March 10, 1953 J. DANIEL 2,630,814

STABILITY OF HYDRAULIC TURBINE REGULATORS

Filed Feb. 12, 1948 4 Sheets-Sheet 1

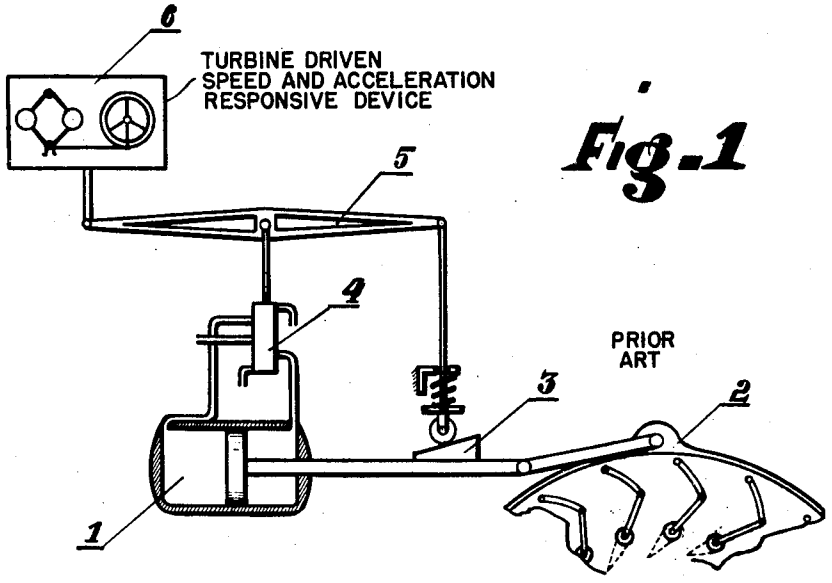


Fig. 1

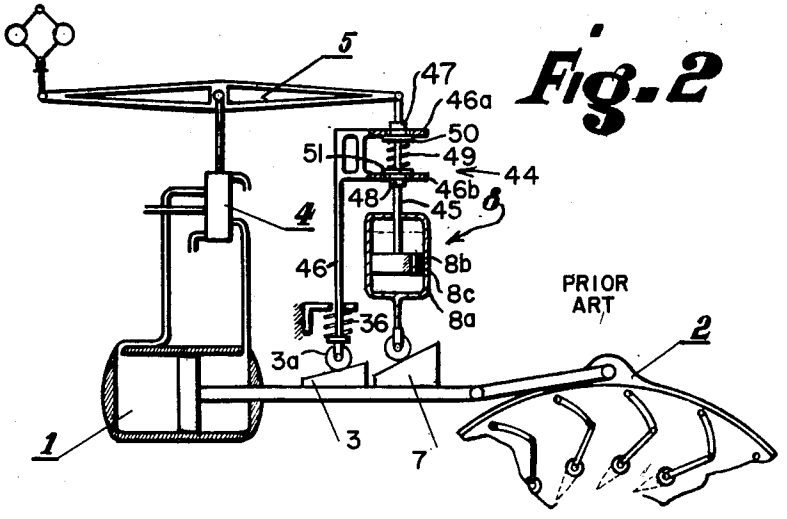


Fig. 2

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STABILITY OF HYDRAULIC TURBINE REGULATORS

Filed Feb. 12, 1948 4 Sheets-Sheet 2

Fig-3

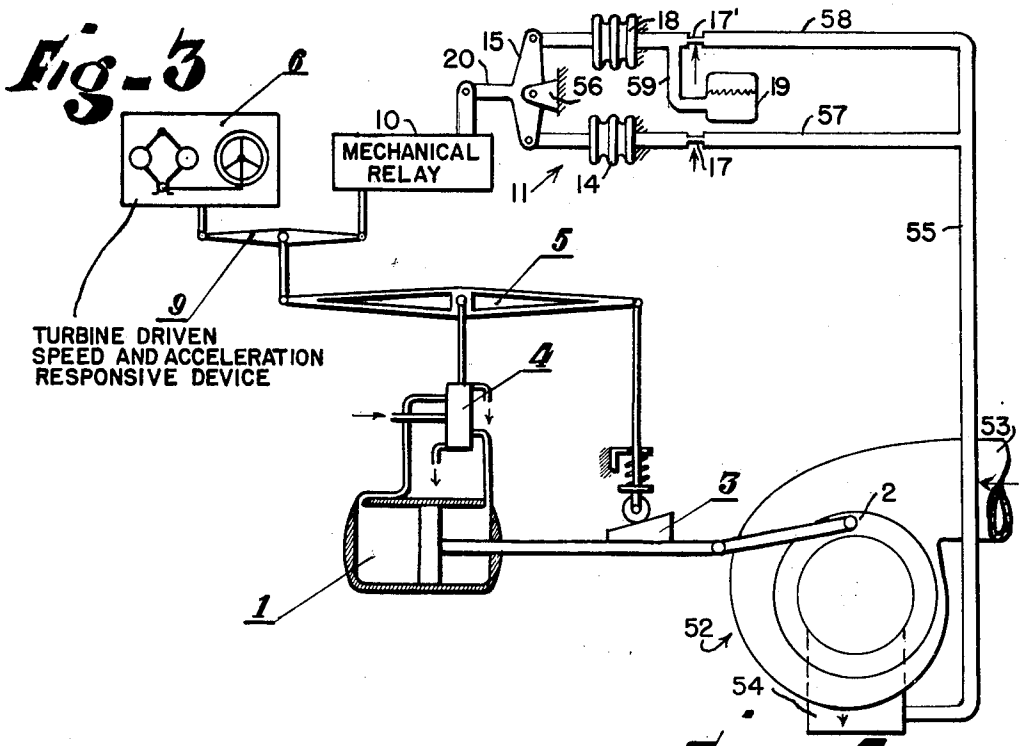
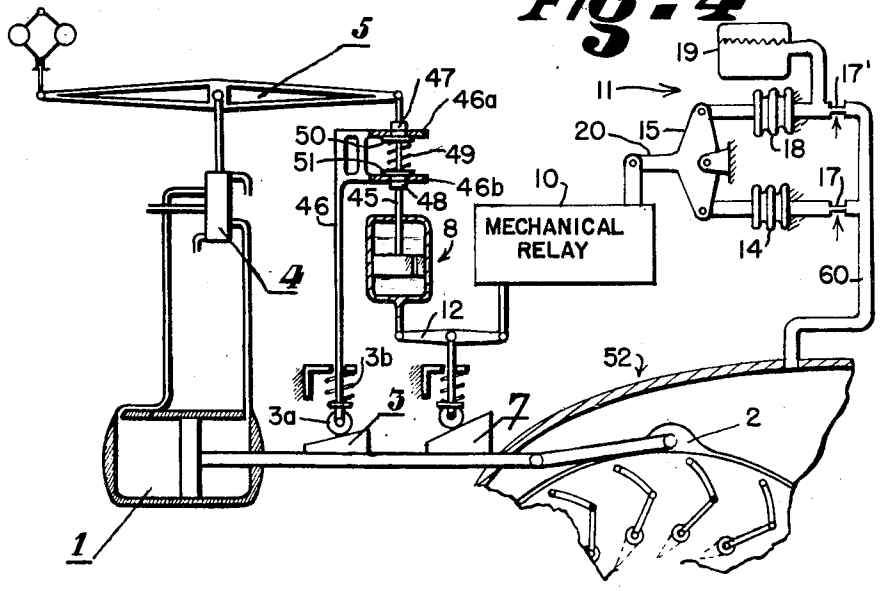


