Oct. 23, 1934. N. ARTSAY 1,977,980

GOVERNING AND REGULATING APPARATUS

Filed June 17, 1932 3 Sheets-Sheet 1

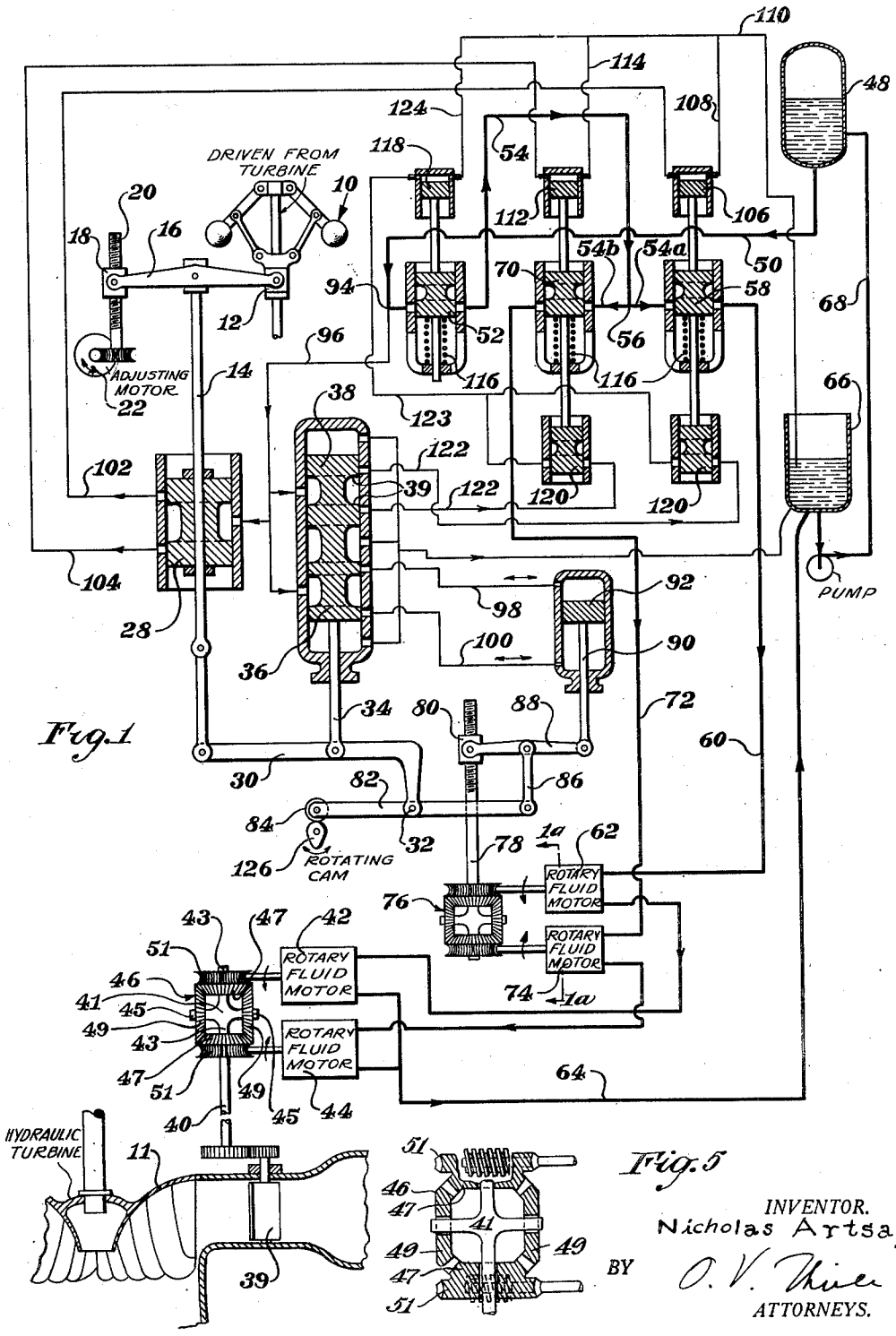


Fig. 1

Fig. 5

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GOVERNING AND REGULATING APPARATUS

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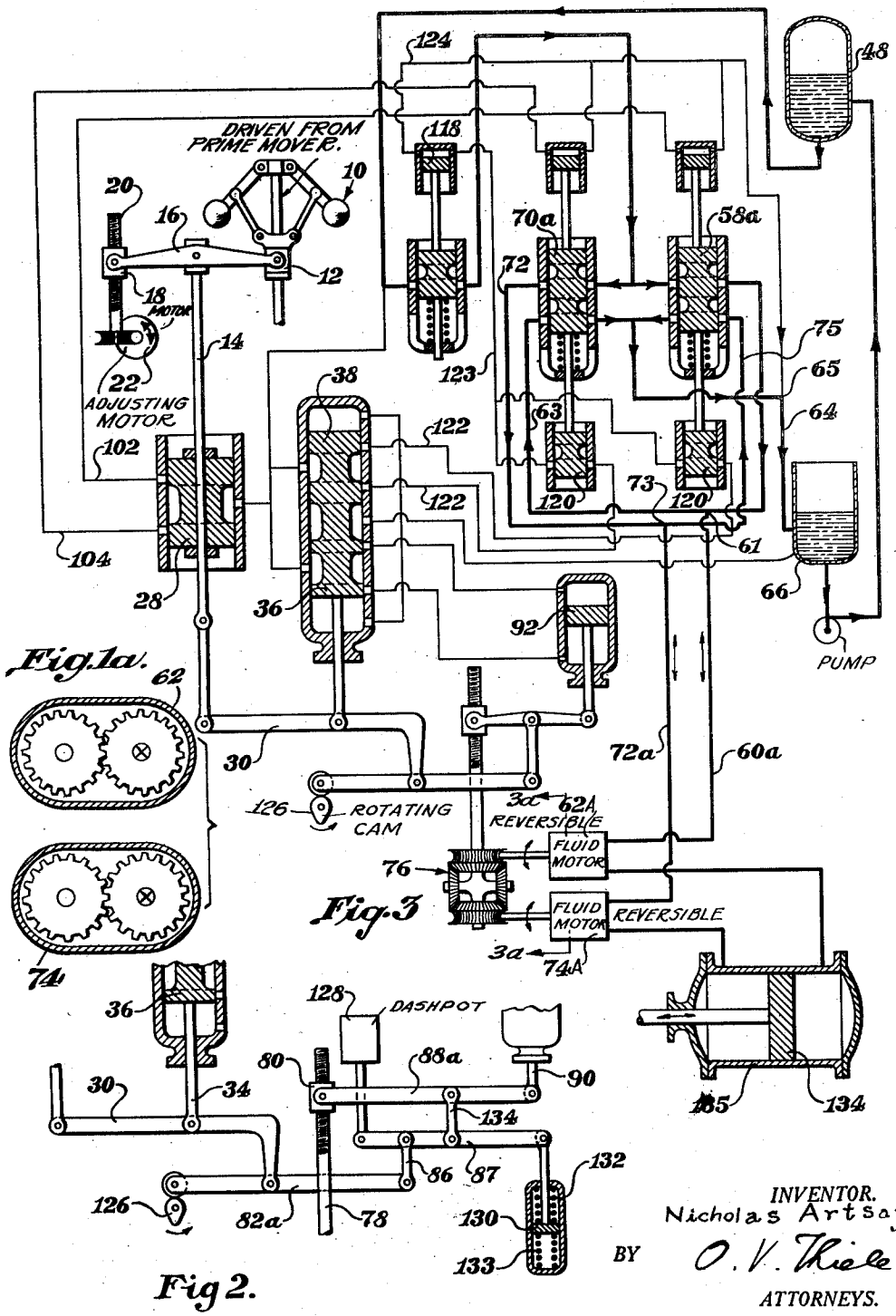


