Dec. 20, 1955 T. W. BROWN 2,727,523

COMPENSATING SPEED GOVERNOR, ESPECIALLY FOR HYDRAULIC TURBINES

Filed May 27, 1950

Fig. 1

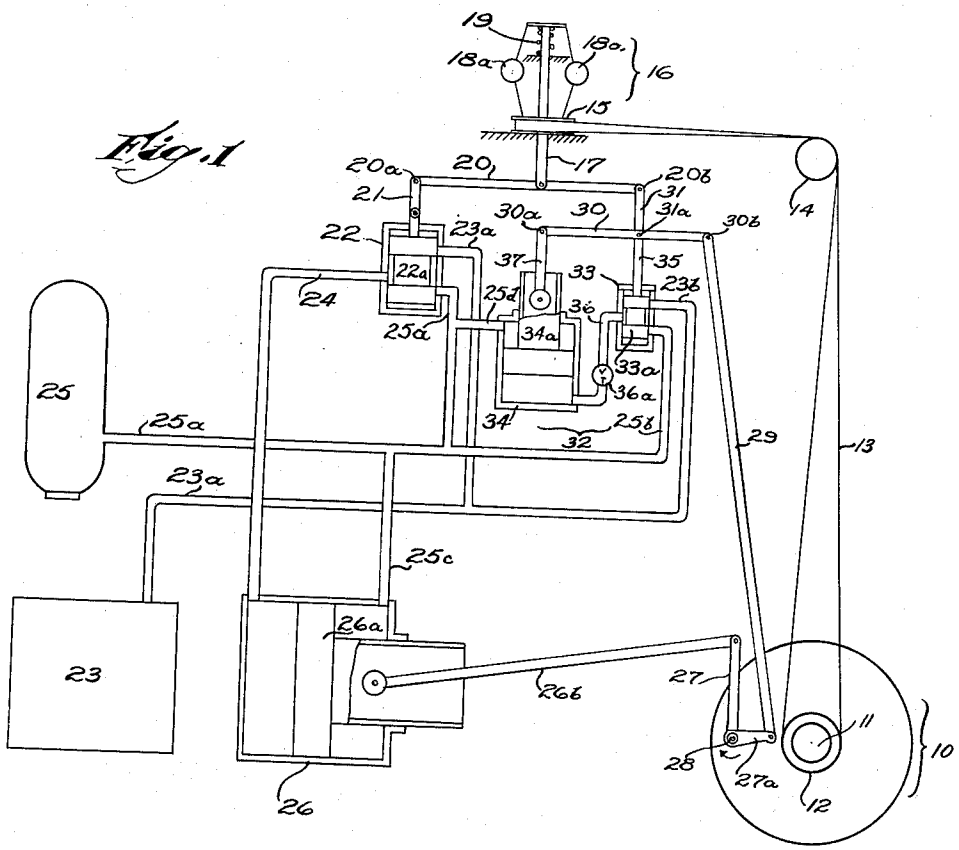
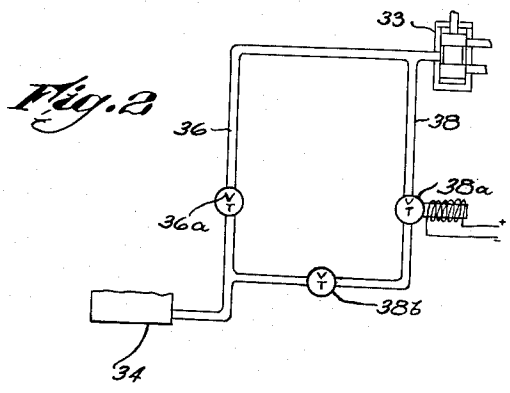


Fig. 2



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United States Patent Office

2,727,523

Patented Dec. 20, 1955

2,727,523

COMPENSATING SPEED GOVERNOR, ESPECIALLY FOR HYDRAULIC TURBINES

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Application May 27, 1950, Serial No. 164,774

5 Claims. (Cl. 137—34)

My present invention relates to governing, regulating and control systems and apparatus generally, and especially as related to governing the speed of prime movers, as for example, hydraulic turbines. More particularly it aims to provide improved controlling means having secondary compensating or follow-up means in association with a primary servo and pilot or other main controlling device.