Fig-4



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March 10, 1953 J. DANIEL 2,630,814

STABILITY OF HYDRAULIC TURBINE REGULATORS

Filed Feb. 12, 1948 4 Sheets-Sheet 3

Fig - 5

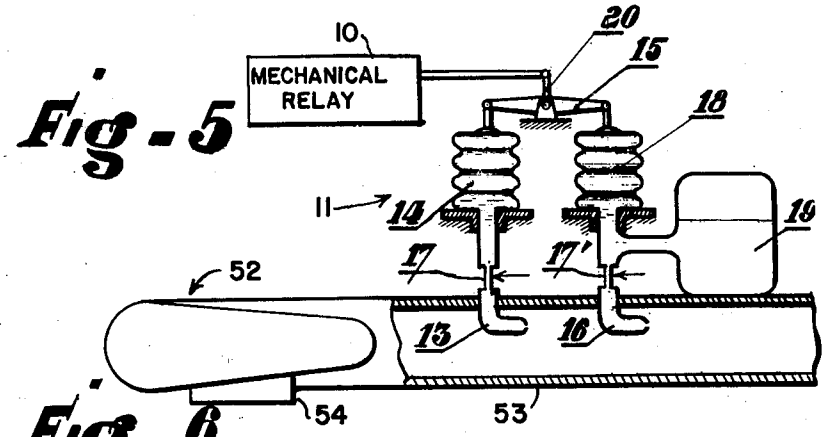


Fig - 6

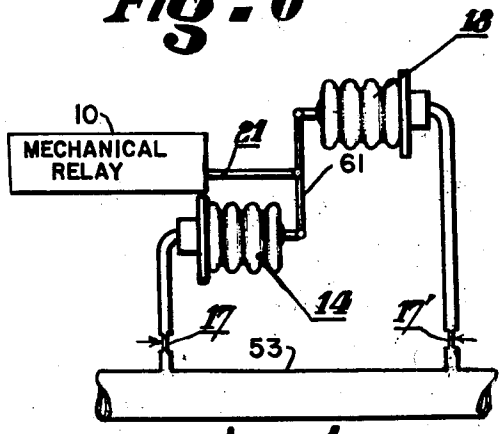


Fig - 7

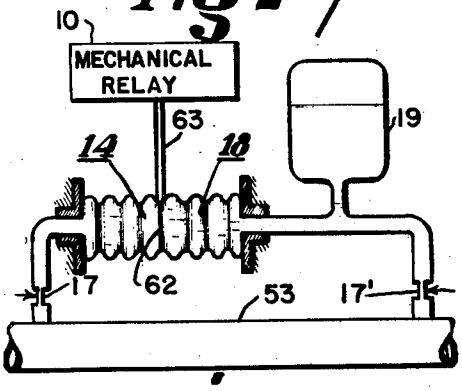


Fig - 8

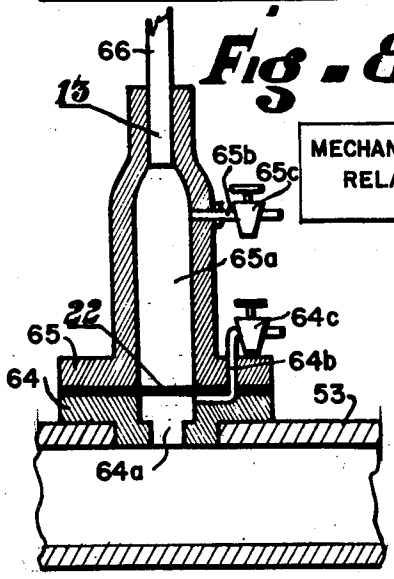
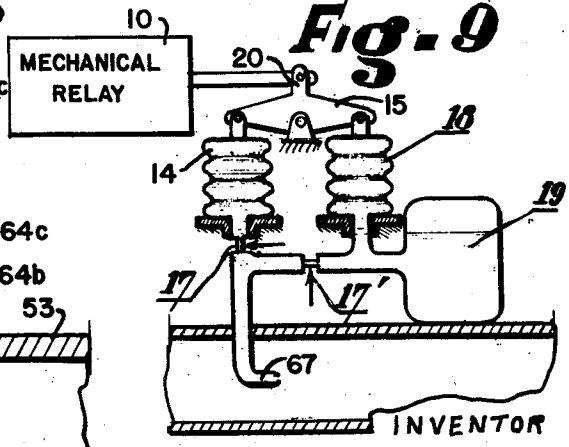


