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FEED WATER CONTROL SYSTEM

Filed May 21, 1930

3 Sheets-Sheet 1

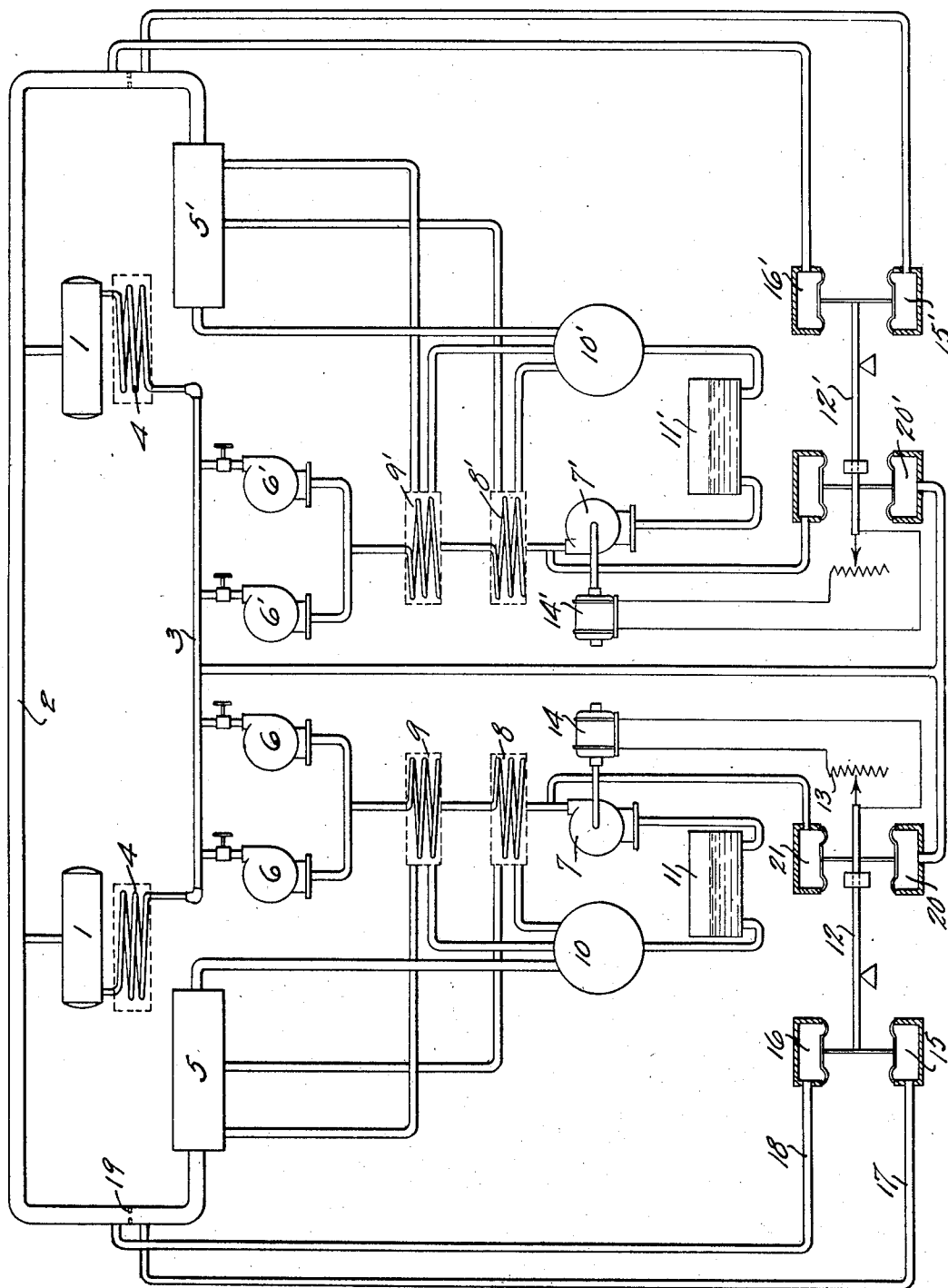


Fig. 1.