It is the general practice in hydraulic turbine governor design to provide a primary means acting back from the supply regulating or gate-operating element for modifying the action of the prime mover speed measuring device upon the primary pilot or main motor controlling device, to prevent overtravel of the gates with consequent instability. It is also not unusual to employ some secondary means to overcome gradually the larger speed changing effect of such primary means, in an effort to produce approximately isochronous governing yet without objectionable instability. However, the provision of such secondary compensating means presents various problems and heretofore has not been accomplished with entire satisfaction.

By my present invention I provide governor apparatus, and especially turbine governing apparatus, incorporating simple and reliable secondary compensating means distinguished by sensitivity and promptness of response, capable of accomplishing substantially isochronous governing with adequate stability, while avoiding difficult mechanical fits, use of critical springs and the like, or the requirement of extended periods for adjustment.

The invention will be more fully understood from the following description taken in conjunction with the accompanying drawings illustrative of one embodiment thereof, in which:

Fig. 1 is a schematic view of a fluid-pressure operated hydraulic turbine governor novelly incorporating secondary compensator means; and

Fig. 2 is a schematic view of an alternative form for the compensator throttle.

In the selected example the novel governor system and compensator means is illustrated in association with an hydraulic turbine indicated generally at **10**, having an output shaft **11** with a pulley **12** thereon. The turbine gate operating element is indicated at **28** as an adjusting shaft, turnable in one direction to close the gate and in the other direction to open it. Here it is assumed that clockwise turning of this adjusting shaft **28** as viewed in Fig. 1 closes the turbine gate to reduce output speed; coversely, counter-clockwise turning of shaft **28** will open the gate and increase the speed.

In the illustrated application of the invention to governing hydraulic turbines, it will be understood that the final control or regulating element is the gate shaft **28** of the turbine whereby the control agent, in this instance the hydraulic driving energy supplied to the turbine, is varied by the automatic governor means here concerned to give to the variable and regulated quantity the desired value, namely, a substantially constant speed for the turbine output regardless of changes, and particularly step changes, in the load.

The governor system comprises first a metering and force relaying element shown as a tachometer of the centrifugal type, of known or preferred construction, designated generally at **16**. It has a spindle **17** driven from the turbine pulley **12** as by a belt **13** passing over a guide pulley **14** to a pulley **15**. The latter is held from axial movement while the spindle **17** is slidably splined or otherwise angularly fixed coaxially in it, with capacity to shift axially, vertically in the diagram, under output speed change at the turbine.

The centrifugal action of the revolvable masses or flyballs **18***a*, **18***a* hung on the spindle **17** and their attendant radial movement is converted to axial movement of the spindle, downward in the drawing under turbine speed increase, and vertically upward under speed decrease. A spring or other counter-balance **19** may assist in the latter direction if desired. Thus the tachometer **16** measures and indicates the occurrence and direction of speed change and relays a force derived from the turbine for instituting a compensating action.

Movement of the tachometer spindle **17** is relayed to a main or primary pilot or control valve **22** through a first horizontal lever **20** to an intermediate point on which the lower end of the spindle is pivoted, and a vertical link **21** pivotally interconnecting the valve stem and the adjacent end of the lever **20** as at **20***a*. The slidable valving spool element **22***a* of the three-way pilot valve **22** cooperates with upper and lower ports to close both in the neutral or equilibrium position, and to open one while closing the other in upper and in lower positions, reversely, thereby placing the opened port in communication with the common third port while closing off the other.

In the illustration the upper port of this primary pilot valve **22** has connected to it an upper fluid conduit or pipe **23***a* leading to a fluid sump **23**. The lower port is connected to admit the oil or other hydraulic fluid under pressure from a pressure source such as the tank **25** via piping connection **25***a*. The third and intermediate port provides communication through a pipe **24** with the primary power piston or servomotor **26**. Terms such as "upper" and "lower" herein are merely for identification with reference to the location of the parts on the schematic Fig. 1. The desired operating pressure is maintained in the pressure tank **25** by any convenient means, not shown, as by return pumping of the fluid from the sump **23**.