Fig - 9



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STABILITY OF HYDRAULIC TURBINE REGULATORS

Filed Feb. 12, 1948 4 Sheets-Sheet 4

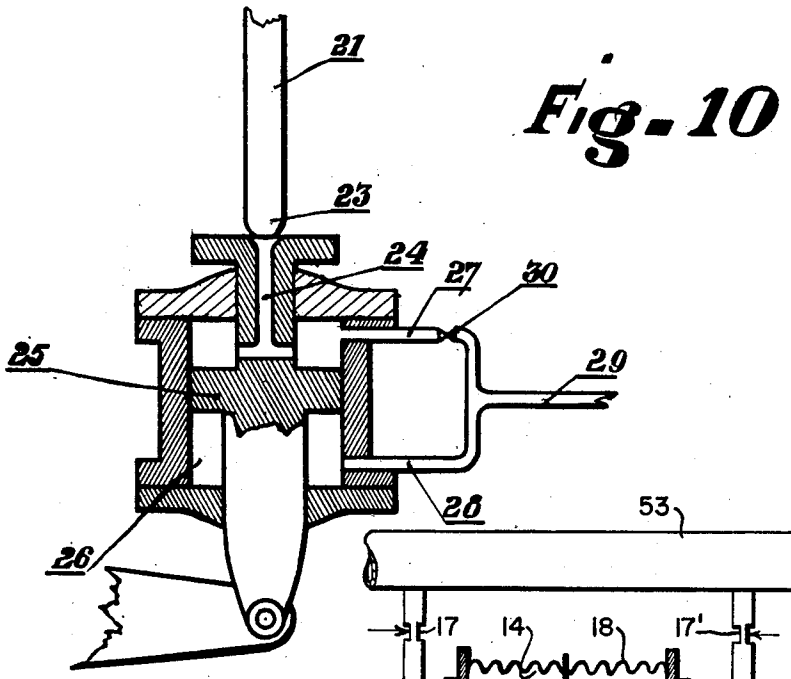


Fig. 10

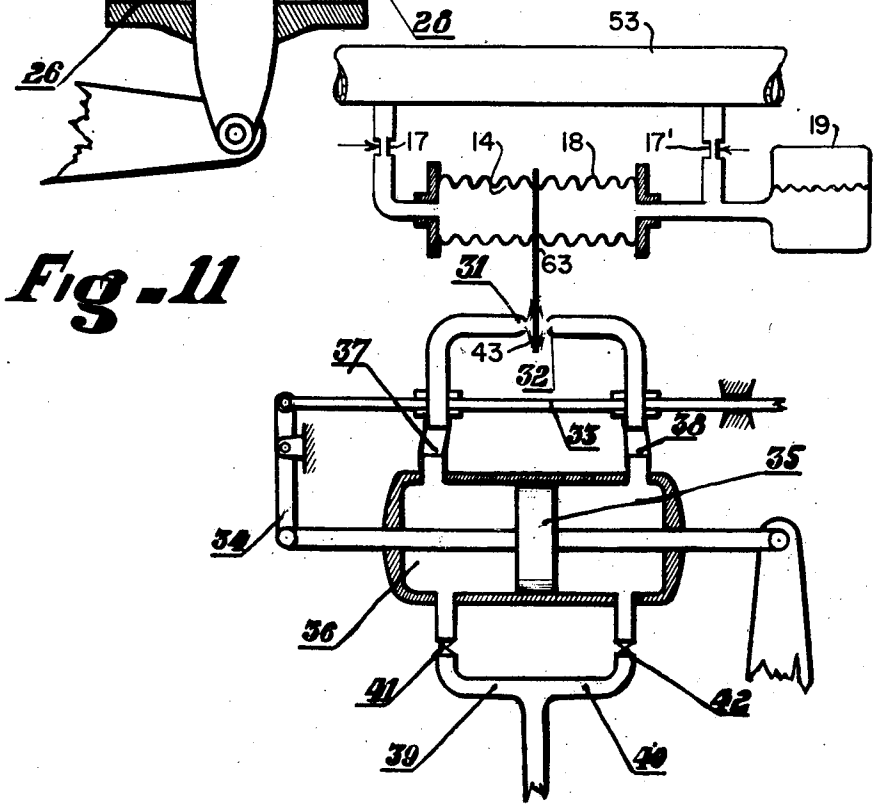


Fig. 11

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STABILITY OF HYDRAULIC TURBINE REGULATORS

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Application February 12, 1948, Serial No. 7,943
In France April 17, 1947

10 Claims. (Cl. 137—29)

1

The present invention relates to regulating systems for hydraulic turbines, and particularly to the modification of such systems so as to increase the turbine stability.

It is known that lack of stability in the operation of governor-controlled hydraulic turbines may be caused, among other things, by the inertia of the water in the supply conduit. Upon closure of the water controlling valve by the governor, a momentary pressure surge occurs upstream from the valve which tends to force an additional quantity of water through the valve and thereby at least partially cancels the effect of the closing movement of the valve. Consequently, the overspeeding of the turbine continues and thereby causes the governor to close the valve to a greater degree than is necessary. Once the pressure surge is over, the valve which was closed too far tends to open; its opening produces a decrease in pressure which decreases the power output and causes the governor to again open the valve to an excessive degree, and so on. Thus a "hunting" effect is produced, which causes the power output and/or speed of the unit to oscillate between limits which vary according to the average load on the unit. The oscillations in speed are practically reduced to zero when an alternator driven by the turbine is connected to an electrical network, since the flywheel effect of the latter generally suffices to prevent the alternators from getting out of step, even under maximum hunting conditions. However, considerable fluctuations in the power output may take place even under those conditions.

When the turbine drives an alternator supplying an independent load, such hunting oscillations are more objectionable and cause difficulty in the operation of the system. The hunting may even cause the parts of the system to get out of step.

In any case, hunting is highly objectionable when the alternator is not connected to a load, since it can prevent the synchronization of the alternator with the network. Such synchronization is necessary before the alternator and the network can be connected. Where the turbine drives machines other than alternators, the speed and power output fluctuations may also be harmful.

A great many methods have been proposed to restrict hunting and improve stability. Generally speaking, two principal types can be distinguished:

I. Accelerometer systems; the governors generally have a permanent speed droop characteristic and the action of the tachometer is combined with that of an accelerometer, with the result that the speed acts through its derivative before an appreciable speed variation has had time to occur. This system yields excellent results. However, the speed of response to this governing action has to be limited to a definite value if sufficient stability is to be obtained.