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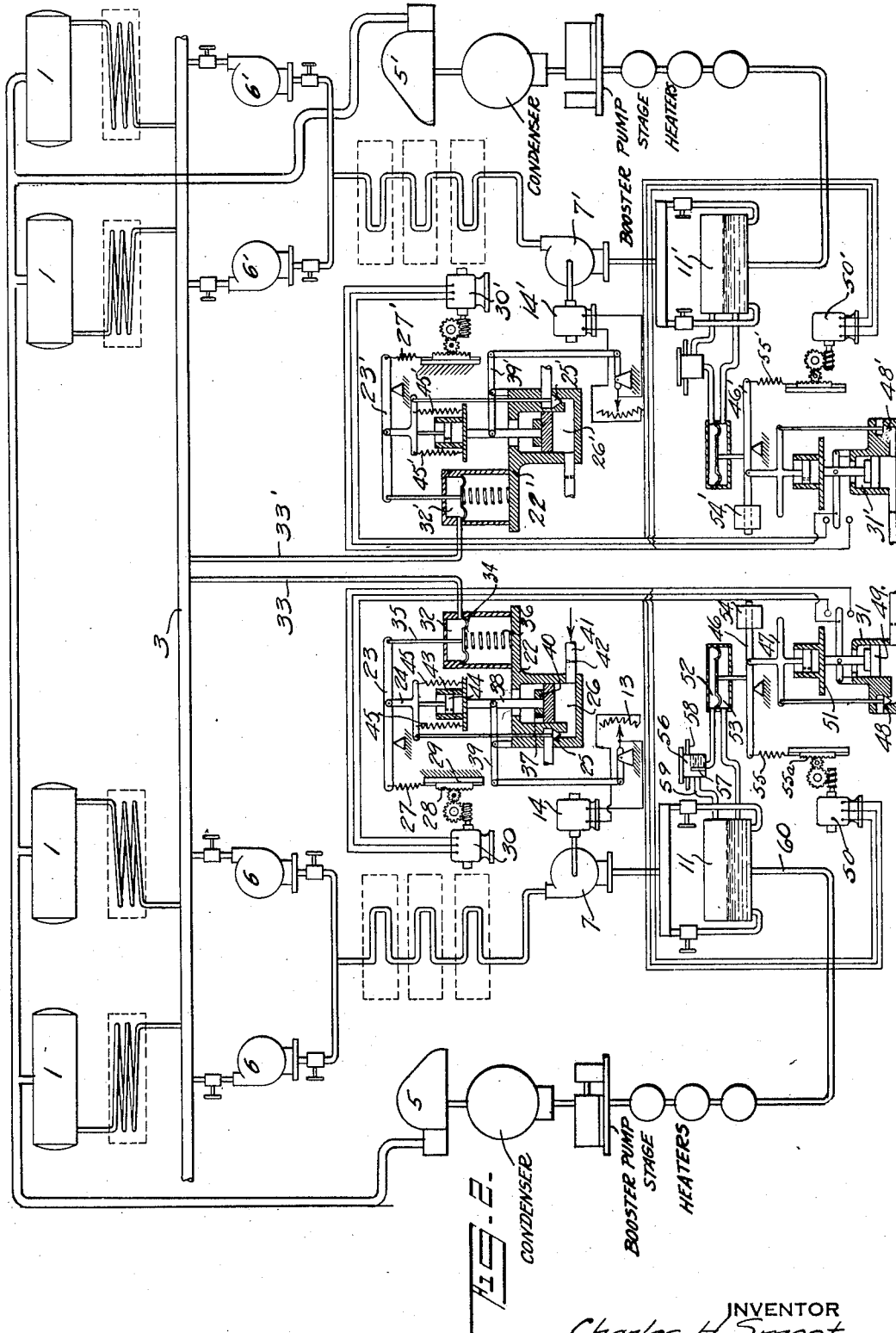
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3 Sheets-Sheet 2