The servo-motor **26** together with its pilot **22** are the primary means by which adjustment of the final control element, the gate shaft **28**, is effected, herein through a crank arm **27** on the gate shaft **28** and connected to the servo piston **26***a* as by a rod **26***b*. Piston movement to the right turns the gate shaft **28** clockwise, in the gate closing and speed reducing direction as previously stated. It is noted that the opposite faces of the piston **26***a* are unequal in area, as for example 2:1, the connecting rod **26***b* being at the lesser face. This power piston **26***a* of the servomotor **26** affords amplification for the governing force as relayed by the governing tachometer **16** to the pilot valve **22**. It is normally, as during periods of no change in the turbine load, balanced between the operating fluid pressure from the tank **25** through a branch line **25***c* to the smaller piston face, and the remaining pressure at the larger piston face, at the left in the diagram, under the closed-off neutral position of the pilot valve **22**.

In this neutral position both the pressure tank **25** and the sump **23** are sealed off from communication with the left side of the servomotor **26** by the valve spool **22***a*. Movement of valve spool **22***a* under the influence of tachometer **16** will, according to the direction of the movement, port either the upper or the lower pipe **23***a*

or 25*a* through the valve to the line 24 to the larger face of the servomotor piston 26*a*. In the diagram down movement of the tachometer spindle 17 and of valve spool 22*a* opens the lower valve port and thus through lines 25*a* and 24 subjects said larger piston face to the oil pressure from the supply tank, thereby moving the piston 26*a* toward the right on the drawing, to close the gate. Conversely, opposite upward movement of the spindle 17 and valve spool 22*a* subjects said larger face of the servo piston 26*a* to the lower pressure side of the system, through the line 24, the then open upper port of valve 22 and the upper pipe 23*a* leading to the sump 23, with resultant piston travel to the left on the drawing, in the gate opening direction.

By way of summary to this point, the desired constant output speed for the turbine over a range of loads requires corrective variation of the turbine input energy at the gate, directly with the load and inversely with the output speed. The described primary control accordingly closes the gate under speed increase (load decrease) and opens it under speed reduction (load increase). With descent of the spindle 17 under speed increase the servo piston 26*a* moves to the right and turns the gate shaft 28 clockwise to close the gate in the speed decreasing direction. And with rise of the spindle 17 under speed decrease the servo piston 26*a* goes to the left and the gate shaft 28 is turned counter-clockwise in the gate opening and speed increasing direction.

To prevent overtravel of the gate and consequent instability in the governing action it is common practice to employ a primary compensating means or follow-up. Herein such primary compensating means to modify the action of the relay governor 16 on the primary control valve or pilot 22 comprises a vertical link 31 connected as at 20*b* to the end of the lever 20 distal to the primary valve 22. This link 31 is intermediately connected as at 31*a* to a second horizontal lever 30. The right end of the latter is pivoted as at 30*b* to the upper end of a follow-up link 29 the lower end of which is pivoted to a short lever arm 27*a* angularly fixed with the lever 27 on the gate shaft 28 previously described. As will be more fully apparent hereinafter, action of this primary compensating means 27*a*, 29, 31, 20*b* is to return the primary pilot or control valve 22 to neutral, as illustrated in Fig. 1, in response to regulating movement of the gate shaft 28, and thus reestablish an equilibrium.

But with such primary compensation if alone and unmodified such equilibrium is restored at a substantially different turbine speed than was in effect before the load change. Accordingly a secondary compensating means, which is itself susceptible of appropriate regulation, is herein novelly provided. The purpose of this secondary compensating means is to overcome the stated turbine speed change or deviation from original speed before the load change, by maintaining an imbalance in the governor until the turbine speed has been returned to approximately its initial value, thereby producing such isochronous governing as is consistent with stability.

