side of piston 23 exposed to the outlet pressure in chamber 28. Communication from the inlet chamber 27 to the outlet chamber 28 is effected by way of a restricted orifice in piston 23, identified 30. This orifice may, for instance, be on the order of 70% of the diameter of the drain passage 29.

The actuating piston rod 24 is arranged to engage the input member of a suitable relay or indicating device, illustrated diagrammatically here as being the actuating lever 31*a* of a switch 31. As will be obvious from the drawing, the switch 31 has contacts 32 which are closed when lever 31*a* is permitted to move counterclockwise under the bias of the light spring 31*b*. Closing of contacts 32 causes the signal light 33 to be energized, or some suitable servo device actuated.

It will now be understood that when operating liquid is supplied through conduit 19*b* to the actuating cylinder 21, the right-hand chamber 27 is filled and liquid passes at a restricted rate through orifice 30 to the outlet chamber 28, until the pressure in chambers 27, 28 becomes equalized at the full supply pressure of pump 18. Because the area of piston 23 exposed to the outlet pressure in 28 is twice that of the piston area exposed to the inlet pressure in 27, the actuating piston 23 will move to the right to engage switch lever 31*a* and open contacts 32. Thus, the switch 32 is open whenever the drain port 29 is blocked so that the pressure in chamber 28 is permitted to build up to equal that in chamber 27. Conversely, when the generously proportioned drain port 29 is unblocked, the pressure in chamber 28 will rapidly fall so that the higher pressure in chamber 27 will cause the actuating piston 23 to move to the left so that switch 31 is actuated to close the contacts 32.

The function of the timing relay cylinder 22 is to provide means for blocking the drain port 29 whenever the speed of toothed disk 9 is above a preselected value, and to unblock the drain port 29 when the speed of disk 9 falls below this preselected minimum value. To this end, the timing cylinder 22 contains a relay piston 35 having a skirt portion of substantial axial length so as to block drain port 29 when in uppermost position against an abutment 20*a* defined by the housing 20, as shown in solid lines in the drawing, and to unblock port 29 when the piston is in its lowermost position at the bottom of the cylinder 22, shown in dotted lines in the drawing.

It will be observed that piston 35 cooperates with the cylinder 22 to define a signal pressure inlet chamber 36 below piston 35, and a drain chamber 37 above the piston in free communication with a drain conduit 38. A "time constant orifice" 39 is formed in piston 35 so as to communicate the inlet signal pressure fluid in chamber 36 to the drain chamber 37 at a predetermined slow rate. The speed signal pressure from chamber 14*b* of the low-speed sensor 12 is communicated to the signal inlet chamber 36 of relay 17 by way of conduit 14*c*. Likewise, the speed signal pressure from chamber 14*a* of the speed sensor 12 is communicated to a duplicate signal chamber not shown in FIG. 1 because it is directly behind cylinder 22, as shown at 22*a* in FIG. 2. Reverse flow into conduit 14*c* from the signal pressure chamber 36 is prevented by a ball check valve 40.

The timing relay piston 35 is at all times biased downwardly with a constant force, in the following manner. Piston 35 is connected to a piston rod 41, which projects slidably through the abutment bushing 20*a* with its free end portion 41*a* disposed in a chamber 42, to which is communicated the full discharge pressure of pump 18 by way of conduit 19*a*. Thus discharge pressure of pump 18 acting on the free end 41*a* of piston rod 41 produces a constant downward biasing force tending always to move piston 35 to the bottom of its stroke, so as to unblock drain port 29 whenever the signal pressure in chamber 36 drops for a sufficient period of time.

It will be apparent that there are no mechanical spring devices in the hydraulic relay 17, both the actuating piston 23 and the timing relay piston 35 being positioned entirely by hydraulic pressure relationships. (It is to be noted that the very light mechanical spring 31*b* of the switch 31 produces a force which is wholly insignificant, by comparison with the hydraulic forces operating on piston 23.) This elimination of mechanical spring devices removes a most prolific source of inaccuracy, due to the difficulty of obtaining springs with precisely the force gradient desired and the tendency of mechanical springs to change their characteristics during the life of the equipment. Mechanical spring devices are also very difficult to calibrate and adjust accurately. With the arrangement shown, the operating characteristics of this relay are obtained entirely by appropriate dimensioning of the pistons 23, 35, and of the orifice 30 relative to the drain port 29, and particularly of the time constant orifice 39.