II. Temporary restoring systems. Here, the governors do not include an accelerometer but instead are provided with a dashpot device, the general effect of which is to momentarily increase the speed droop to a considerable extent, while reducing the speed of response for smaller speed variations. Such systems have a response characteristic which is somewhat different from that obtained in the above described system, but which is likewise limited as to its speed of response.

Still other governor systems exist which may be more or less reduced to either one or the other of the above-described arrangements. For example, there are direct acting governors, the use of which is restricted to those turbines in which the valve or gate operation requires only a very little energy. As another example, there are manual governor systems wherein a human operator replaces the automatic control applied to indirect governors. It will be observed that even with a direct or manual governor, lack of stability and hunting effects are encountered when it is attempted to control the valve operation of the unit in response to the speed of rotation.

It should be pointed out that the hunting described herein is independent of various secondary adjustments which may act on the governor in response to other factors than the speed of rotation.

According to the present invention, the action of the governor, or other control device, which operates the valve mechanism controlling the flow of fluid through the turbine, is supplemented by the action of a device responsive to variations in pressure in the fluid conduit associated with the turbine. This pressure responsive device is arranged so that when the pressure changes at a rate in excess of a predetermined value, the valve mechanism of the turbine is operated in the proper sense to reduce the rate of change of pressure.

A pressure responsive device suitable for use in accordance with the present invention must be actuated by the variations of pressure and

not by the pressure itself. Such a device may, for instance, be a differential pressure responsive device having one pressure sensitive element which measures the instantaneous value of the pressure and a second pressure sensitive element which measures the average value over a predetermined long period. Should a rapid variation occur, it may be considered that the latter element reacts slowly if at all, and the difference between the deflections of the two elements measures the rate of change of the pressure. In order to obtain the average value, it is necessary to provide a suitable dampening device in the mechanical or hydraulic mechanism of the second element. Almost any common dampening device may be used, such as a dashpot, a restriction, etc.

In some cases, the average pressure differs very little from the static head. The second element of the pressure gauge may in such cases be replaced by a level indicator. Since such an indicator gives practically a constant pressure indication, the second element of the differential pressure gauge may be replaced by a fixed member in the mechanism of the first element, or preferably by a manually adjustable member.

The resultant of the deflections of the two pressure responsive elements is transmitted to the apparatus controlled by the governor, if necessary by means of a relay which can transmit the resultant deflection without appreciably loading the pressure responsive elements.

The immediate function of the rate of change of pressure responsive device or of the relay depends upon the type of governor. In the accelerometric type, the relay must act together with the tacho-accelerometer, while in the temporary restoring type the relay must act so as to alter that temporary restoring action.

All other factors remaining constant, this function of the rate of change of pressure responsive device is to shift the parts of the governor so as to alter its characteristic considered as a function of speed. In an accelerometric type of system, this function is performed in the same manner as the tachometer acts as a function of speed. In a restoring type of system, the function is performed in the same manner as the valve position acts on the system.

The present invention provides apparatus for stabilizing hydraulic turbines equipped with governors so as to increase the stability of the power output. Such governors are responsive to the variations of a controlling condition from a predetermined standard. The controlling condition usually is the speed of revolution, but might be any other selected quantity (such as a water level, a spring force, or the like). For the sake of greater clearness in the present disclosure, the invention will be described on the basis that the controlling condition is speed, but this should not be taken as restricting in any way the scope of the invention.

The main object of the invention is therefore to provide means for acting upon the turbine regulating apparatus in response to the inertia of the water within the conduit system, as measured by pressure surges or depressions at certain points of the hydraulic system. Through such means, the governor is operated to obtain a much higher rate of response for an equal degree of stability or conversely a much higher stability for a given rate of response, or both. Hunting is thus attenuated and the connection of the generator to the electrical system and the assumption of the load by the generator may thus be expedited. Where several units are equipped with apparatus constructed in accordance with the present invention, the actual operation of the network itself is improved to a substantial extent.

A more specific object of the invention is to provide various manometer or pressure responsive devices which make it possible to obtain the desired controlling action from pressure variations due to inertia of the body of water.

Another object of the invention is to determine the precise manner in which said pressure responsive devices are to operate in acting upon the governor, accordingly as the invention is to be applied to a tachometeric regulator, an accelerometric regulator, a temporary restoring system regulator, a manual regulator, etc.

Further objects and advantages of the invention, and further features of the apparatus will appear from the following description and appended claims, which description is made with reference to the accompanying drawings which illustrate some exemplary embodiments and wherein:

Figs. 1 and 2 diagrammatically illustrate, for explanatory purposes, an accelerometer type of governor and a temporary restoring system regulator, respectively, as used in the prior art.

Figs. 3 and 4 are similar diagrams illustrating the application of this invention to said types of governors, respectively.

Figs. 5, 6 and 7 show differential pressure-gauge arrangements according to the invention.

Figs. 8 and 9 illustrate pressure intake taps and Figs. 10 and 11 show some suitable types of relays.

In Fig. 1 there is shown a servomotor 1 operating a gate valve mechanism 2 on a hydraulic turbine (not shown). A restoring cam 3 moves with the gate valve mechanism 2. A pilot valve 4 controls the servomotor 1 and is actuated by a floating lever 5. The left end of the floating lever 5 is positioned by a combined speed and acceleration responsive device 6 hereinafter referred to as a tacho-accelerometer unit. The right end of the floating lever 5 is positioned by a follower which cooperates with the cam 3.

Upon an increase in speed above the value for which the device 6 is set, it moves the left end of lever 5 upwardly thereby moving the pilot valve 4 upwardly and supplying fluid under pressure to the servomotor 1 to move the valve mechanism 2 in a closing direction. As the valve 2 closes, the cam 3 acts through its follower and moves the right end of lever 5 downwardly, thereby restoring the pilot valve 4 to its original position.

Fig. 2 illustrates another type of governor mechanism of the prior art, employing a temporary follow-up mechanism. Those elements in Fig. 2 which correspond to certain elements in Fig. 1, have been given the same reference characters and will not be further described.