Fig.1a.

Fig.3

Fig 2.

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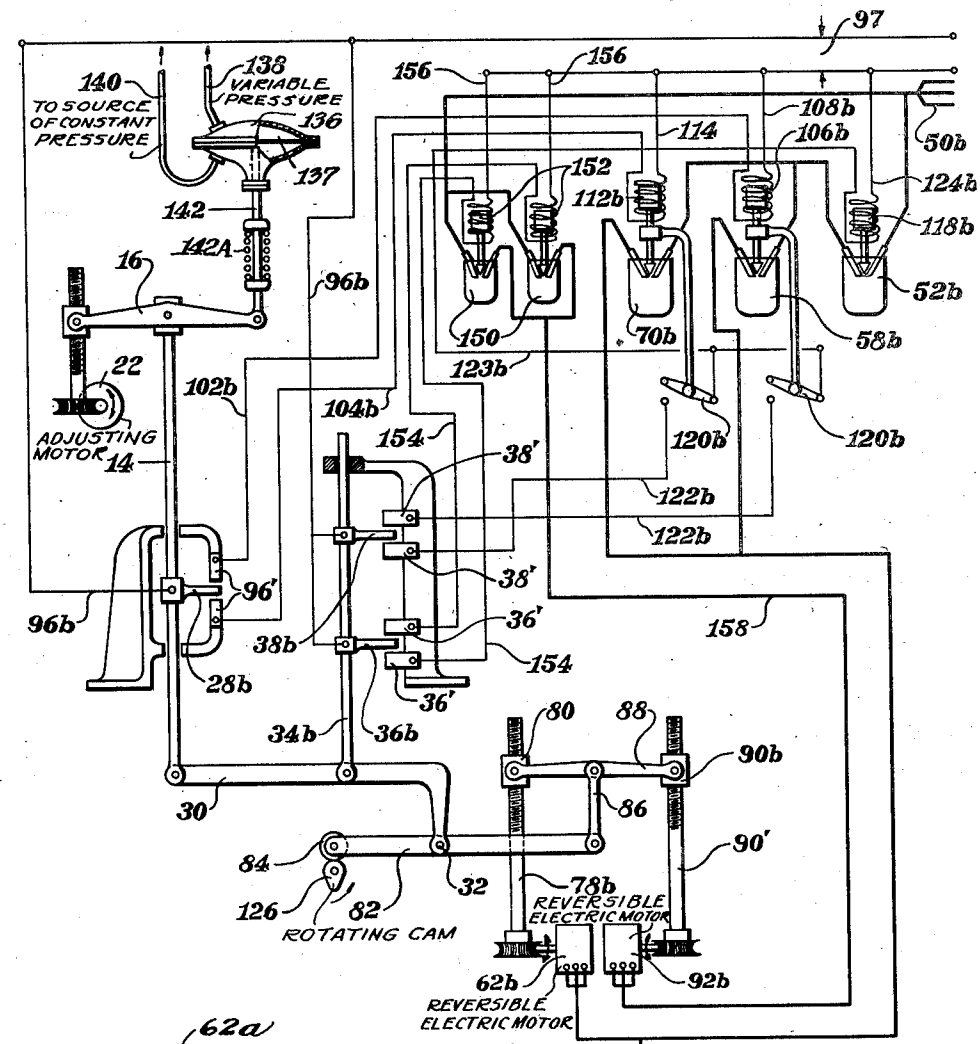


Fig 4.

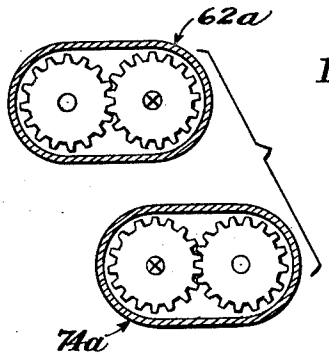
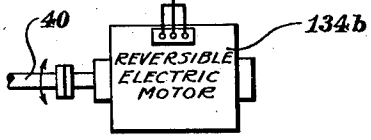


Fig. 3a.



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1,977,980

GOVERNING AND REGULATING APPARATUS

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Application June 17, 1932, Serial No. 617,795

20 Claims. (Cl. 264—4)

My invention relates to control apparatus adapted to govern the speed of hydraulic or steam turbines or to control any other characteristic of apparatus to maintain it constant within close limits.

The speed control of certain types of apparatus, of which hydraulic turbines may be considered as an example, has been a difficult problem, but the art has finally adopted almost exclusively for such purposes an apparatus in which a servo-motor controls the gate of the turbine, or equivalent member, and is controlled or governed in turn by a pilot element or valve actuated primarily by a centrifugal type governor, the governor operating thru a lever on a control member in the line for supplying energy to the motor.

It has been found desirable in such apparatus to provide an "inherent speed drop"; that is, the turbine speed is somewhat lower under higher loads and at larger gate openings than under lower loads and at smaller gate openings. Such inherent speed drop has come to be generally considered a necessary evil without which it is impracticable to obtain sensitive and stable governing. In order to maintain a constant speed at all loads, a supplementary mechanism, usually in the form of a synchronizing motor, is provided which acts thru suitable mechanism on the lever to which the ball governor is connected, such motor being regulated by electrical devices sensitive to the frequency changes of the electric generator which ordinarily forms the load of the turbine.

