FIG. 1

FIG. 2

FIG. 3
METHOD AND SYSTEM FOR ADJUSTING THE CLOSURE OF FLOWRATE ADJUSTING DEVICES FOR HYDRAULIC TURBINES, PUMP TURBINES, PUMPS, AND THE LIKE

FIG. 4

FIG. 5

HEAD RESPONSIVE DEVICE
METHOD AND SYSTEM FOR ADJUSTING THE CLOSURE OF FLOWRATE ADJUSTING DEVICES FOR HYDRAULIC TURBINES, PUMP TURBINES, PUMPS, AND THE LIKE

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Filed May 5, 1964, Ser. No. 364,942

10 Claims. (Cl. 137—12)

This invention relates to automatic control of liquid flowrates in hydraulic turbines, pump turbines, and the like operated under conditions of a fluctuating head. More particularly, the invention relates to servomotor systems and devices for automatically actuating liquid flow valving devices for the purpose of controlling and suppressing fluctuations in both the rotational speed and liquid pressure in cases when flowrate adjusting devices (such as, for example, guide vanes and sluice valves) used for the aforesaid control are rapidly or abruptly closed. Still more specifically, the invention concerns a new liquid-level-responsive servomotor system which operates automatically in response to head fluctuations arising from variation of the liquid level in the liquid head tank.

In general, in conventional systems of the above stated character (for example, according to Japanese Utility Model Publication No. 7,723/1955), the above mentioned operational speed of the servomotor has been adjusted in accordance with only fluctuations in the head arising from variation in the liquid tank level. This practice gives rise to difficulties and disadvantages as described more fully hereinafter.

It is the primary object of the present invention to overcome these difficulties and disadvantages. Other objects and advantages of invention, together with its nature, principle, and details, will become apparent by reference to the following description taken in conjunction with the accompanying drawings in which like parts are designated by like reference characters, and in which:

FIG. 1 is a graphical representation showing curves indicating the relationships between degree of opening of guide vanes and closing time in the conventional case of a hydraulic turbine or a pump turbine;
FIGS. 2 and 3 are graphical representations showing curves indicating the relationships between degree of opening of guide vanes and closing time in the conventional case of a hydraulic turbine or a pump turbine with the use of the system of the invention;
FIG. 4 is a simplified schematic diagram indicating the specific construction and arrangement of a preferred embodiment of the system according to the invention;
FIGS. 5 and 6 are simplified schematic diagrams indicating other preferred embodiments of the invention; and
FIGS. 7 and 8 are enlarged, fragmentary views showing a part of the system shown in FIG. 6.

As conducive to a better understanding and appreciation of the nature and utility of the present invention, the following brief consideration of conventional systems of the instant type is first presented.

Referring to FIG. 1, the curves shown indicate the relationships between the degree of opening of the guide vane and the closing time for different heads in the case of a hydraulic turbine provided with flowrate control means in which the servomotor movement speed is adjusted in accordance with only fluctuations in the head arising from variation in the liquid level in a liquid head tank. It will be observed that, although with varying head the corresponding closure time differs with the head in the order of H₂, H₃, and H₄ beginning with the highest head H₄, the characteristic over the entire closure stroke of the servomotor is readily determined. That is, the closure characteristic of the servomotor in the case of a degree of opening P does not differ from that in the case of a degree of opening P₂.

For this reason, in the case of a water turbine for low head, for example, a water turbine of the characteristic indicated by the curve H₂, the closure time from P₂ becomes excessively short. Consequently, there is the possibility of the water pressure in the water pressure tubes exceeding the allowable value.

Furthermore, in the case where the draft tube is extremely long because of some reason such as the terrain, if the guide vane is rapidly closed through its total range of movement, the pressure at the lower part of the turbine runner will be caused by the inertia of the liquid within the draft tube to drop abnormally, whereby the resulting excessive negative pressure and the accompanying pressure wave will tend to cause the rotating part of the runner to float upwardly. As a result, there is a possibility of damage to the turbine and related parts.

The present invention, which has as its prime object the elimination of the above described difficulties, has the following specific objects. Referring to FIG. 2, the closure characteristics, in the case of guide vane opening P, are as indicated by H₂, H₃, and H₄ for respective fluctuating heads and, in the case of guide vane opening P₂, are as indicated by H₂a, H₃a, and H₄a. The present invention contemplates automatically selecting the optimum closure characteristic of the guide vane in accordance with the operational opening of the guide vane and with the state of the head at this operational time, and thereby to prevent rise in speed of the turbine and generator and suppress water pressure rise.