In Fig. 2, a temporary follow-up cam 7 is provided in addition to the permanent follow-up cam 3. The cam 7 is made steeper than the cam 3, and acts on the right hand end of lever 5 through a dashpot 8. The permanent follow-up cam 3 acts on the right end of lever 5 through a strain release connection, generally indicated by the reference numeral 44. The dash pot 8 includes a cylinder 8a in which moves a piston 8b having a restricted passage 8c formed therein to provide fluid communication between the opposite ends of the cylinder. The cylinder is filled with oil or some other suitable liquid. The piston 8b

is attached to a piston rod 45 which extends upwardly through the end of cylinder 8a and has its upper end pivotally connected to the right hand end of the lever 5. The cam 3 positions a follower 3a mounted on the end of a stem 46 which extends upwardly and is provided at its upper end with a pair of projecting flanges 46a and 46b. The stem 45 extends through suitable apertures in the flanges 46a and 46b, and is provided with two fixed shoulders 47 and 48 which are spaced apart by a distance substantially equal to the distance between the flanges 46a and 46b. The shoulders 47 and 48 are normally held in alignment with the flanges 46a and 46b, respectively, by means of a spring 49 compressed between two annular retainer discs 50 and 51 located between the flanges 46a and 46b and encircling the piston rod 45. The apertures in the flanges 46a and 46b are of greater diameter than the shoulders 47 and 48 on the piston rod, but are of smaller diameter than the outside diameter of the annular discs 50 and 51. The inside diameter of discs 50 and 51 is smaller than the diameter of shoulders 47 and 48.

During slow movements of the gate valve mechanism 2, the cam 7 displaces the cylinder of the dash pot, but not the piston 8b, because the oil has sufficient time to pass through the restricted opening 8c of the dash pot. During this time, the cam 3 displaces the rod 46, which positions one of the retainers 50 and 51 and hence drives the spring 49. If the movement is upward, for example, the spring 49 is raised by retainer 51 and forces retainer 50 against the shoulder 47 on the piston rod 45 and thereby raises the piston rod 45 and the right hand end of the lever 5. During this movement, the spring 49 is not compressed because it is stronger than the force necessary to move the lever 5. Therefore, during a slow movement of the gate valve mechanism 2, the cam 3 moves the right hand end of the lever 5 just as though there were a rigid connection between them as in the case of Fig. 1.

On the other hand, during a rapid movement of the gate valve mechanism 2 (that is to say, a movement for which it is necessary to increase the speed droop substantially but momentarily), the cylinder of the dash pot also moves rapidly and carries along the piston 8b and its piston rod 45, because the oil does not have time to pass through the aperture 8c in the piston. Since the cam 7 has a substantially greater slope than the cam 3 (and if it is assumed that the movement of the gate valve mechanism is such that the cams are displaced from right to left), the piston rod 45 is raised more than the stem 46. Spring 49 is compressed by the retainer 51, which separates from the flange 46b. During this time, the follower 3a remains in contact with the cam 3, because the spring 3b is selected stronger than the spring 49. As the movement of the gate valve mechanism slows down, the spring 49 slowly moves the piston 8b in the cylinder 8a, together with the right hand end of lever 5 until the retainer 51 is restored to contact with the flange 46b.

It may be seen that the cam 7 and the dashpot 8 insert a temporary further displacement of the lever 5, which is removed after a time interval depending upon the characteristics of the dashpot 8.

It has been stated above that modern indirect-acting governors may be reduced to one or the other of the above two basic arrangements. Although there are governors which do not include a floating lever, they always do comprise a broadly equivalent device capable of combining the movements of the tachometer with those of the restoring system. The floating lever is used herein merely to exemplify such a device and, while the effect of the floating lever may differ somewhat from that obtained with such an equivalent device, such differences are irrelevant to the present invention.

In Figs. 3 and 4, there are illustrated governors and relays operated by differential pressure responsive elements and connected with the governors, all in accordance with the invention. The connections are there illustrated as including the floating levers and other members diagrammatically illustrated in Figs. 1 and 2. It should be understood, however, that the invention is by no means restricted to governors built exactly as here shown. After studying the structures described herein, it should be an easy matter to see how the invention may be applied to a governor of different design. In particular, the invention is applicable to governors which comprise a servomotor and a relay which are not hydraulically operated, but are, for instance, electrically operated.

Fig. 3 shows the tacho-accelerometer type of governor shown in Fig. 1, but the tacho-accelerometer rather than directly acting on the end of the floating lever as in Fig. 1, acts upon an auxiliary balance member or lever 9, the midpoint of which is connected by a link with the floating lever 5, so that its action upon the latter is the same as before, when the right hand end of the balance member 9 remains stationary. According to the invention, this last-mentioned end may be displaced by a relay 10 as a function of the pressure surge measured, as mentioned above, by means of a device generally indicated at 11 and responsive to the rate of change of pressure of the fluid passing through the turbine.

The gate valve mechanism 2 is shown in Fig. 3 as part of a turbine 52 having an intake conduit 53 and a discharge conduit or draft tube 54. The device 11 is responsive to the rate of change of pressure in the draft tube, being connected thereto through a conduit 55. The device 11 includes a pair of expansible bellows 14 and 18, each fixed at one end and having their free ends connected to the opposite ends of a lever 15, which is pivoted at its center on a fixed support 56. The lever 15 is provided with an arm 20 connected through suitable linkage to the mechanical relay 10. The conduit 55 is connected to the interior of bellows 14 through a branch conduit 58 and a variable restriction 17. The conduit 55 is connected to the interior of bellows 18 through a branch conduit 57 and a variable restriction 17'. The interior of bellows 18 is also in communication through a conduit 59 with the interior of an air chamber or trap 19, for a purpose to be later described. The restriction 17 is designed to transmit to the bellows 14 an average pressure value taken over a short interval, rather than the instantaneous pressure, so as to eliminate any rapid pressure fluctuations due to turbulence. The period of response in such a pressure tap should in most cases be substantially less than one second. (The period of response, or time constant, may be defined as the period of time necessary for the pressure gauge to respond to a given pressure variation.) It may be greater than that if the "hunting" period of the turbine itself is very long. The period of response may easily be adjusted by varying the opening through the restriction or valve 17. The variable restriction 17' is much more restricted than the restriction 17 so as to

impart to its related bellows 18 a period of response which is long as compared to the hunting period of the unit. If, for example, the latter ranges for instance from 5 to 20 seconds, the bellows 18 should have a period of response (or natural cycle period) in the range of from five to ten times greater; for instance, a response period equal to one minute or more.