An additional difficulty which has been encountered in systems of the type above mentioned is that in many cases there is a considerable time lag between the movement of the lever caused by the centrifugal governor and the response of the system which carries such lever back to its normal position. In the type of system under consideration, an appreciable time lag in the response by the turbine to the movement of the gate will result in an over-travel and so-called "hunting" of the governor, thereby causing a constant oscillation of the apparatus around the desired position of equilibrium. This evil is usually lessened by the addition of compensating devices consisting of springs and a dash pot connected to the fulcrum of the governor operated lever. Such compensating dash pot mechanism reduces the time required for the governing mechanism to reach its position of equilibrium, but the springs used therewith tend to give a slow additional opening of the gate if the speed is not restored to normal. When the time lag is a matter of a fraction of a second only, such compensating devices work satisfactorily, but when the time lag is of the order of minutes as happens in certain systems, for instance in combustion control for steam boilers, the compensating devices are not sufficient to eliminate the hunting. Moreover, in the case of large time lag, a device providing sufficient compensation will reduce the sensitiveness of the governor. The problem is complicated by the fact also that the correctness of the regulation is proportional to the inherent speed drop. This results that, in case of large time lag, the speed fluctuations due to a given change in load will be relatively large and that, if the load fluctuations are quicker than the time lag, the turbine will be hunting and out of control.

It is the principal object of my invention to provide a governing or regulating apparatus adapted to minimize the above mentioned difficulties.

The novel features of my invention are pointed out in the appended claims. In order, however, that my invention, together with its objects and advantages, may be readily and fully understood, I will now describe in detail and in connection with the accompanying drawings, several forms of governing or controlling apparatus in accordance with my invention and which have been selected by way of example from a number of possible embodiments thereof. In the drawings,

Fig. 1 is a diagrammatic view of an apparatus in accordance with my invention and adapted to control a turbine gate by fluid actuated servo-motors, the parts being shown in the position of equilibrium assumed at constant speed.

Fig. 1*a* is a detail sectional view taken on a line 1*a*—1*a* of a pair of motors and associated gearing appearing in Fig. 1 and looking in the direction of the arrows.

Fig. 2 is a fragmentary view of a portion of a system similar to that shown in Fig. 1, but containing compensating devices.

Fig. 3 is a view of a system similar to that shown in Fig. 1, but modified to employ a single reciprocating servo-motor.

Fig. 3*a* is a detail sectional view taken on a line 3*a*—3*a* of a pair of motors and associated gearing appearing in Fig. 3 and looking in the direction of the arrows.

Fig. 4 is a diagrammatic view of a system in accordance with my invention employing an elec-

trical servo-motor and designed for fuel control or like purposes.

Fig. 5 is a sectional view, parts being broken away, of one of the differential drives appearing in Fig. 1.

Referring more particularly to Fig. 1, 10 is a governor of the centrifugal type whose weights change their position in response to changes in speed of a water turbine or like prime mover 11 whose speed it is desired to regulate. The collar 12 of governor 10 operates a pilot member 14 shown as being formed by a rod and which is moved by governor 10 in either direction from a neutral position in response to changes in speed of the turbine. In the arrangement illustrated, the governor acts on rod 14 thru a lever 16, one end of which is pivoted to a nut 18 on a worm spindle 20 which is operated thru suitable gearing by an adjusting motor 22, whereby the neutral point of the governor 10 and member 14 may be adjusted as desired. Such motors are commonly known to users of governing apparatus as "synchronizing" motors because they are used chiefly when synchronizing. However, spindle 20 may be hand operated if desired. The purpose of the spindle 20 when associated with gearing for changing the fulcrum of the lever 16 will appear hereinbelow, but it will be understood that such arrangements are not new in the art and that I do not limit myself thereto. On the pilot member 14 is a primary pilot valve 28 while the lower end of the rod 14 is pivotally linked to a lever 30 having a fulcrum at 32 which is movable in the plane of lever 30 in either direction from a neutral position. Pivoted to lever 30 also is a rod 34 which carries two auxiliary pilot valves 36 and 38 which physically may be considered as one valve having two control grooves for actuating fluid.

The gate 39 of turbine 11, or other main member which it is desired to control is shown as operatively connected to a shaft 40. For maintaining such gate in its desired normal position, means are provided for rotating shaft 40 in one direction or the other, depending on whether the speed is above or below normal. For this purpose I have illustrated two servo-motors 42 and 44 coupled to the shaft 40 thru suitable gearing 46 which is of known type and includes a cross 41 fixed to the upper end of shaft 40 and having a pair of vertical arms 43, 43 and a pair of horizontal arms 45, 45. A pair of bevel gears 47 are swivelled on vertical arms 43 and another such pair 49 are swivelled on horizontal arms 45. Gears 47 and 49 are intermeshed and gears 47 are connected by irreversible drives including worm wheels 51, 51 one to motor 42 and one to motor 44 so that when one motor operates, the wheels 49 roll on the gear 47 of the stationary motor and so turn cross 41 and shaft 40. Motors 42 and 44 turn shaft 40 in opposite directions. Motors 42 and 46 are adapted to be operated by energy supplied by pressure fluid from a source 48. For purposes of convenience, the paths of pressure fluid used for operating the main servo-motors 42 and 44 are shown in relatively heavy lines to distinguish from the paths of fluid used for other purposes. The path of the fluid from source 48 to motor 42 includes a conduit 50 which extends to a main cut-off valve 52. From valve 52 the liquid is conducted by a pipe 54 to a branch point 56 from which point fluid for motor 42 flows to a valve 58 thru a branch conduit 54*a*. From valve 58 fluid passes thru a conduit 60 and an auxiliary servo-motor 62 to the motor 42. Fluid discharged from motor 42 is returned by line 64 to a sump 66 from which it is pumped back to the reservoir 48 thru line 68.

The path of energy fluid from reservoir 48 for operating motor 44, after passing thru lines 50 and 54 to the point 56, as previously described, instead of passing thru branch 54*a*, turns at the point 56 into branch 54*b* and passes thru valve 70 and line 72 to auxiliary motor 74 and thence to servo-motor 44 to operate the shaft 40 in the opposite direction from that in which it is turned by motor 42. From motor 44 the energy-conveying fluid returns to the reservoir 48 thru line 64, sump 66 and line 68.

The auxiliary motors 62 and 74, when used, form part of a restoring mechanism whereby the valves 36 and 38 are moved back toward their normal position while the servo-motor mechanism is operating on shaft 40. By such restoring mechanism, as will hereinafter more clearly appear, the motion of the shaft 40 is rendered independent of the return motion of pilot valve 28 to its normal position thereby rendering the apparatus as a whole free from hunting and permitting it to be given an isochronous characteristic without the accompanying disadvantages present in previous isochronous governing mechanisms. In the arrangement illustrated for this purpose, auxiliary motors 62 and 74 are connected thru suitable gearing 76 (shown as of the same construction as gearing 46) to a threaded shaft 78 on which is a threaded nut 80, the position of which affects the position of the lever 30 and the rod 34 by an arrangement now to be described. As previously mentioned, one end of lever 30 is connected to the pilot rod 14. The other end of lever 30, however, is pivoted on a lever 82 one end of which is fulcrumed at 84 and the other end of which is pivotally connected thru a link 86 to the center of a lever 88 one end of which is pivoted on the nut 80. Therefore, whenever the servo-motor means of which motors 42 and 44 form a part is in operation, one of the motors 62 and 74 turns the rod 78 thru the gearing 76 to move nut 80 and thereby affect lever 30 and valves 36 and 38. The parts are so connected also as to move the rod 34 in the direction toward its neutral position, whichever one of auxiliary motors 62 and 74 happens to be in operation.