As herein illustrated such secondary compensating means of my present invention is indicated generally at 32, centrally of Fig. 1. It comprises a three-way secondary control or pilot valve 33 which may be similar in type to primary pilot 22. Operatively associated with it is a secondary servomotor 34. The secondary compensating means further comprises a lever connection between the secondary pilot and servo, and with the follow-up means, together with piping connections as indicated. The slidable valve spool 33*a* of the secondary pilot 33 is reciprocable by a link 35 which may be an extension of vertical link 31 of the follow-up or primary compensator means. It is pivoted at 31*a* intermediary of the second horizontal lever 30 already mentioned.

The secondary pilot or control valve 33 is connected to the sump 23 through an upper pipe branch 23*b* from the sump line 23*a*, and to the pressure tank 25 through a lower pipe branch 25*b* from the pressure line 25*a*. This secondary pilot 33 is adapted to place the lower and large face of the piston 34*a* of the secondary servo 34 alternatively in communication with the low-pressure or sump side of the system or with the pressure side. This is accomplished through the pipe connection 36 between the common intermediate port of the secondary pilot 33 and said lower end of the secondary servo 34. The upper end of the latter, and upper and smaller face of the secondary servo piston 34*a* have a pipe connection 25*d* to the pressure fluid line 25*a*.

An adjustable flow restrictor or throttle 36*a* limits the rate of flow through the pipe 36 between the secondary servo and its pilot. Under equilibrium conditions piston 34*a* is balanced in the secondary servo 34 by a constant pressure supply from tank 25 through pipe 25*d*. It is coupled by its rod 37 to the adjacent end of the second horizontal lever 30 as at 30*a*, opposite to the primary compensator arm connection 30*b*. It will be seen that the secondary pilot or control valve 33 will be shifted through lever 30 under the combined influence of the primary compensator or follow-up arm 29 and of the secondary servo 34. This secondary pilot 33, like main pilot valve 22, will have upper, intermediate, and lower positions in which it supplies variously sump, equilibrium or system, and pressure tank pressures to the larger-area face of piston 34*a* of the secondary servomotor 34. The linkage 37, 30, 35 in a sense provides a follow-up action between this secondary servo 34 and its pilot 33.

It will be obvious that in the operation of the described system and means the similar sequence of events will occur in response either to a decrease or to an increase in the turbine load, but with the various motions having opposite directions. For purposes of the present discussion it will be assumed that the system has been in operation at the desired speed under some fixed load in the turbine, and that this load decreases suddenly in a step change to another fixed load. The resultant increase in the regulated quantity or turbine speed will effect a corresponding increase at the tachometer 16 and the governing apparatus proceeds in effect to cut off the necessary amount of hydraulic energy from the turbine to suit the new load and to operate the turbine at the same speed as formerly.

Under such load drop and speed increase the attendant radial outward movement of the tachometer masses 18*a* will drop the spindle 17 and the valve spool 22*a* of the primary pilot 22. The distal or right end 20*b* of horizontal lever 20 initially remains fixed. Oil from the pressure tank 25 is thus admitted to the primary servomotor 26, forcing its piston 26*a* to the right and rotating gate shaft 28 clockwise to close the turbine gate. Closing of the gate tends to reduce the speed; the speed measuring force of masses 18*a* is accordingly reduced and the tachometer spindle 17 is permitted to return upward.

Coincident to this, the primary follow-up arm 29 is urged downwardly by the clockwise rotation of the gate shaft, drawing down with it end 20*b* of lever 20. The secondary servo piston 34*a* may be regarded as stationary for the moment. These two results of the gate shaft movement combine to raise lever end 20*a* and primary valve spool 22*a* to an equilibrium or neutral position, cutting off the oil to servo 26 and so halting movement of the gate. Assuming suitable adjustments throughout, and supposing the secondary compensating means were inoperative or not present, the sequence of events started by the initial load change is thus ended. But equilibrium is thus reestablished at a higher turbine speed than formerly, due to the fact that a lower position of tachometer spindle 17 will suffice to hold valve 22 closed, in view of the lowered position of the end 20*b* of lever 20.