By way of example, one hydraulic relay incorporating the invention had the following critical dimensions:

Element:	Diameter (in).
Actuating cylinder 21	2.625
Piston rod 24	1.855
Bypass orifice 30	.052
Drain port 29	.125
Timing relay cylinder 22	1.250
Relay piston rod 41	.375
Time constant orifice 39	.042

It may also be noted that the low speed sensor has supply orifices 13*a*, 13*b* of .062 inch diameter, and nozzles 15*a*, 15*b* of .125 inch diameter.

The above describes completely one of the timing relay cylinders and the actuating cylinder components. As shown in FIG. 2, the duplicate cylinder 22*a* has all elements equivalent to those described in connection with cylinder 22. As clearly shown in FIG. 2, both timing relay cylinders 22, 22*a* are connected to the single actuating cylinder 21 by the drain ports 29, 29*a*.

Operation

Generally stated, the operation of relay 17 is that the pressure supplied from pump 18 causes the actuating piston 23 to move to the left and close the switch 31 whenever either drain port 29 or 29*a* is uncovered by the respective relay piston 35 or 35*b* moving to the bottom of its cylinder; but piston 23 moves to the right to open switch 31 whenever both timing relay pistons 35, 35*b* rise so as to cover the drain ports 29, 29*a*.

The detailed operation of the timing relay piston 35 is as follows.

As noted above in connection wtih the low-speed sensor 12, the pressure in the signal chambers 14*a*, 14*b* rapidly builds up whenever a tooth 10 blocks the respective nozzles 15*a*, 15*b*, and rapidly drops whenever a recess 11 comes opposite a nozzle. Thus, rotation of the toothed disk 9 produces fluctuating pressures in the signal chambers 14*a*, 14*b*. At normal operating speeds of the disk 9, which may be on the order of 1800 or 3600 r.p.m., or lower in "mechanical drive" turbines, the rapid succession with which the teeth 10 pass the nozzles 15*a*, 15*b* provides an effective resistance to the discharge of operating fluid from the nozzles, so that only very small pres-

sure fluctuations are produced in the chambers 14*a*, 14*b*. The result is that the signal pressure therein is maintained at a significant value. For instance, at normal operating speed, the pressure in chamber 13 may be 25 pounds per square inch, while that in the signal chambers 14*a*, 14*b* may vary from 4 to 6 pounds per square inch. This signal pressure communicated through conduit 14*c* causes the ball check valve 40 to open and apply the signal pressure to the inlet chamber 36, causing the relay piston 35 to rise against abutment 20*a*, thus blocking drain port 29 and causing actuating piston 23 to move to the right to open switch 31. Thus, during normal operation there is a substantially continuous flow of signal pressure fluid past check valve 40 into chamber 36, and through the "time constant orifice" 39 to drain chamber 37 and out conduit 38.

Assume now that the steam turbine valve gear 1*a* discontinues the supply of motive fluid to turbine 1 and the speed of rotor 8 begins to drop. The pressure fluctuations in the signal chambers 14*a*, 14*b* will decrease in frequency, and the amplitude of the pressure changes will increase as the speed of the toothed rotor 9 decreases. Each time the signal pressure increases, fluid is supplied through conduit 14*c* to the inlet chamber 36 of the relay piston 35, causing it to move upwardly. Each time the signal pressure drops, the signal pressure in chamber 36 likewise drops, ball check valve 40 closes, and the piston 35 starts to move downwardly, as fluid escapes through the timing orifice 39, under the constant biasing force provided by full inlet pressure acting on the upper end 41*a* of piston rod 41. Because of the substantial axial extent of the skirt of piston 35, it must move downwardly almost to the bottom of its stroke before uncovering the drain port 29. If before it descends far enough to open drain port 29 there is a new supply of signal pressure fluid from the nozzle chamber 14*b*, then piston 35 again moves up so as to block the drain port 29.

It will now be apparent that as the speed of the toothed disk 9 decreases, eventually a condition will be reached where the length of the low-pressure condition caused by a recess 11 passing the nozzle 15*b* will just equal the length of time required for piston 35 to descend and open the drain port 29. When this happens, fluid is discharged rapidly from the actuating chamber 28 through the drain conduit 29, and piston 23 moves to the left under the influence of full inlet pressure in chamber 27.

Thus by suitable proportioning of the pistons and orifices, the timing relay piston 35 can be caused to actuate piston 23 when a predetermined low-speed condition is detected by the sensor 12. With a relay having the dimensions listed above, it has been found that the critical speed required to actuate piston 23 may be as low as ¼ r.p.m., or even less with appropriate design refinements.