Preferably, the other end of lever 88 is pivotally connected to the rod 90 of a piston 92, the motion of which also necessarily has a restoring effect on lever 30 and pilot member 34 and the valves associated therewith because of the connection between lever 88 and lever 30. The operating fluid for piston 92 is controlled by the valve 36. The path for such fluid is shown in light lines and the same plan is followed for showing the paths of fluid for all auxiliary purposes. The path of fluid for piston 92 branches from the line 50 at the point 94 and flows thru the line 96 to the valve 36. Valve 36 controls two ports which are connected to opposite ends of the cylinder for piston 92 thru lines 98 and 100. When the valve rod 34 and valve 36 move in one direction due to the movement of pilot valve 14, fluid is admitted thru line 98 or 100 so that the piston 92 is moved and thereby the lever 88 causes a restoring movement of the rod 34 toward its neutral position. Preferably, when the restoring means of a given apparatus includes both the motors 62 and 74, or their equivalents, and the piston 92 or its equivalent, one-half the restoring motion is produced by piston 92. While each of the two restoring means, one involving piston

92 and the other involving differential gearing 76, produces in general the same effect on the lever 30 and the auxiliary pilot valve 38, the use of the piston operated restoring means alone is not so desirable as the use of the two restoring means for the reason that the piston restoring means must be either geared up or have a very long piston travel if it is to act alone, thereby reducing its sensitiveness. Similarly, the use of a geared restoring means alone produces a control or regulating mechanism of insufficient sensitiveness and one containing possibilities of stalling under certain conditions. However, I do not limit myself to the use of either of the particular restoring means above described. In the arrangements shown, such restoring motion renders the movement of shaft 40 substantially independent of the return movement of the main pilot member 14, an important feature of my invention. It is obtained in the following way:

The flow of energy to the main servo-motor means is controlled by relays, the motive fluid, or energy, for which is controlled by the position of valves 28 and 38. In the arrangement shown, the main pilot valve 28 receives energy-carrying fluid from the line 96 and controls two ports one of which connects to a line 102, the other of which connects to a line 104. Line 102 runs to the cylinder of a relay piston 106. Fluid discharged from cylinder of piston 106 passes thru line 108 to line 110 and thence to the sump 66. Fluid passing thru the line 104 flows to the cylinder of a relay piston 112. Fluid discharged from the cylinder of piston 112 flows thru line 114 to the line 110 and thence to sump 66. The outlets 107 and 113 for fluid from the cylinders for pistons 106 and 112 are restricted so that pressure builds up quickly in the cylinders to operate the pistons whenever valve 28 opens the proper ports. Pistons 106 and 112 are both single-acting and serve to throw valves 58 and 70 respectively into position to permit energy-carrying fluid to flow thru the lines controlled thereby. Pistons 106 and 112 being single-acting, valves 58 and 70 are returned to normal position in which flow through such valves is cut off by means of springs 116, 116. When either valve 58 or valve 70 is in open position, energy can not flow to the servo-motor means unless the valve 52 is also open. The valve 52 is operated by a piston 118, the operating fluid for which is controlled thru two auxiliary valves 120, 120 one of which is on the stem of valve 58 and the other of which is on the stem of valve 70. Fluid for operating piston 118 is also controlled by pilot valve 38 in series with the valves 120. When pilot valve 28 is moved by the governor 10 in a given direction so as to operate one of the valves 58 or 70, the valve 38 is also operated in the same direction and so that fluid passes into one of the lines 122, 122 from one of its ports. Fluid for this purpose is derived from the line 96 and passes from valve 38 into one of lines 122 which lead thru the valves 120 into a common line 123 which supplies the cylinder of piston 118. Piston 118 also is of the single-acting type and is returned to its normal or inoperative position in which flow through such valves is cut off by a spring 116. Its cylinder also has a restricted discharge, permitting the omission of further control means. Fluid discharged from the cylinder of piston 118 flows thru line 124 to a line 110. It will appear, therefore, that the movement of the pilot valves 28 and 38 in a given direction will open a path for the energy fluid to pass to the servo-motors 42 and 44 to operate the shaft 40 in the appropriate direction. It will be noted, however, that the valve 38 has an overlap 39, 39 on both its outlet ports, the purpose of which is to prevent the motion of the main servo-motor means from being affected by the return motion of main pilot 28 toward normal position after it has initiated a movement of the main servo-motors.

It will be understood that the description of function and results given herein, in so far as speed regulation is concerned, applies only to cases in which the changes of speed are caused by changes in load, as it is considered impossible that a governing mechanism off-set the effects of changes in pressure of the medium driving the prime mover.

While the operation of the mechanism above described will be obvious to those skilled in the art from the foregoing description, it may be summarized for purposes of convenience as follows:

Roughly speaking, the operation of the governing or regulating apparatus is divided into three periods.

First period.—Assuming an increase of load with consequent decrease in speed of the turbine 11, the movements are; rod 14 and with it main pilot 28 and auxiliary pilots 36 and 38 move downwardly. Thru the lower left hand port of the main pilot 28 fluid passes thru line 104 to piston 112 of valve 70 causing valve 70 to open. Thru the right hand lower port of valve 36 the fluid begins to fill the space below the piston 92 of the restoring mechanism, thereby moving such piston upwardly and also moving up thru links 88, 86 and 82 one end of the lever 30 and thereby simultaneously moving upwardly the auxiliary pilots 36 and 38 toward closed or neutral position to thereby cut off fluid flow therethrough. Thru the lower right hand port of auxiliary pilot valve 38, fluid passes thru one of the valves 120 which was opened by the movement of main valve 70, into the cylinder of piston 118 thereby opening the main power valve 52. Valve 52 and one of the valves 58 or 70 thus being open, the servo-motor apparatus is operated. Since valve 70 is assumed to be opened, the motor 44 will operate and such operation continues to the extent of operating the shaft 40, and thereby the turbine gate, to an extent proportional to the initial displacement of pilot valve 28.