Now consider the secondary compensator means including the secondary servo 34 and its pilot valve 33. With these present and operative, the above mentioned

down movement of the lever end **20***b* effects a like down movement of the secondary valve spool **33***a*, admitting oil from pressure tank **25** to the larger under face of the piston **34***a* of the secondary servo **34**. This forces said piston **34***a* and the adjacent end **30***a* of the second horizontal lever **30** upward. The opposite end **30***b* of said lever being momentarily fixed, the secondary valve spool **33***a* and the overlying end **20***b* of the first horizontal lever **20** are likewise raised, thus simultaneously tending to return the secondary valve **33** to its neutral position and the end **20***b* of lever **20** to its original position. This will initially force main valve **22** from its momentarily established neutral position, in the speed reducing direction. The result is that the turbine speed is required to return through a rapid series of approximations to its desired initial value preliminary to re-establishing equilibrium in the governor system. It will be observed that the secondary compensation is mechanically opposite to the primary follow-up lever action, thereby tending to prolong the total unbalance until the original speed value is reached. At the same time the secondary compensation affects the primary pilot in the same directional sense as did the load change, thereby overcoming the deviation otherwise resulting as between the regulated speed and the set point or original speed.

The flow of oil from the secondary valve **33** to its associated servomotor **34**, and consequently the rate at which the described secondary compensation can take place is determinable by the throttling valve **36***a* in the pilot to servo connection **36**, which provides the minimum damping or drag necessary for appropriate governor stability. With proper adjustment of this throttle, the entire operation will be stable, and the result of the described load decrease will be to close the gate just the right amount to return the entire governing system to neutral position with the turbine speed unchanged from that established before the load decrease occurred.

As stated previously, the same sequence of events would result from a turbine load increase, with the directions of the described motions reversed, and with the same resultant of exact same speed maintenance. In the case of a continuously changing load the same events will take place, but will overlap in accordance with the particular form of the load variations, the net effect of the governing system being to cause the speed deviations to be minimized.

For certain installations, for example those involving higher turbine loads, having higher inertia and requiring less damping for governor stability, the modified construction of Fig. 2 may be employed. There I have shown a central portion of a secondary compensator corresponding to that of Fig. 1, other parts of the system being understood as the same. The similar pressure fluid connection between the secondary pilot **33** and the associated servo **34** is indicated at **36** and the adjusting throttle at **36***a*. In this instance the system further includes a second connecting line **38** between the secondary pilot and servo **33**, **34**. This may generally parallel the line **36** and forms a shunt or alternate therefor. In it are incorporated a remote-control on-and-off valve **38***a* herein shown as solenoid operated, and a manually or otherwise operatable flow restrictor or throttle **38***b*. This latter corresponds in general function to the throttle **36***a* and has a predeterminedly settable and in assumed higher-load example a smaller throttling effect than the other throttle **36***a*. The solenoid of the on-off valve **38***a* is suitably connected for actuation, preferably automatically, when the turbine such as **10** is placed under known heavy-load condition on the power line. The solenoid is thereby energized to open valve **38***a*, the effect of which is to by-pass throttle **36***a* and permit a higher velocity flow through throttle **38***b* as consistent with the lesser requirement of damping under the higher inertia conditions.

It will be understood that for any particular application of the system, the amount of hunting or oscillation which must be removed by the above mentioned throttling for purposes of stability can be predetermined, as well as whether alternatively selectable speeds of response are desirable or necessary under given operating loads.

It will be understood that my invention, either as to system, means or method, is not limited to the exemplary embodiments or steps herein illustrated or described, and I set forth its scope in my following claims.