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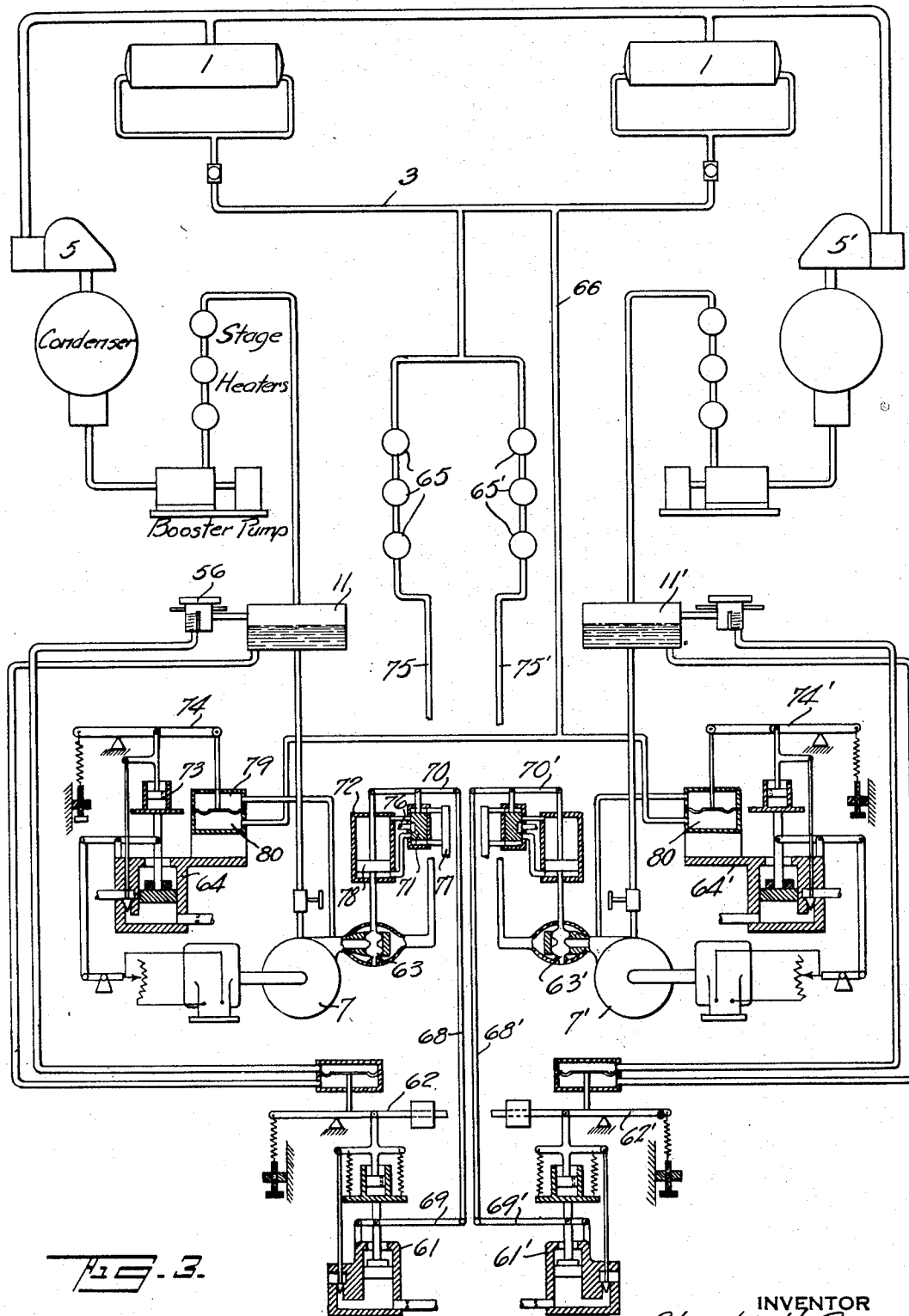
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3 Sheets-Sheet 3



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FEED WATER CONTROL SYSTEM

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9 Claims. (Cl. 60—107)

My invention is concerned with a feed water control system for boiler plants that will properly distribute the load between the various pumping units, that will insure economy of the feed water and safety of operation of the entire system. My invention is more particularly directed to the proper distribution of the feed water through the pumping units prior to its introduction into the feed water header and is not concerned with the distribution from the header to the various boilers of the plant, which latter distribution may be effected in any well known manner.

In modern high pressure boiler plants, the feed water system is divided into a plurality of separate units corresponding in general to the number of turbines receiving steam from the boilers. Each pumping unit receives the condensate from one turbine and pumps the same through various preheaters to the common feed water header of the plant; the preheaters being heated by steam withdrawn from different stages of the turbine and returned to the condenser.

Satisfactory regulation for such feed water system must insure at all times a sufficient pressure in the feed water header, and must be so arranged that the various pumping units deliver water to the header as it is received from the corresponding condenser, and in such a way as to equalize the stored water in the various surge tanks, and obviate as far as possible the temporary addition of makeup water or removal of excess water from surge tanks. Without such a system of control, it is difficult to maintain the quantity of water going through the pumps close enough in quantity to the amount of water delivered to the surge tanks, so that the tanks become neither empty nor overfilled.

The regulating system which I have devised meets these requirements and precludes the necessity of temporarily adding makeup water or the waste of feed water from the condensate of any unit. Insuring a flow of water through the heaters in proportion to the load on the turbine, it assists in maintaining a proper temperature of the water delivered to the header and insures further a pressure in the header sufficient at all times to care for the boilers at all ratings. A control of the water distribution between the various pumping units to insure the desired equalization of the water stored in the surge tanks may be effected by the automatic proportioning of the water delivered by any one pumping unit to the load upon the turbine supplying condensate to that unit. My invention, therefore in one respect, comprises a regulating system wherein each

pumping unit is responsive to and varies with the load on the individual turbine associated therewith, and all the units are conjointly responsive to maintain adequate header pressure. Preferably, to prevent temporary slight variations in load reacting upon the regulator, the control of each unit is arranged to be more rapidly responsive to header pressure variations, or to rate of water delivery from the unit than to changes in the turbine load.