It is another specific object to render the closure characteristics shown in FIG. 2 into the form indicated in FIG. 3, wherein the closure characteristics have distinct sharp bonds. By utilizing such closure characteristics, it is possible to suppress fluctuations in the speed of the prime mover and in the liquid pressure and, at the same time, to obtain a system free of trouble even with synchronous parallel operation.

That is, with closure characteristics as indicated by the curves of FIG. 2, the distinguishing of the limiting point (bend point) at the beginning of synchronous operation is difficult, and for this reason the distinguishing of the synchronous position is also difficult, whereby the start of operation becomes unstable. However, by utilization of closure characteristics as indicated in FIG. 3, it becomes possible to set and distinguish readily the limiting point of the closure speed, and it is possible to obtain reliability and positiveness of the closure operation.

It is a further object of the invention to provide an automatic system wherein a distribution valve governing the actuation instruction for the servomotor is used to obtain nonlinear closure movement characteristic of the servomotor. By this arrangement, it is possible to install the distribution valve control means together with the distribution valve. Accordingly, maintenance and checking are greatly facilitated. Moreover, since special piping for the valve device for producing nonlinear movement is thereby unnecessary, the construction can be made compact. In order to indicate still more fully the nature of the
invention, the invention is described hereinbelow with respect to preferred embodiments thereof.

Referring first to FIG. 4, the guide vane regulating ring 5 of a turbine (not shown) is coupled to and actuated by the piston rod of a servomotor 3 supplied with hydraulic actuating pressure through lines 6 and 7 and controlled principally by a distribution valve 2, whose pilot valve is actuated through a mechanism by a speed governor 1. A governor return device 4 is coupled to the said mechanism and is actuated by the axial movements of the piston rod of the servomotor. To the other end of the piston rod, there is secured a cam 8 which produces vertical movements of an actuating rod 9. These movements of the rod 9 are transmitted to a shaft 15 to cause a cam shaft 14 to rotate, thereby finally causing a three-dimensional cam 16, fixed to the cam shaft 14, to rotate.

A water level responsive device 11 of known type is provided which operates in response to variation in head due to change in water level to cause, through a lever 12 and a connecting rod 13, axial movements of the cam shaft 14, thereby finally causing the cam 16 to shift axially. In contact with the cam surface of the three-dimensional cam 16, there is provided a follower rod 17 which is actuated in vertical movement by the combined cam action and axial movement of the cam 16, the resulting vertical movement of the follower rod 17 being transmitted through a lever 18 pivoted at a pivot 19 to a regulating valve 20 provided in the line 7 from the distribution valve 2 to the side of the servomotor 3 opposite to that connected to the regulating ring 5.

At the time of closure actuation of the servomotor 3, when hydraulic pressure in the servomotor 3 is relieved through the line 7, regulating valve 20 operates to regulate the flowrate of the fluid being exhausted from the servomotor 3, thereby regulating the closure time of the servomotor 3. On the other hand, the line 6 functions as the fluid pressure supply path from the distribution valve 2 at this time of closure actuation of the servomotor 3. This closure operation of the servomotor 3 causes the three-dimensional cam 16 to rotate clockwise as viewed in FIG. 4, whereupon the follower rod 17 moves downward. Consequently, the regulating valve similarly described operates to restrict the fluid flowrate through the line 7.

When the fluctuating head increases, the water level responsive device 11 causes the cam 16 to move to the right as viewed in FIG. 4, thereby lifting the follower rod 17 and the regulating valve 20 and permitting the fluid flowrate through the line 7 to increase. When the head decreases, the reverse operation occurs, and the fluid flowrate through line 7 is restricted.

In the case when the guide vane is closed rapidly, the water level responsive device 11 actuates the cam 16 in axial movement by an amount corresponding to the fluctuating head, thereby holding the regulating valve 20 in a flowrate restricting position suitably corresponding to the head. However, the regulating valve 20 is actuated downwardly by the angular position of the cam 16 which is rotated by the cam 8 driven by the servomotor 3, thereby restricting the flowrate through the line 7 and lengthening the closure time of the servomotor. That is, the operation of the regulating valve 20 is determined by the combined effect of the head and the degree of opening of the guide vane, and the closure characteristics of the guide vane are set as indicated in FIG. 2 by this regulating valve 20.