Moreover, as mentioned above, the interior of bellows 18 is in communication with an air chamber 19 of adequate size, which provides a further delay in the response of bellows 18 to a pressure variation.

The arm 20 is subjected to a displacement proportional to the difference between the displacements of the two bellows, that is, proportional to the rate of pressure variation which is to be detected. When starting from a state of equilibrium, both bellows are equally expanded and the arm 20 occupies its intermediate position.

If a sufficiently rapid pressure variation then occurs, such as a sudden pressure drop in the draft tube resulting from a gate closing operation, said pressure drop will quickly contract the bellows 14, whereas it will be more slowly transmitted to the bellows 18, because of the greater loss of head caused by the flow through restriction 17'. The pressure in the air chamber 19 is therefore not immediately altered as a result of the pressure drop in the conduit, and the bellows 18 is expanded under the action of the force exerted by the bellows 14 upon the balance member 15. The lever 15 is therefore rotated counterclockwise moving the arm 20 downward. This downward movement is transmitted through relay 10 to the right hand end of lever 9, where it is effective either to produce an opening movement of the gate valve, or to slow the closing movement which caused this sudden pressure drop. This movement stops as soon as the pressure decrease in the air chamber becomes equal to that prevailing in the conduit 55. Because of the resiliency of both bellows 14 and 18, the arm 20 will therefore be displaced through an angle substantially proportional to the rate of change of pressure.

It will of course be understood that if the pressure decrease is a slow one, it will be transmitted nearly simultaneously to both bellows and also the air chamber, and the arm 20 will remain stationary.

It may therefore be seen that the arm 20 is deflected from its normal position only if the pressure changes faster than a rate which is predetermined by the size of the restrictions 17 and 17' and of the air chamber 19. Furthermore, the deflection of lever 20 is proportional to the amount by which the rate of change of pressure exceeds that predetermined rate.

Upon a sudden opening movement of the gate valve mechanism 2, the pressure in the draft tube 54 will increase suddenly. This increase in pressure is communicated through the conduit 55 to the rate of change of pressure responsive device 11. If this rate of change of pressure is sufficiently fast to actuate that device, it will cause a clockwise movement of the lever 15, since the bellows 14 acts more rapidly than the bellows 18. This produces an upward movement of the arm 20 which is transmitted through the mechanical relay 10 to produce an upward movement of the right hand end of lever 9. This upward movement of the right hand end of lever 9 tends either to cause a closing movement of the gate or to restrict a previously initiated opening movement.

In Fig. 4, a governor similar to that shown in Fig. 2 is illustrated; in this case, the relay 10 controlled by the rate of change of pressure responsive device 11 is connected between the cam 7 and the temporary restoring dashpot 8. The follower roller of the cam 7, rather than directly causing a displacement of the dashpot cylinder, is connected with the midpoint of a balance member 12 the left-hand end (as herein shown) of which is connected with the dashpot 8 and the right hand end with the relay 10. The structure of the rate of change of pressure responsive device 11 of Fig. 4 is the same as that shown in Fig. 3. The interiors of the bellows 14 and 18 of Fig. 4 are connected through a conduit 60 to the casing of the turbine 52 on the upstream side of the gate valve mechanism. Consequently, a closing movement of the gate valve mechanism produces a pressure surge at that point in a positive direction, rather than in a negative sense as in the case of the arrangement in Fig. 3, where the pressure sensing conduit 55 is connected to the draft tube 54. In the arrangement of Fig. 4, such a positive increase in pressure produces a clockwise movement of the lever 15, which is transmitted through the mechanical relay 10 to produce an upward movement on the right hand end of lever 12. The relay 10 acts cumulatively with the temporary restoring system. In other words, an increase in pressure causes the right end of lever 12 to move upwardly, thereby moving dashpot 8 downwardly in the same direction that it is moved by a closing movement of the gate valve mechanism acting through cam 7.

It will be an easy matter to ascertain the manner in which the relay will have to operate in any one of said other types of governor systems, by comparing the similar parts therein. Their operation may also be determined through calculation. The approximate amount by which the pilot valve, or other corresponding governor element, should be displaced in response to a given pressure surge may be determined by comparing the effect to be obtained to the variation in speed which would effect a similar result through the governor. The results thus obtained are obviously of an approximate nature and an empirical adjustment will generally be found necessary.

The differential pressure responsive device, in any modification of the invention, may be arranged at any point in the vicinity of the turbine, as for instance on the conduit upstream of the turbine, or on the turbine casing, as shown in Fig. 4. It may alternatively be connected to the draft tube, as shown in Fig. 2. In any given installation, the direction in which the rate of change of pressure responsive device acts on the pilot valve 4 must be reversed for a pressure connection downstream from the main valve mechanism from the direction used when the pressure connection is upstream from the main valve mechanism. This is so because a pressure surge upstream of the main valve mechanism corresponds with a depression in the draft tube and vice-versa.

As regards the pressure intake connections or taps they may be ordinary static pressure taps (as in Figs. 3, 4 and 6) or dynamic ones which are adapted to measure the total head (as in Fig. 5). In either case, the pressure responsive device may comprise two similar pressure intakes, or it may comprise a single bifurcated pressure intake as shown in Fig. 9.

Fig. 5 illustrates the rate of change of pressure responsive device 11 as connected to two sep-

arate dynamic pressure intakes 13 and 16. These intakes are located in the example illustrated at the inlet 53 of the turbine 52. The bellows 14 is connected to the intake 13 and the bellows 18 is connected to the intake 16.

Fig. 6 shows a modified form of rate of change of pressure responsive device in which the two bellows 14 and 18 have their free ends connected to opposite sides of the ends of a lever 61. The mid-point of lever 61 is not fixed and is directly connected with the relay 10 through rod 21. It will be seen that the displacements of this rod are proportional to the differential of the displacements of the elements 14 and 18. In order to illustrate an alternative, the pressure intakes for the two bellows are herein shown as being static ones.

A great many other forms of differential pressure responsive devices may be used. For example, rather than interconnecting both elements through a balance member, said elements may simply be assembled in opposition as shown in Fig. 7. The pressure connections shown in Fig. 7 are the equivalents of those shown in Fig. 6. The two bellows 14 and 18 have a common end wall 62 having a lateral projection 63 shown as being connected to the mechanical relay 10. In this particular arrangement, the form of mechanical relay shown in Fig. 11 is particularly suitable. In this case, the position of the common end-wall or partition 62 is a function of the rate of pressure change. In this arrangement an air chamber 19 is required.