I claim:

1. In combination with a prime mover having a supply regulating element, a main motor connected to and positioning said element, a pilot controlling said motor and having a neutral position when the speed of the prime mover is at set point value, a prime mover speed sensing device, a first floating lever connected at one end point to said pilot and at an intermediate point to said device, a secondary motor, a second floating lever connected at one end to said secondary motor and through its other end to said regulating element, and a secondary pilot controlling said secondary motor and connected to an intermediate point on said second floating lever and to the other end point of said first floating lever, said speed sensing device moving the first mentioned pilot through said one end and without moving said other end point of said first floating lever in one direction from said neutral position upon departure of the prime mover speed from said set point value, movement of said regulating element effecting follow up action through said first and second floating levers and moving the secondary pilot from neutral position while moving and returning the primary pilot in a direction opposite to said one direction and to its neutral position, and the secondary motor returning the secondary pilot to its neutral position while acting through the other end and about the intermediate point on said first floating lever to move the primary pilot from its returned neutral position and in the same sense as initially moved by the speed sensing device.

2. In combination with a prime mover having a supply regulating element, a primary pilot having a neutral position when the speed of the prime mover is at set point value, a main motor controlled by said pilot and connected to and for positioning said supply regulating element, follow up means comprising a floating lever connected at a first point to said regulating element and at a second point to said primary pilot, a prime mover speed sensing device connected at a lever point intermediate said first and second points and for moving the primary pilot in one direction from said neutral position upon departure of the prime mover speed from said set point value, movement of said regulating element effecting through said floating lever return movement of said primary pilot in a direction opposite to said one direction and to the neutral position, and a secondary motor and pilot, said secondary pilot connected to said follow up means and moving from neutral position upon said opposite return movement of the primary pilot, and said secondary motor controlled by said secondary pilot and connected through said second lever point to move the primary pilot from its returned neutral position and in the same sense as initially moved by the speed sensing device, whereby said speed sensing device and said secondary motor govern said primary pilot directly and also independently one of the other.

3. In combination with a prime mover having a supply regulating element, a primary pilot having a neutral position when the speed of the prime mover is at set point value, a main motor controlled by said pilot and connected to and for positioning said supply regulating element, follow up means comprising a floating lever connecting said regulating element to said primary pilot, a prime mover speed sensing device connected to said follow up means and to move the primary pilot in one direction from said neutral position upon departure of the prime mover speed from said set point value, movement of said

regulating element effecting through said follow up means return movement of said primary pilot in a direction opposite to said one direction and to the neutral position, and secondary compensator means including a motor and a motor controlling pilot connected to said follow up means, the secondary pilot moving from the neutral position upon said primary pilot returning movement of the regulating element, the secondary motor moving the primary pilot from its returned neutral position and in the same sense as initially moved by the speed sensing device, and said prime mover speed sensing device and said secondary motor interconnected through said floating lever whereby to govern said primary pilot independently one of the other.

4. In combination with a prime mover having a supply regulating element, a main motor connected to and positioning said element, a pilot controlling said motor and having a neutral position when the speed of the prime mover is at set point value, a prime mover speed sensing device connected to said pilot and for moving the pilot in one direction from said neutral position upon departure of the prime mover speed from said set point value, follow up means connecting said supply regulating element to said primary pilot and for opposite return movement of the pilot to the neutral position, a secondary motor and pilot, said secondary pilot connected to said follow up means and moving from neutral position upon said primary pilot return movement, said secondary motor connected to and for moving the primary pilot from the neutral position and in the same sense as initially by the speed sensing device, means for selectively varying the rate of movement of said secondary motor comprising parallel

fluid lines between said motor and pilot, adjustable throttling elements in both said lines, and on-off valve means in one said line.

5. In combination with a prime mover having a supply regulating element, a main motor connected to and positioning said element, a pilot controlling said motor and having a neutral position when the speed of the prime mover is at set point value, a speed sensing device connected to said pilot and for moving the pilot in one direction from said neutral position upon departure of the prime mover speed from said point value, follow up means connecting said supply regulating element to said primary pilot and for opposite return movement of the pilot to the neutral position, a secondary motor and pilot, said secondary pilot connected to said follow up means and moving from neutral position upon said primary pilot return movement, said secondary motor connected to and for moving the primary pilot from the neutral position and in the same sense as initially by the speed sensing device, parallel fluid lines between said secondary motor and pilot, throttling elements in each of said lines and adapted to afford different degrees of throttling, and remotely controllable valve means normally closing the lesser throttled line and automatically operable to open the same during predetermined load conditions.

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