A governor in which closure characteristics having readily distinguishable limiting points as indicated in FIG. 3 can be obtained is described hereinbelow with respect to a specific example in conjunction with FIG. 5.

Referring to FIG. 5, the speed of a prime mover is detected by a speed governor 101 which actuates, through a lever 102, the pilot valve of a distribution valve 103 adapted to supply driving instruction to a servomotor 104.

The distribution valve 103 is provided with a return device 105.

When a sudden change in the load causes the speed governor 101 to move the pilot valve of the distribution valve 103 downwardly as viewed in FIG. 5, a line a supplied constantly with liquid pressure is thereby communicated with a line c, and the piston rod of the servomotor 104 is thereby moved rightwardly as viewed in FIG. 5 for closing. Consequently, in accordance with this movement of the servomotor piston rod, a follower rod 107 is caused by a cam 106 mounted on the piston rod to descend. The follower rod 107 is connected at its upper end to one end of a horizontal lever 111. A head responsive device 112 is provided which rotates the effective head and in response thereto rotates a cam 109, which in turn causes vertical movement of a follower rod 110 connected at its upper end to the other end of the aforesaid horizontal lever 111. Thus, this combination of cam devices 106 and 109 causes respective vertical movements of the follower rods 107 and 110 whereby the horizontal lever 111 is caused to undergo movement due to two effects. That is, a contact member 112 fixed to the horizontal lever 111 is caused to move vertically in accordance with variation in the head and with the position of the piston rod of the servomotor 104, thereby, the degree of operating position.

The contact member 112 is adapted to actuate a pilot valve 115 disposed within a switch valve 113 and normally maintained in the position nearest the contact member 112 by a spring 114.

There is further provided a time regulating valve 117 for controlling the flowrate of the exhaust fluid in a pressure fluid exhaust line b, thereby setting the speed of the servomotor 104, at the time when the distribution valve 103 descends, and the servomotor 104 undergoes closure movement. The time regulating valve 117 is directly coupled to a piston 119 which is normally pressed and maintained in position by a spring 118 at the right-hand position (as viewed in FIG. 5) so that valve 117 will not restrict the flow in line b.

A line c in which hydraulic pressure is being constantly supplied is connected to the aforementioned switch valve 113. When the pilot valve 115 is actuated by the contact member 112 against the force of the spring 118, the fluid pressure is supplied through a line d to the piston 119, whereby the fluid pressure is supplied to the right-hand end of the valve 119, which thereby moves leftwardly against the force of the spring 118 to cause the regulating valve 117 to restrict the exhaust fluid flowrate in the line b.

If, at this time, the distribution valve 103 descends, and the servomotor 104 undergoes closure motion, the horizontal lever 111 will be caused by the cam 106 and follower rod 107 to descend with the cam position corresponding to the head as a pivot point, and the contact member 112 thereby will also descend to actuate the pilot valve 115. Consequently, the line d which has been communicating with a fluid exhaust port 116 will be shut off, and the line c will communicate with the line d, whereby the fluid pressure will cause the time regulating valve 117 to move leftwardly. At a result, a closure characteristic as indicated by the curves in FIG. 3 can be obtained. That is, by the use of the above described system, it is possible to set and distinguish readily the limit point corresponding to the time of no-load opening.

A system adapted to obtain the closure characteristic indicated in FIG. 2 without the use of the valve devices shown in FIGS. 4 and 5 is schematically shown in FIG. 6.

In this system, the pilot valve 207 of a distribution valve 208 is connected to and actuated by a connecting rod 206, which in turn is actuated through a horizontal lever 202 by a governor 201 constituting a source of operation.

The connecting rod 206 has upper and lower spring retaining flanges 204 fixed thereto and is supported indirectly on the end of the horizontal lever 202 opposite the governor end by springs 203 encompassing the rod 206 and disposed between the flanges 204 and the end.
of the lever 202. Therefore, when the governor 201 imparts an upward movement (as viewed in FIG. 6) to the end of the lever 202, the pilot valve 207 is moved downwardly. Consequently, a line a constantly supplied with hydraulic pressure communicates with a line c to cause a servomotor piston rod 210 of a servomotor 209 to move toward the right and close a water flow regulating device such as, for example, a guide vane assembly (not shown).