In the case where static pressure taps are used, a resilient diaphragm 22 (Fig. 8) may be interposed at the inlet to the tap, said diaphragm being adapted to transmit the pressure variations from the water to a fluid arranged at the other side of the diaphragm and which advantageously may be oil. This system is adapted to prevent the entry of any foreign materials into the pressure responsive elements.

As shown in Fig. 8, the diaphragm 22 has its edges clamped between a lower casting 64 and an upper casting 65. The lower casting 64 is adapted for insertion in a suitable aperture in the wall of the turbine intake 53. The casting 64 encloses a central chamber 64*a* which opens into the interior of the turbine intake 53. The casting 65 encloses a central chamber 65*a* which is separated from the chamber 64*a* only by the flexible diaphragm 22. The upper end of chamber 65*a* communicates with a conduit 66 which may lead to either one or both of the bellows 14 and 18. Purging conduits 64*b* and 65*b* are provided for the chambers 64*a* and 65*a*, respectively. These purging conduits have valves 64*c* and 65*c* respectively through which any gas or vapor bubbles appearing in the chambers may be drawn off so as to insure an accurate transmission of pressure through the diaphragm 22.

In most of the examples described so far, and as diagrammatically illustrated in the drawing, the manometric or pressure responsive elements comprise deformable bellows. It is known that such bellows operate somewhat as springs, that is to say, they have a certain resistance to displacement. This characteristic is necessary to the invention since it is due to this that such elements are adapted to occupy a definite position in response to a given pressure. The same is true of most pressure responsive systems of known types.

Intead of dual pressure taps, a single pressure tap 67 comprising a bifurcation therein can be arranged as shown in Fig. 9, wherein similar reference numerals have been used to designate the same elements as in Figs. 5 and 6. All of the previously described alternatives and modifications are applicable also to this arrangement, the operation of which is similar to that of the other embodiments illustrated so far.

The relay 10 of Figs. 3 and 4, may take any well-known form. For example, the known device illustrated in Fig. 10 may be used. The rod 21, which may be the same as the rod 21 shown in Fig. 6, or some equivalent member, terminates in a needle valve member 23 adapted to obturate more or less the mouth of a passage 24 formed in a differential piston 25. The latter travels in a cylinder 26 supplied at its top and bottom ends from two oil passages 27, 28 supplied in turn under a common pressure as at 29. The conduit 27 comprises a restriction 30. A permanent leakage is set up through the outer end of passage 24 and its rate of flow is controlled by the needle valve 23. The pressure prevailing below the differential piston is higher than that above it because of the loss of head through 30 but the piston is balanced by having a greater area subject to the lower pressure existing above the piston. The pressure above the pistons is varied by variations of the restriction formed between the aperture and the needle valve 23. That is, if the needle valve 23 is raised, the rate of flow through the aperture increases and the pressure above the piston drops because of the reduction in the loss of head at the outlet and the increase in the loss of head at 30 due to the increase in the rate of flow. The piston rises and balance is restored only when the piston again reaches a position at its original distance from the needle valve. The piston faithfully follows all of the movements of the needle valve. There is no amplification of the displacement, but there is a considerable amplification of the energy of displacement, so that the piston can actuate the pilot valve of the turbine control mechanism even if it meets with considerable resistance.

Another example of a suitable relay system is shown in Fig. 11. The rate of change of pressure responsive device shown in this figure is the same as that shown in Fig. 7, and the same reference numerals have been applied to it and to its pressure connections, and it will not be further described in connection with this figure. The extension 63 of the partition 62 carries at its free end a vane member 43 which moves between two orifices 31 and 32 (Fig. 11) which are also movable and are assembled on a rod 33 connected through a lever 34 with the rod of a piston 35. The orifices 31 and 32 are connected through flexible tubes 37 and 38 with respective ends of the cylinder 36 in which piston 35 moves. The cylinder is in turn supplied through conduits 39 and 40 having restrictions 41 and 42 therein. The pressure at both ends of the cylinder is the same so long as the rate of flow through the orifices 31 and 32 is the same. The piston is stationary when the vane is in a position exactly centered between the orifices 31 and 32 since the rates of flow through the latter are then equal. If the vane moves closer to either of the apertures, the pressure increases in the pipe supplying that aperture and drops in the other pipe, and the pressure differential acts upon the piston. The piston in its resulting motion displaces both apertures in the same direction as the vane and comes to a stop as soon as the latter again occupies a central position therebetween. This

arrangement forms a restoring device operative to link the position of the piston to that of the vane with any desired amplificaton of energy and/or displacement.

The flexible hose elements 37 and 38 are provided for the purpose of enabling the apertures 31 and 32 to be moved relative to the fixed cylinder. They could of course be replaced by any appropriate movable seal means.

Many other systems of composite hydraulic and electric character involving continuous restoring operation could be used which would produce an amplification not only of energy but also of the displacement. The amplification of the displacement could also easily be obtained in a relay such as that shown in Fig. 10, through an appropriate mechanical system such as a lever.

The invention is by no means restricted to the forms of embodiment and examples described, but includes many possible alterations thereof, such as those involving the form and arrangement of the pressure taps, the pressure responsive elements, relays and types of governors to which the invention may be applied, or those required by the particular characteristic displacement of the governor parts in response to the pressure variation, which characteristic may or may not be substantially linear in character, and which may be controlled for instance through the use of cams and the like.

I claim:

1. Apparatus for controlling a hydraulic turbine comprising a valve mechanism for regulating the flow of fluid through said turbine, turbine speed responsive means, means responsive to the rate of change of a pressure of the fluid regulated by said valve mechanism, means for operating said valve mechanism including a control member having a neutral position in which said valve mechanism remains stationary, said operating means being effective when said control member is moved to one side or the other of said neutral position to cause opening and closing movements respectively of said valve mechanism, a connection between said speed responsive means and said control member for moving said control member in a valve opening direction in response to a decrease in speed and for moving the control member in a valve closing direction in response to an increase in speed, restoring means connected to the valve mechanism for concurrent movement therewith and connected to said control member for moving said control member back toward its neutral position as said valve mechanism moves in response to a deviation of the control member from its neutral position, and means connecting said rate of change of pressure responsive means and said control member and effective upon a change in said pressure at a rate in excess of a predetermined rate to operate said control member in a sense to reduce said rate of change.