The turbine gate is moved proportionately to the change in speed because the change of speed is assumed to be due to a change in load. Hence, a proportionately greater gate opening is required to carry the new load at the original speed. The mechanism illustrated in Fig. 1 causes such proportional movement of the gate for the reason that the main servo-motors 42 and 44 run throughout the time during which the auxiliary pilots 36 and 38 are returning to their new positions after having been displaced by the movement of the main pilot control valve 28. But the mechanism which restores members 36 and 38 to neutral is, throughout such period, being operated by motor 62 or 74, both of which are propelled by fluid at constant pressure derived from reservoir 48 and move therefore at a constant rate of speed because the load on such motors is obviously constant. The length of time required for members 36 and 38 to return to the neutral position is therefore proportional to their initial displacement away from neutral caused by movement of member 28. However, motor 42

or motor 44 runs until members 36 and 38 reach their neutral positions. Motors 42 and 44 also are constant speed motors, operating under constant pressure from reservoir 48 and run throughout the periods the auxiliary pilots 36 and 38 are returning to their neutral positions. The movements of the gate produced by 42 and 44 are therefore also proportional to the initial displacement of the main pilot valve 28, movements of members 36 and 38 away from their neutral obviously being proportional to the movements of member 28 away from its neutral. However, the restoring mechanism moves the valves 36 and 38 back to neutral thereby cutting off the restoring action of piston 92 and also cutting off the flow of energy to the piston 118 of main stop valve 52. The condition at this point, which is assumed to be the end of the first period, is such that the turbine speed is increasing but not yet normal due to the time lag, so that the pilot valve 28 is not in neutral position. Consequently, the valve 70 remains open but there is no flow of energy to the servo-motor means because the stop valve 52 is shut.

Second period.—The second period starts when the turbine begins to speed up, thus overlapping somewhat the first period. During the second period, the pilot valve 28 begins to move toward its neutral due to the governing action, but valves 36 and 38 having been already moved to neutral position by the restoring means are then moved into position above neutral, thus supplying actuating fluid to the space above piston 92 and such piston thereupon begins to return the pilot valves 36 and 38 to neutral. The main stop valve 52, however, remains shut because of the overlap 39 of valve 38 which covers the lower port of such valve and the opened upper port can not pass fluid because the circuit for the piston 118 is closed by the auxiliary valve 120 belonging to the closed valve 58 and valve 58 is maintained closed by the position of pilot 28 which is below the neutral. Therefore, during the second period, the turbine gradually speeds up, shaft 40 remaining stationary so that the gate remains in the position given it during the first period. The restoring piston 92 slightly over-balances the movement of the main pilot 28 in its effect on lever 30 to bring the pilots 36 and 38 into neutral. Such restoration of valves 36 and 38 to neutral is important in that it restores the sensitiveness of the governing system so that it can respond to a further slowing down of the turbine if an additional increase in load occurs during the second period.

Third period.—The third period occurs only occasionally and is produced in cases where the time lag is considerable and the increase in load with consequent decrease in speed is continuous. Under such conditions, the amount of opening of the gate effected during the first period is insufficient and consequently the governor 10 will not be brought back to normal speed and the pilot valve 28 will not reach its neutral position. The governing system, however, will be inactive because the pilot valves 36 and 38 have been restored to their neutral positions.

There is thus a residual error in the operation of the system as heretofore described for conditions stated under the third period, and I prefer to provide means for correcting such error. In the arrangement shown for this purpose the fulcrum 84 of lever 82 has the form of a cam surface which rests upon a rotating cam member 126. The cam member 126 causes a continuous oscillation of lever 82 which is communicated thru pivot 32 and lever 30 to the auxiliary pilots 36 and 38 as a reciprocating action. Pilot 28 being below its neutral, no effect is produced by cam 126 when it lifts pilots 36 and 38 above their neutrals, but when the cam permits valves 36 and 38 to drop below their neutrals there will be a slight additional movement of servo-motor 44 and shaft 40 in the same direction as assumed in the first period. If the speed is correct the action of cam 126 will not produce any movement of shaft 40 because pilot 28 is shut.

In the arrangement illustrated in Fig. 1, separate motors 62 and 74 are provided as part of the restoring means. Such servo-motors 62 and 74 are, however, the equivalent of driving the spindle 78 by gearing from the spindle 40, motors 62 and 74 each operating concurrently with one of the motors 42 and 44.

The system illustrated in Fig. 1 does not contain any means corresponding to the damping device usually employed in governor mechanisms. Whenever conditions make it advisable to employ such damping means in connection with my invention, it may be provided conveniently by interposing such damping device between the levers 82 and 88. Such an arrangement is illustrated in Fig. 2 in which the link 86 for supporting the lever 82*a* is connected to a lever 87 one end of which is connected to a dash pot 128 and the other end of which is connected to a piston 13 whose normal position is determined by springs 132 and 133 acting on its opposite face. Lever 87 is connected at its center by link 134 to the lever 88*a*. Otherwise, the arrangement of Fig. 2 is assumed to be the same as that illustrated in Fig. 1, parts having the same function in the two arrangements having the same reference character.

While the apparatus within my invention can not altogether prevent variations in speed of turbines used to drive generators due to disturbances on the lines, which cause the generator whose turbine may be governed by my apparatus sometimes to become "motorized", as it is called in the art, even in such cases, the apparatus in accordance with my invention is adapted to maintain the turbine load fluctuations within more narrow limits than do the governors in accordance with the prior art.

In case rotating motors such as 42 and 44 are too slow for the conditions under which the turbine is to operate, the arrangement such as that illustrated in Fig. 3 may be substituted and in which a piston 134 and its associated cylinder 135 is used instead of motors 42 and 44. In such an arrangement, valves 58 and 70 are substituted by two-way valves 58*a* and 70*a*, the arrangement otherwise being the same as indicated by the reference character on Fig. 3, except as to the conduit arrangement for the energy conveying liquid between valves 58*a* and 70*a* and the sump 66. As shown in Fig. 3 conduit 65 extends from the upper high pressure port of valve 58*a* to a junction point 61 from which point the operating liquid is conveyed by conduit 60*a* thru reversible series motor 62A to one end of the cylinder of piston 134 to move such piston in one direction, which will be called the forward direction. On the return stroke of piston 134, however, liquid flows from the cylinder thru motor 62A and conduit 60*a* to point 61 and thence thru conduit 63 to the low pressure or return port of valve 70*a* thru which it flows to point 65 where it enters return conduit 64. The power fluid for the return stroke of pis-

ton 134 is delivered by valve 70*a* to conduit 72 thru which it flows to junction point 73 and thence it flows by conduit 72*a* thru reversible series motor 74A to the other end of the cylinder of piston 134 to operate such piston on its return stroke in the opposite direction to that in which it is moved by fluid reaching its cylinder thru conduit 60*a*.