When the pilot valve 207 is moved in the opposite direction, that is, upwardly as viewed in FIG. 6, the line a communicates with a line b, and the servomotor piston rod 210 is moved toward the left to cause the flow regulating device to open.

A return cam 212 is provided on the servomotor piston rod 210 for operating through a follower roller 213a and a rod 213b to cause the movement of the piston rod 210 to return to the distribution valve 208 by way of lever 202 and the parts interposed therebetween.

The servomotor piston rod 210 is further provided with a cam 211 for detecting the movement of the piston rod 210. Movements of this piston rod 210 are transmitted by the cam 211 through a follower roller 214 and a rod 215, leftward and rightward movements of the piston rod 210 causing, respectively, downward and upward movements of the rod 215. A lever contacting member 216 is provided on the upper end of the rod 215. A servomotor contacting lever 220 is adapted to hold a limiting lever 220 in cooperation with a spring 217 encompassing the end portion of the rod 215.

The righthand end of the limiting lever 220 is provided with a cam roller 221 resting on a cam 222 driven by a water level responsive device 223 for detecting variations in the so-called effective head. Pressures corresponding to the water level in the head tank and that of the discharge water are introduced into the water level responsive device 223 through lines f and g, respectively.

Thus, the limiting lever 220 is actuated by movements from the servomotor 209 and from the water level responsive device 223. The limiting lever 220 is adapted to actuate the pilot valve 207 in the upward direction by contact against a flange 205 fixed to the connecting rod 206. Excessive upward movement of the lefthand end of the limiting lever 220 is restricted by a stop 219 supported on a support column 218. When the servomotor piston rod 210 is moved in the closure direction (rightward as viewed in FIG. 6), the limiting lever 220 is moved upwardly to push upwardly the flange 205 and, therefore, the pilot valve 207.

When the pilot valve 207 is caused by actuation from the governor 201 to move downwardly by a distance a as indicated in FIG. 7 so as to cause the servomotor 209 to be operated rapidly in the closure direction, the line a communicates with the line c, and, on the other hand, the line b communicates with an exhaust link d, whereupon the servomotor undergoes rapid closure movement.

However, when the servomotor attains a certain required degree of opening, the pilot valve 207 is moved upwardly by the upward movement of the limiting lever 220 resulting from the action of the cam 211 or from the combined setting value due to the positions of the cam 211 and the cam 222 actuated by the water level responsive device 223. A resultant displacement 41 is produced as indicated in FIG. 8, whereby the exhaust flowrate from the line b is greatly restricted. As a result, the speed of the servomotor is also restricted, and a nonlinear motion as indicated in FIG. 2 is produced. This operation is further described hereinbelow with reference again to FIG. 7.

When the pilot valve 207 descends and operates as indicated in FIG. 7, and the servomotor is caused to undergo rapid closure movement (to the right), the rod 215 ascends, in accordance with this rightward movement, with the cam 222 as a pivotal point. In this case, the limiting lever 220 contacting member 216 and the spring 217, is caused to rise together therewith by the rod 215. Then, when the servomotor attains a certain predetermined degree of closure, the limiting lever 220, acting through the flange 205, causes the pilot valve 207 to ascend and operate as indicated in FIG. 8, thereby limiting the closure movement of the servomotor.

This limiting lever 220 is so prejudged that it will be movable upwardly only through a lift distance 1-2 where determined by the stop 219 and cannot ascend further. That is, even if the servomotor rod 210 moves further, and the rod 219 rises, the lever 220 is arrested by the stop 219 and cannot rise further, and the only result is that the spring 217 is compressed.

Under the above condition, the actuation position of the limiting lever 220 with respect to the flange 205 is determined by the cam 222 actuated in response to variation in the effective head.

As described above, the present invention provides a method and system affording optimum selection of the closure characteristics of the flowrate adjusting devices (for example, guide vanes and sluice valves) of hydraulic turbines, pump turbines, pumps, and the like operating under fluctuating head conditions.