2. Apparatus for controlling a hydraulic turbine as defined in claim 1, in which said means responsive to the rate of change of a pressure is responsive to the pressure of the fluid upstream from said valve mechanism and said connecting means is effective upon an increase in said pressure at a rate in excess of said predetermined rate to operate said control member in a valve mechanism opening sense.

3. Apparatus for controlling a hydraulic turbine as defined in claim 1, in which said means responsive to the rate of change of a pressure is responsive to the pressure of the fluid downstream from said valve mechanism and said connecting means is effective upon an increase in said pressure at a rate in excess of said predetermined rate to operate said control member in a valve mechanism closing sense.

4. Apparatus for controlling a hydraulic turbine comprising a valve mechanism for regulating the flow of fluid through said turbine, turbine speed responsive means, turbine acceleration responsive means, means responsive to the rate of change of a pressure of the fluid rgulated by said valve mechanism, means for operating said valve mechanism including a control member having a neutral position in which said valve mechanism remains stationary, said operating means being effective when said control member is moved to one side or the other of said neutral position to cause opening and closing movements respectively of said valve mechanism, connections between said speed responsive means and said acceleration responsive means and said control member for moving said control member in a valve opening direction in response to a decrease in speed or acceleration and for moving the control member in a valve closing direction in response to an increase in speed or acceleration, restoring means connected to the valve mechanism for concurrent movement therewith and connected to said control member for moving said control member back toward its neutral position as said valve mechanism moves in response to a deviation of the control member from its neutral position, and means connecting said rate of change of pressure responsive means and said control member and effective upon a change in said pressure at a rate in excess of a predetermined rate to operate said control member in a sense to reduce said rate of change.

5. Apparatus for controlling a hydraulic turbine comprising a valve mechanism for regulating the flow of fluid through said turbine, turbine speed responsive means, means responsive to the rate of change of a pressure of the fluid regulated by said valve mechanism, means for operating said valve mechanism including a control member having a neutral position in which said valve mechanism remains stationary, said operating means being effective when moved to one side or the other of said neutral position to cause opening and closing movements respectively of said valve mechanism, a connection between said speed responsive means and said control member for moving said control member in a valve opening direction in response to a decrease in speed and for moving the control member in a valve closing direction in response to an increase in speed, permanent restoring means including a first element operatively connected to the valve mechanism for concurrent movement therewith and yieldably connected to said control member and tending to move said control member back toward its neutral position as said valve mechanism moves in response to a deviation of the control member from its neutral position, temporary restoring means including a second element operatively connected to the valve mechanism for concurrent movement therewith and means including a dashpot connecting said second element to said control member for imparting to the control member a temporary displacement toward its neutral position and varying with the rate of movement of the valve mechanism, and a connection between said rate of change of pressure responsive means and said control member and

effective upon a change in said pressure at a rate in excess of a predetermined rate to operate said control member in a sense to reduce said rate of change.

6. Apparatus for controlling a hydraulic turbine as defined in claim 1, in which said rate of change of pressure responsive means comprises two pressure sensitive elements, means for communicating to said elements a pressure of the fluid regulated by said valve mechanism, said communicating means including means for differently delaying communication of changes in said pressure to the respective elements, so that said elements have different rates of response to changes of said pressure, and a member connected to both said pressure sensitive elements for movement by the respective elements in opposite senses upon a change in pressure, so that said member is moved substantially only when the rate of change of pressure exceeds a predetermined value.

7. Apparatus for controlling a hydraulic turbine as defined in claim 1, in which said rate of change of pressure responsive means comprises two pressure sensitive elements subject to a pressure of the fluid regulated by said valve mechanism, one of said elements having a period of response which is substantially shorter than the hunting period of the turbine and the other of said elements having a period of response which is substantially longer than the hunting period of the turbine, and a member connected to both said pressure sensitive elements for movement by the responsive elements in opposite senses upon a change in pressure, so that said member is moved substantially only when the rate of change of pressure exceeds a predetermined value.

8. Apparatus for controlling a hydraulic turbine as defined in claim 1, in which said rate of change of pressure responsive means comprises first and second expansible bellows, each fixed at one end, first and second means for supplying to the interior of the respective bellows fluid at a pressure regulated by said valve mechanism, a first restriction in said first fluid supplying means for delaying the transmission of fluid so that the response period of the first bellows is substantially shorter than the hunting period of the turbine, a second restriction in the second fluid supplying means for delaying the transmission of fluid so that the response period of the second bellows is substantially longer than the hunting period of the turbine, a lever having its center mounted on a fixed pivot and its ends connected to the free ends of said bellows, and a connection between said lever and said control member.

9. Apparatus for controlling a hydraulic turbine as defined in claim 1, in which said rate of change of pressure responsive means comprises first and second expansible bellows, each fixed at one end, first and second means for supplying to the interior of the respective bellows fluid at a pressure regulated by said valve mechanism, a first restriction in said first fluid supplying means for delaying the transmission of fluid so that the response period of the first bellows is substantially shorter than the hunting period of the turbine, a second restriction in the second fluid supplying means for delaying the transmission of fluid so that the response period of the second bellows is substantially longer than the hunting period of the turbine, a lever having its ends connected to the free ends of the bellows, and a link pivotally attached at one end to an intermediate point on the lever and at its opposite end to said control member.

10. Apparatus for controlling a hydraulic turbine as defined in claim 1, in which said rate of change of pressure responsive means comprises first and second expansible bellows, each fixed at one end, and having their free ends connected in opposed relation, first and second means for supplying to the interior of the respective bellows fluid at a pressure regulated by said valve mechanism, a first restriction in said first fluid supplying means for delaying the transmission of fluid so that the response period of the first bellows is substantially shorter than the hunting period of the turbine, a second restriction in the second fluid supplying means for delaying the transmission of fluid so that the response period of the second bellows is substantially longer than the hunting period of the turbine, and a connection between the connected free ends of said bellows and said control member.

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