When now the piston 134 has completed a given return stroke and the positions of valves 58*a* and 70*a* have been shifted so as to cause a second forward stroke, liquid flows from cylinder 135 thru pipe or conduit 72*a* to branch point 73 and thence thru conduit 75 to the lower port of valve 58*a* and thru such valve to the common return conduit 64 at junction point 65. It will be noted from Figs. 1*a* and 3*a* that the motors 62A and 74A associated with the gearing 76 in Fig. 3 are of the same type as the motors 62 and 74 associated with the gearing 76 of Fig. 1. The motors 62 and 74 of Fig. 1 need turn in one direction only, the liquid flow through such motors being in one direction only. The motors 62A and 74A, however, must reverse in order to permit the operating liquid to flow into and out of the opposite ends of the reciprocating piston motor 135. In order therefore, that the motors 62A and 74A shall have the necessary action on the adjusting rods 78 and nuts 80, the operating shaft of motor 62A is connected to the right hand gear of such motor and the operating shaft of motor 74A is connected to the left hand gear. This distinction between motor 62A and motor 74A is indicated in Figs. 1*a* and 3*a* by crosses (×) on the axes of the gears having the motorshafts fixed thereto. It results that, when the fluid is passing thru motors 62A and 74A in opposite directions, the driving shafts acting on the gearing 76 turn in the same direction. The differential feature of gearing 76 therefore is not so important in Fig. 3 as in Fig. 1 although it is preferred to use a differential gear in Fig. 3 in order to accommodate any slight differences of speed between the motors 62A and 74A and/or back-lash of liquid in motor 135.

In some cases of remote control, it is desirable to utilize electric energy in place of the liquid assumed in the arrangements illustrated in Figs. 1, 2 and 3. Such an electric system is illustrated in Fig. 4. In Fig. 4, it is assumed that the mechanism is to be utilized for combustion or pressure control instead of for speed control so that a diaphragm 137 within a casing 136 supplies the initial impulse for moving the pilot members from their neutral positions. As illustrated, pressure differences are set up on each side of the diaphragn within casing 136 by fluid entering such casing thru pipes 138 and 140 on opposite sides of the diaphragm, pipe 138 being connected, for instance, to a source of variable pressure such as boiler and pipe 140 connected to a source of constant pressure produced by any suitable or known means. The diaphragm is connected to a rod 142 the movements of which are transmitted to the lever 16 which connects in turn with the pilot rod 14. Surrounding rod 142 is a spring 142A which serves to fix approximately the zero or neutral point of the diaphragm. The neutral point of the pilot member 14 and the pilot contact 28B may, however, be adjusted during operation when desired, for any given spring 142A and constant pressure source attached to pipe 140, by adjusting one end of lever 16 by operating adjusting motor 22. On the pilot rod 14 is fixed a movable contact 28*b* which is connected thru line 96*b* with one side of an auxiliary circuit 97 for supplying the electric energy to the contacts and relays of the apparatus. The circuits of all such auxiliary apparatus are shown in light lines to distinguish them from the circuits for the main servo-motor which are shown in heavy lines. The movable contact 28*b* lies normally between two fixed contacts 96', 96'. The upper of contacts 96' connects thru line 102*b* with an operating relay 106*b* the other side of which connects to the circuit 97 thru line 108*b*. The lower of the contacts 96' connects thru the line 104*b* with the relay 112*b*, the other side of which connects to the circuit 97 by line 114*b*. Relays 106*b* and 112*b* control the switches 58*b* and 70*b* of a reversible servo-motor 134*b* for operating the shaft 40. If the apparatus of Fig. 4 is to be used to control the pressure in a steam boiler having dampers and/or fuel valves (not shown), the shaft 40 of servo-motor 144*b* is connected to open such dampers and fuel valves whenever the shaft turns in one direction and to close such dampers and fuel valves when the shaft 40 turns in the other direction. In the illustration of the arrangement of which motor 134*b* forms a part, I have shown also arranged in series with whichever one of the switches 58*b* or 70*b* is in closed position a main switch 52*b* having a relay 118*b* the current for which is supplied from the circuit 97 thru lead 96*b*, movable contact 38*b* on rod 34*b* and one of the fixed contacts 38', 38'.

From either of the fixed contacts 38' current flows to the relay 118*b* thru one of the leads 122*b*. Each of leads 122*b* has in it a switch 120*b* which is fixed to the rod of one of the switches 58*b* or 70*b* so that one of switches 120*b* is closed whenever either of switches 58*b* or 70*b* is closed. Line 122*b* joins after passing thru switches 120*b* in lead 123*b* which conducts the current to the relay 118*b* from which it returns to the circuit 97 thru line 124*b*.

Rod 34*b* has thereon also a second movable contact 36*b* which is adapted to contact with either of fixed contacts 36', 36' depending on the direction and motion of rod 34*b* from its neutral position. Rod 34*b* is pivoted to a lever 30 which is pivoted in turn at point 32 to a lever 82. One end of lever 82 is supported at 84 on a rotating cam 126 while the other end of lever 82 is pivotally supported by a link 86, the upper end of which is pivoted to the centre of lever 88. One end of lever 88 is pivoted to a nut 80 and the other end of lever 88 is pivoted to a nut 90*b*. Parts 30, 82, 86 and 88 of the arrangement illustrated in Fig. 4 have the same functions as the same parts in the apparatus of Fig. 3. The lever 88 therefore forms part of a restoring means for restoring the rod 34*b* and its associated contacts to a neutral position irrespective of the motion of the pilot rod 14. To perform this function, nut 80 which supports one end of the lever 88 is threaded on a shaft 78*b* which is turned in one direction or the other by a motor 62*b* connected in parallel with the motor 134*b*. The nut 90*b* which supports the other end of lever 88 is threaded on a shaft 90' which is operated in one direction or the other by a motor 92*b* the circuit for which is controlled by two switches 150, 150, the relays 152, 152 for which receive operating current from the contact 36*b* and either one or the other of contacts 36'. Each of contacts 36' connects with one of the relays 152 thru one of the lines 154, 154. The other side of relays 152 connects with the relay operating circuit thru the return leads 156, 156. Switches 150 are connected in parallel with the power line 50*b* for the main servo-motor 134*b* and the line 158 for the restoring motor 92*b*. It will be seen there-

fore that in the arrangement illustrated in Fig. 4 the restoring motion is given the rod 34*b* both by the motor 62*b* which operates at the same time as the main servo-motor 134*b* and also by the motor 92*b* whose action is controlled by the position of rod 34*b* itself. It will be seen therefore that the action of the apparatus illustrated in Fig. 4 is quite similar to that illustrated in Figs. 1 and 3 so that it need not be further described.

In each of the mechanisms shown in Figs. 1, 3, and 4, I have illustrated means foreign to the regulating system for effecting corrections of performance, and shown as a synchronizing mechanism comprising parts 18, 20 and 22 and connected to the lever 16. Such synchronizing means is common in the art and I do not limit myself thereto, altho its use is advantageous in making final adjustments to compensate for inaccuracies in the action of the governor or controlling mechanism due to any inaccuracies of construction or adjustment as well as to damp the departures from normal speed which will be inevitably caused by line disturbances, some of which produce conditions which it is impossible for any governing mechanism to completely counteract.