The reason for having two identical timing relay pistons 35, 35*b* is so the toothed disk 9 will be in position to uncover at least one of the nozzles 15*a*, 15*b*, regardless of the position in which the disk stops. Thus it is impossible for the signal light 33 to give a false indication, since actuation of piston 23 means that one or both of the timing pistons 35, 35*b* have reached the critical condition corresponding to the preselected low speed at which it is desired to have the signal 33 energized. Lighting of the signal lamp 33 means that it is safe to engage the jaw clutch 6 of the turning gear 3 and to then open valve 5 and supply hydraulic actuating liquid to motor 4. The turning gear is of course disengaged or motor 4 shut off when the turbine has cooled sufficiently.

In starting a turbine with a hydraulic speed sensing system in accordance with the invention, the motor-driven pump 18 is first energized by closing switch 18*a* so that operating liquid is supplied to the relay 17, to the speed sensor 12, and lubricating oil to the bearings of turbine 1. During shutdown, gravity will have caused one or both of the timing relay pistons 35, 35*b* to descend to the bottom of their stroke so as to uncover the drain port 29 or 29*a*. Thus, the supply of operating liquid through conduit 19*b* initially causes the actuating piston 23 to move to the left and close the switch 31, so that signal lamp 33 is lighted to indicate that the speed is below the preselected minimum value.

If now turbine valve gear 1*a* is opened to admit motive fluid to turbine 1, the toothed disk 9 begins to turn, generating the above-described pressure fluctuations in the signal chambers 14*a*, 14*b*. This fluctuating pressure causes the relay pistons 35, 35*b* of the relay 17 to "bob up and down," alternately blocking and unblocking the drain ports 29, 29*a*. Because of the configuration of the teeth 10 and recesses 11 of the toothed disk 9, one or the other of the nozzles 15*a*, 15*b* will be unblocked at all times, with the result that at least one of the relay pistons 35, 35*b* will be in its lowermost position, unblocking the drain port 29 or 29*a* and causing the actuating piston 23 to close switch 31, so that the signal lamp 33 remains lighted. Eventually, the rapidity with which the signal pressure fluctuations occur gives insufficient time for the relay pistons 35, 35*b* to descend, and both are held upwardly in a position to block the respective drain ports 29, 29*a*. When this occurs, the actuating piston 23 is caused to move to the right so as to open the switch 32 and signal light 33 goes out. As noted above, the critical speed at which this condition occurs may be only on the order of ¼ r.p.m. Thus the signal light 33 is extinguished almost immediately when the turbine starts.

Instead of merely actuating signal light 33 to tell the operator it is safe to engage the turning gear clutch, the relay 17 may be arranged to energize appropriate servo-mechanism for automatically actuating the turning gear when switch 32 closes. This would be the usual mode of operation.

Thus it will be apparent that the invention provides an improved hydraulic timing relay which effectively gives very reliable actuation of an indicating or servo device in response to a fluctuating signal pressure provided by the low-speed sensor. This is accomplished without the use of mechanical springs, using only differential area pistons and metering orifices which may be very accurately designed to provide the desired operating characteristics, which will remain constant throughout the life of the equipment and are incapable of getting out of adjustment. It has been found that a hydraulic relay as described herein has the additional advantage that it is relatively insensitive to variations in the hydraulic supply pressure furnished by the pump 18. Specifically, the supply pressure may drop to perhaps half of its normal rated value without significantly affecting the operation of the relay. By eliminating mechanical springs, the chance of failure is reduced; and the reliability of the mechanism is greatly improved by eliminating errors due to changes in the force gradient of mechanical springs which may occur over the life of the relay.

While only one preferred embodiment of the invention has been described specifically herein, it will be apparent that numerous modifications and substitutions, for instance of electrical components for certain of the mechanical-hydraulic components disclosed herein, may be made, and it is of course desired to cover by the appended claims all such modifications as fall within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A hydraulic relay for use in a low speed sensing system including a rotor member with circumferential portions adapted to alternately cover and uncover a pair of circumferentially spaced nozzles to provide two signal pressures fluctuating as a function of rotor speed, said relay including:

housing means forming a first actuating cylinder and a second timing relay cylinder,

an actuating piston disposed in the first cylinder and

forming therewith a first inlet pressure chamber at one side of the piston and a second outlet pressure chamber at the opposite side of the piston,