It should be understood, of course, that the foregoing disclosure relates to only preferred embodiments of the invention and that it is intended to cover all changes and modifications of the described embodiments which are chosen for the purposes of the disclosure, which do not constitute departures from the spirit and scope of the invention as set forth in the appended claims.

We claim:
1. A method for automatically adjusting the closure of the flowrate adjusting devices of hydraulic turbines, pump turbines, pumps, and the like operating under fluctuating head condition, which comprises automatically setting the closure characteristic of each of said flowrate adjusting devices in accordance with the fluctuation of the head and with the degree of opening of said flowrate adjusting device.
2. A system for automatically adjusting the closure action of the flowrate adjusting devices of hydraulic turbines, pump turbines, pumps, and the like operating under fluctuating head conditions, comprising automatic means to set the closure characteristic of each of said flowrate adjusting devices in accordance with the fluctuation of the head and with the degree of opening of said flowrate adjusting device.
3. The system for automatically adjusting the closure action of the flowrate adjusting devices of hydraulic turbines, pump turbines, pumps, and the like operating under fluctuating head condition according to claim 2, comprising: the flowrate adjusting device in each case; a servomotor to actuate the flowrate adjusting device; a pressure distribution valve actuated by a speed governor operating in response to the rotational speed of the machine whose flowrate is being controlled and adapted to switch the hydraulic fluid pressure for driving the servomotor; a water level responsive device for detecting head variations and operating in response thereto; and a regulating valve provided in a fluid exhaust line for exhausting pressure fluid from the servomotor when the servomotor operates in the direction causing closure of the flowrate adjusting device and actuated by the combined effect of the action of the water level responsive device and of the degree of opening of the flowrate adjusting device, the closure characteristic of the flowrate adjusting device being set by the operation of the regulating valve.
4. The method according to claim 1, wherein the closure characteristic of the flowrate adjusting device is set by causing a pressure distribution valve for switching hydraulic fluid pressure to be actuated by the combined effect of the action of a water level responsive device for detecting head variations and operating in response thereto and of the operation of the flowrate adjusting device.
5. The system according to claim 2, wherein said automatic means includes a pressure distribution valve for
switching hydraulic fluid pressure in a hydraulic system actuating the flowrate adjusting device and a water level responsive device for detecting head variations and operating in response thereto, the pressure distribution valve being actuated by the combined effect of the operations of the water level responsive device and the flowrate adjusting device to set the closure characteristic of the flowrate adjusting device.

6. The system according to claim 3, wherein, between the regulating valve and a combined setting device composed of the flowrate adjusting device and the water level responsive device, there is interposed an instruction device actuated by the combined setting device and promptly actuating the regulating valve.

7. A system for the automatic control of the closure action of the flowrate adjusting devices on hydraulic turbines, pump turbines, pumps and the like, operating under fluctuating head conditions, which comprises, in combination, a servomotor provided with a piston and a piston rod extending therefrom, connected to said adjusting device; a first and a second cam disposed on said rod; water level responsive means; a speed governor; a pressure distributor valve actuated by said governor and operating in response to the rotational speed of the device whose flowrate is to be controlled; actuating means for said distributor valve from said first cam; a tridimensional cam connected to said water level responsive means and to said second cam; pipe line means for the supply of hydraulic actuating pressure to said servomotor from said distributor valve; and control means for said supply, actuated by said tridimensional cam.

8. The system as defined in claim 7, wherein said piston rod extends from said piston at both sides thereof; said first and said second cams being disposed at opposite sides; the connection from said water level responsive means to said first cam being by way of a cam shaft and a further cam; said tridimensional cam also being disposed on said cam shaft.

9. The system as defined in claim 7, wherein said piston rod extends from said piston at both sides thereof; said first and second cams being disposed at opposite sides; said distributor valve being actuated by a switch valve, with pilot valve attached thereto, and connected by spring means, for the regulation of hydraulic actuating pressure; and supply and exhaust lines from said valves to said servomotor.

10. The system as defined in claim 7, wherein said piston rod extends from one side of said piston; said first and second cams being disposed adjacent to each other near the end of said rod; said governor being connected to a horizontal lever; said horizontal lever being connected to said first cam; said horizontal lever actuating said distributor valve by means of a connecting rod and spring and flange means disposed thereon; said connecting rod further being connected to a limiting lever actuated by said tridimensional cam on one side; its other side being connected to said cam by a rod and being limited by a stop.