While I have described the structures illustrated in Figs. 1, 2 and 3 as arranged to control the speed of a turbine or like prime mover and have described the structure illustrated in Fig. 4 as arranged to control the pressure of a boiler or the combustion in a furnace, it will be evident that the structures of Figs. 1, 2 or 3 may be utilized for controlling pressures, rates of combustion, or other functions, while the apparatus illustrated in Fig. 4 is adapted to control the speed of a prime mover, equally well as the structures of Figs. 1, 2 and 3, the rod 142, however, being substituted in such case by the collar of a ball governor as in Fig. 1. In general, the electric embodiment of the invention illustrated in Fig. 4 is less expensive than the hydraulic apparatuses of Figs. 1 and 3, but cannot be employed where there is danger of explosion.

A comparison of the foregoing embodiments of my invention with apparatus according to the prior art shows that while, in usual governors or regulators, the gate, or the like regulated element, follows the forward and return motion of the ball governor's rod and different gate openings are secured by allowing a so-called inherent speed drop, in apparatus in accordance with my invention, the gate, or the like, does not follow the return motion of the regulating rod, being prevented from so doing by a combination of valves or members, controlled by an auxiliary pilot valve, or member. This allows apparatus in accordance with my invention to operate without the inherent speed drop while having at the same time a damping effect produced by the restoring motion. The so-called isochronous governors may also operate without an inherent speed drop, but they are unstable because of the lack of restoring motion which in turn allows continuous hunting between the extreme gate positions whenever there is the slightest time lag. A governor or regulator mechanism in accordance with my invention is inherently isochronous, while the various gate openings are secured by the action of mechanism which stops the gate movement during the return of the ball governor's rod to neutral position. For other purposes than turbine speed regulation, apparatus in accordance with my invention achieves a correct correspondence between the movement of the regulated element and that of the regulating impulse or element without following the latter's return action, thus making the governor or regulator entirely independent of the time lag between the initial impulse and the restoration of normal condition. This feature has hitherto been unattained in the art and is very advantageous in, for instance, combustion control apparatus for steam boilers, for keeping steam pressure or steam temperature constant at various steaming rates, and for regulating other features of steam generation.

In short, in apparatus in accordance with my invention the position of the regulated element is always proportional to the algebraical sum of the displacements of the governor's collar, or other regulating element, away from its neutral or normal position.

What I claim is:

1. In a governor or regulating apparatus the combination with a pilot element adapted to move in either of two directions from a neutral position in response to changes in a condition which it is desired to maintain constant, means for moving said element in response to the changes in said condition, a second pilot member auxiliary to said element and also moved by said means, a motor driven means adapted to operate in either of two directions for altering said condition, and means whereby said first pilot element and said auxiliary pilot member control said motor driven means, said control means comprising a pair of energy controlling members in the path of the energy supply of the motor of said motor driven means, one member of said pair controlling a given direction of movement of said motor and the other controlling the opposite direction of movement of said motor driven means, means whereby said pair of members are controlled by the position of said first pilot element, another energy controlling member in the path of the energy supply of said motor and arranged to act in series with whichever one of said pair of members is active, and means whereby said last mentioned member is controlled by the position of said auxiliary pilot member.

2. In a governor or regulating apparatus the combination as set forth in claim 1 together with means whereby the auxiliary pilot member is moved toward its neutral position during the operation of the motor driven means.

3. In a motor-operated governor or regulating apparatus, the combination of a pilot element arranged to move in either direction from a neutral position, a lever having a pivot and operated by said element, an auxiliary pilot member operated from said lever, a main governing element, and motor means for moving said main element in one direction or the other as circumstances may require and including two energy controlling members arranged to act in series on the energy supplied to the motor of said motor means, means whereby one of said energy controlling members is controlled by said first pilot element and the other by said auxiliary pilot member, and means for moving said auxiliary pilot member in the direction toward its neutral position independently of said motor means, said members and means being constructed and arranged to prevent disturbance of the energy supply to said motor means by said restoring action.

4. The combination in a regulating mechanism for keeping constant a certain condition of a pilot element responsive to the variations of the desired condition in a system to be regulated, of a power operated means for effecting changes

to counteract said variations, a system of members for controlling flow of actuating energy to said power means and so associated with said element that, when the variation of condition indicated by said element has been corrected, said power operated means stands still while the full response of the regulated system to the new setting of parts brings said elements back into neutral position whenever there is no additional departure from the desired condition of the regulated apparatus during the return movement of said element, a mounting for said pilot element adapted to bring it to rest when normal performance of the regulated system is reached, and including an auxiliary element mounted to move away from its neutral position whenever said pilot element is displaced from neutral and means for restoring said auxiliary element to neutral while said pilot element is still displaced therefrom, said means adapted to fix the relation between the final amount and direction of the displacements of the power means and the initial amount and direction of the corresponding displacements of said pilot element away from the latter's neutral position.

5. The combination in a regulating mechanism for keeping constant a certain condition of the pilot elements responsive to the variation from the desired condition, power operated means for effecting changes to counteract said variations, a system of members having control of the flow of actuating energy to said power actuated means and so associated with said pilot element that, when the variation of condition indicated by said pilot element has been corrected, said power operated means stands still while the full response of the regulated apparatus to the new setting of parts brings said pilot element back into neutral position whenever there is no additional departure from the desired condition of the regulated apparatus during the return movement of the pilot element, said system of members for controlling the actuating energy including a first control member direct connected to said pilot element, a floating lever one end of which is connected to the first element and a restoring mechanism to which the other end of said lever is connected, two other control members connected to move together and to be operated by an intermediate point or part of said lever, means whereby the one of said control members connected to said lever affects said restoring mechanism, and means whereby the other of said control members connected to said lever indirectly controls the flow of energy to said power operated means.

6. The combination in a regulating mechanism for keeping constant a certain condition in a regulated apparatus of a pilot element responsive to the variation from the desired condition in said apparatus, a power operated means for effecting changes in the regulated apparatus to counteract said variations, a system of members for controlling flow of actuating energy to said power means and so associated with said pilot element that, when the variation of condition indicated by said pilot element has been corrected, said power operated means stands still while the full response of the regulated apparatus to the new setting of parts brings said pilot element back into neutral position whenever there is no additional departure from the desired condition of the regulated apparatus during the return movement of the pilot element, said system of members including a first control member direct connected to said pilot element, a floating lever, one end of which is connected to said pilot element, a restoring mechanism to which the other end of said lever is connected, two control members connected to move together and to be operated by an intermediate part of said lever, means whereby one of said two control members connected to said lever affects said restoring mechanism, and means whereby the other of said two control members connected to said lever controls the flow of energy to the power operated means, said last mentioned means including a pair of power control members one in the line of the power element for forward running and one in the line of the power element for reverse running and a third power control member in series with both said power control members, means whereby the control member on said pilot element controls said pair of power control members, a pair of additional members connected to operate simultaneously with said pair of power control members and adapted to inhibit or permit the operation of said series power control member, and connected between the said members so constructed and arranged that when the second and third control members connected to said lever are brought to neutral by said restoring motion and then carried beyond neutral by the return motion of said pilot element toward its neutral, the energy for the power element is cut off.