means for supplying actuating fluid at substantially constant inlet pressure to the first chamber,

restricted bypass passage means communicating fluid from the first chamber to the second chamber,

walls defining a drain passage communicating with the second chamber and opening into an intermediate portion of the second cylinder,

a timing relay piston disposed in the second cylinder and forming therewith a third signal pressure inlet chamber at one side of the piston and a fourth drain chamber at the opposite side of the piston,

conduit means for supplying one of the fluctuating speed signal pressures to the third chamber,

restricted bypass passage means communicating fluid from the third chamber to the fourth chamber,

and means biasing the timing relay piston toward the third chamber to effect communication between said drain passage and the fourth drain chamber, whereby the second chamber is drained to effect movement of the actuating piston when the length of the low-pressure portion of the fluctuating pressure signal equals the length of time required for the timing relay piston to uncover the drain passage.

2. A hydraulic relay in accordance with claim 1 in which the biasing means for the timing relay piston includes a piston rod with one end portion engaging the relay piston and having an opposite end portion projecting into a chamber supplied with fluid at the constant inlet pressure, whereby the relay piston is biased with a substantially constant force toward the third chamber.

3. A hydraulic relay in accordance with claim 1 and including check valve means for preventing reverse flow of fluid from said third signal pressure inlet chamber backwardly into the speed signal pressure supply conduit.

4. A hydraulic relay for use in a low speed sensing system including a rotor member with circumferential portions adapted to alternately cover and uncover a pair of circumferentially spaced nozzles to provide two signal pressures fluctuating as a function of rotor speed, said relay comprising:

housing means forming a first actuating pressure chamber and a second timing relay cylinder,

means for supplying actuating fluid at substantially constant inlet pressure to said first chamber,

a pressure responsive member disposed to be moved to a first position by fluid pressure in the first chamber,

first means biasing said pressure responsive member away from said first position to a second position,

drain passage means communicating with the first chamber and opening into an intermediate portion of said second cylinder,

a timing relay piston disposed in the second cylinder and forming therewith a signal pressure inlet chamber at one side of the piston and a drain chamber at the opposite side of the piston,

means for supplying one of the fluctuating speed signal pressures to said signal pressure inlet chamber,

restricted bypass passage means communicating fluid from the signal pressure inlet chamber to said drain chamber,

and second means biasing the timing relay piston toward the signal pressure inlet chamber to uncover said drain passage means, whereby fluid is drained from the first chamber to the drain chamber to effect movement of the pressure responsive actuating member to said second position when the fluctuating signal pressure is ineffective to hold the timing relay piston in position to cover said drain passage means.

5. In a hydraulic relay for use in a low speed sensing system including a rotor member with portions adapted to alternately cover and uncover a pair of circumferentially spaced nozzles to provide two signal pressures fluctuating out of phase with each other as a function of rotor speed, the combination of:

housing means forming a first actuating pressure chamber and a second timing relay cylinder,

means for supplying actuating fluid at substantially constant pressure to said first chamber,

pressure responsive means disposed to be moved by fluid pressure in the first chamber to a first position,

means biasing said pressure responsive means away from said first position to a second position,

drain passage means communicating with the first chamber and opening into an intermediate portion of said second cylinder,

timing relay piston means disposed in the second cylinder and forming therewith a signal pressure inlet chamber at one side of the piston and a drain chamber at the opposite side of the piston,

means supplying a first one of the fluctuating speed signal pressures to said signal pressure inlet chamber,

and means biasing the timing relay piston toward the signal pressure inlet chamber to uncover said drain passage means whereby fluid is drained from the first chamber to said drain chamber to effect movement of the pressure responsive actuating member to said second position when fluctuation of the speed signal pressure in the signal pressure inlet chamber effects movement of the timing relay piston to uncover the drain passage means.

6. A hydraulic relay in accordance with claim 5 and including check valve means for preventing reverse flow of signal pressure fluid from the signal pressure inlet chamber back to the speed signal supply means, and

restricted passage means for communicating signal fluid from the signal pressure inlet chamber to the drain chamber at the opposite side of the timing relay piston.

7. A hydraulic relay in accordance with claim 5 and including a third timing relay cylinder and piston connected to be actuated by the second of the fluctuating signal pressures out of phase with the first timing relay piston means, whereby the pressure responsive actuating member is positively caused to move to its second position whenever the speed signal pressure fluctuations cease entirely, regardless of the position in which the rotor member stops.

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