7. A governing or regulating mechanism having substantially zero inherent speed drop and comprising a pilot element, a regulating element, a servo-motor for moving said regulating element in one direction or the other depending upon the position of said pilot element, a lever directly connected to said pilot element, a movable fulcrum for one end of said lever, an auxiliary pilot member connected to an intermediate point of said lever, means controlled by the displacement of said pilot members in a given direction from their neutral positions for operating said servo-motor in one direction or the other, and a restoring movement adapted to move said pivot of said lever in the direction to restore said auxiliary pilot member to a neutral position while said first element is still out of neutral position.

8. A regulating mechanism as set forth in claim 7 and in which the restoring movement includes an auxiliary servo-motor operating in parallel with the main servo-motor.

9. The mechanism as set forth in claim 7 together with a continuously rotating member arranged to produce an oscillation of the lever to which the auxiliary pilot member is connected.

10. The combination in a governing mechanism of main and auxiliary pilot members, means for moving said main member in either direction from a given position in response to changes in a condition which it is desired to maintain as constant as possible, means whereby said auxiliary pilot member is moved one way or the other from a neutral position at the same time said main pilot member is moved away from its said position, a servo-motor, means for conducting energy to said motor, means whereby initiation of the flow of energy to said motor through said means is controlled by said main pilot member, means for restoring said auxiliary pilot member to its neutral position ahead of the return of the said main pilot member to its original position, and means whereby the flow of energy through said conducting means is interrupted when said auxiliary pilot member is substantially in neutral position.

11. The combination as set forth in claim 10

and in which the means for restoring the auxiliary pilot member is adapted and arranged to restore such auxiliary member substantially to its neutral position prior to the beginning of the return movement of the main pilot member toward its given position.

12. The combination as set forth in claim 10 and in which the parts are so arranged that the movement of the auxiliary pilot member toward its neutral position has substantially no effect in assisting the movement of the main pilot member to its given position.

13. The combination in a governing mechanism of the servo-motor type of a main pilot member and an auxiliary pilot member both having neutral positions, a servo-motor, means including said main pilot member, for supplying energy to said motor, and means for interrupting the action of said means when said auxiliary pilot member is in its neutral position irrespective of the position of said main pilot member.

14. The combination in a governing or regulating mechanism of the servo-motor type, of a servo-motor means, a source of supply of energy therefor, means for conducting energy from said source to said motor means including a line leading from said source and having two branches extending from a branch point to said motor means, a means individual to each of said branches for controlling the passage of energy therethrough, a means individual to the portion of said line intermediate said source and said branch point for controlling the flow of energy through such portion, a main pilot element, means whereby the motion of said pilot element causes the energy controlling means in one or the other of said branches, depending on the direction of said motion, to assume a position to pass energy to said servo-motor means, an auxiliary pilot member, means whereby said auxiliary pilot member moves at the same time as said main pilot element whenever the main pilot initiates a movement which is to cause the energy controlling means in one of said branches to assume a position to pass energy, energy using means whereby said auxiliary pilot member causes the energy controlling means in said portion of said line between said source and said branch point to pass energy whenever such auxiliary pilot moves together with said main pilot and irrespective of the direction of motion of the auxiliary pilot, and means individual to each of the energy controlling means in said branches and adapted to interrupt the action of said energy using means to permit the interruption of flow of energy to said servo-motor means.

15. The combination in a regulating mechanism of a main pilot member and an auxiliary pilot member connected together, a servo-motor means, means whereby simultaneous motion of said pilot members in directions away from given positions inaugurates flow of energy to said servo-motor means, and means for restoring said auxiliary pilot member to its given position ahead of said main pilot, said restoring means including means whereby the auxiliary pilot is moved toward its own given position to compensate for the return movement of the main pilot member toward its own given position, said energy inaugurating means including means whereby an overrunning of said auxiliary pilot on its return movement due to the return motion of said main pilot member is ineffective to inaugurate a flow of energy to said servo-motor means.

16. The combination in a governing or regulating apparatus for keeping constant a certain condition in a system controlled thereby and having an arrangement producing a substantially zero inherent speed drop of a pilot element having a neutral position, a servo-motor means, and mechanism including parts for controlling the flow of energy to said servo-motor means whereby such means is caused to operate in one direction or the other depending on the displacement of said pilot element from its neutral position, said mechanism adapted to remain unaffected by movements of said element in the direction toward its neutral position irrespective of the speed of response of the said controlled system.

17. The combination in an apparatus as set forth in claim 16 and in which the parts are constructed and arranged so that the net regulating action is proportional to the algebraic sum of the movements of the pilot element away from its neutral position.

18. The combination in an apparatus for governing or regulating a given condition in a system controlled thereby and adapted to act substantially without inherent speed drop of a pilot element having a neutral position and adapted to move either way therefrom, and means including a servo-motor and an energy supply therefor whereby the net governing or regulating action is proportional to the algebraic sum of displacements of said pilot member away from its said neutral position independently of the speed of response of said controlled system, said means including parts for isolating said servo motor from its energy supply during movements of said pilot member toward its neutral.

19. A regulating apparatus for keeping substantially constant a desired condition in a system controlled thereby, said apparatus having a pilot element responsive to the variations from said desired condition and having a neutral position, a power operated means for effecting changes to counteract said variations, members for controlling the flow of actuating energy to said power means and so associated with said pilot element that, when the variation of conditions indicated by said pilot element has been corrected said power operated means stands still while the full response of the regulated system to the new position brings said pilot element back into its neutral position whenever there is no additional departure from the desired condition of the regulated system during the return movement of the pilot element and independently of the speed of response of the regulated system.

20. A regulating apparatus as set forth in claim 19 and in which the members for controlling flow of actuating energy to the power operated means are arranged to remain inoperative when the pilot element returns to its neutral position.

NICHOLAS ARTSAY.

CERTIFICATE OF CORRECTION.

Patent No. 1,977,980. October 23, 1934.

NICHOLAS ARTSAY.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 7, line 97-98, claim 6, for "connected" read connections; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 8th day of January, A. D. 1935.

Leslie Frazer

Acting Commissioner of Patents.

(Seal)