For a better understanding of my invention, reference may be had to the accompanying drawings, of which:

Fig. 1 illustrates diagrammatically a feed water regulating system embodying my invention;

Fig. 2 illustrates in more detail a modification of the invention representing a preferred embodiment thereof; and

Fig. 3 illustrates a control system generally similar to that of Fig. 2 but showing a slightly different arrangement of the regulators.

Referring first to Fig. 1, two boilers of a high pressure boiler system are diagrammatically illustrated by the drums 1 delivering steam to a common header 2 and receiving feed water from a common header 3 through the usual economizers 4. In the particular installation illustrated, two turbines, 5 and 5', receive steam from the header 2 and four constant speed or booster pumps 6, 6 and 6', 6', of which one pump 6 and one pump 6' may be a spare, deliver feed water to the water header 3. A pump 7 delivers feed water through preheaters 8 and 9 to pumps 6, 6. Preheaters 8 and 9 are heated by steam withdrawn from different stages of turbine 5, which steam, together with the exhaust steam from the turbine, is condensed in the condenser 10 and passes from there into the storage or surge tank 11, from which it is withdrawn as feed water by the pump 7. A second pumping unit comprises the pump 7' receiving condensate from the turbine 5' and delivering it as feed water through the preheaters 8' and 9' to the booster pumps 6', 6'.

To regulate the operation of the pumping units, I provide for each unit a regulator responsive both to a function of the operation of that pumping unit and to a function of the rating of, or load upon, the particular turbine associated therewith. In this particular embodiment the regulator is responsive to a function of the rate of flow of the water from the pumping unit 7 and to a function of the rate of flow of steam to the turbine 5. The simplest type of such a regulator is illustrated diagrammatically in Fig. 110

1 as comprising a pivoted balance lever 12 adapted, upon displacement from neutral position, to directly vary the speed of pump 7 by adjustment of a resistance 13 in the armature circuit of the motor 14 driving the pump.

A pair of chambers 15 and 16, each having one wall movable in response to the pressure within the chamber and so connected to the lever as to tend to act oppositely thereupon, are connected by means of pipes 17 and 18 respectively with the steam supply pipe for turbine 5 at either side of a restriction 19 so as to be responsive to a function of the rate of flow of steam to the turbine. Similarly, a second pair of diaphragm closed chambers 20 and 21 oppositely connected to lever 12 are connected respectively with the feed water header 3 and the outlet of pump 7 to be responsive to a function of the rate of flow of water delivered by the pump. The arrangement is such that an increase in turbine load with consequent increase in steam flow thereto reacts upon the balance in a direction to increase the pump speed until the water flow there-through is increased to a value sufficient to restore balance upon the lever. In this manner the pump is continuously operated at such a rate as to insure at all times a sufficient, but not excessive, supply of water thereto, and furthermore, because the flow of water through the preheaters 8 and 9 is continuously maintained in proportion to the steam supplied to the turbine 5 and hence also to the steam withdrawn from the turbine for heating the preheaters, a uniform temperature of the feed water is insured. Pump 7' is likewise provided with a regulator 12' responsive to the rate of steam flow to turbine 5' and to the differential in pressure between the pump outlet and the feed water header. The pressure in chambers 20 and 20' will be equal as each is equal to that in the header 3.

It will be apparent that an increase or decrease in load upon one turbine will cause the regulator associated with the pumping unit receiving condensate from that turbine to correspondingly increase or decrease the rate of operation of that pumping unit but will have no effect upon the regulator for other pumping units, for the flow of steam to any one turbine reacts only on the regulator associated with the pumping unit receiving condensate from that turbine.

If the pressure in header 3 varies for any reason, as for example a change in the total load upon the plant, all of the regulators will be effected simultaneously, causing like changes in the rate of pumping of each unit without disturbing the distribution therebetween; header pressure 3 being connected as shown, to act upon each regulator.

From the broad aspects of my invention it is immaterial what particular force or forces varying with the turbine operation are selected to act upon the respective regulators. Instead of a pressure differential varying with the steam flow to the turbine, any other force varying with the load thereupon, could as well be employed.

Theoretically, the arrangement of Fig. 1 will insure equalization of the stored water in the tanks 11 and 11'. In that arrangement, however, as no means are provided directly responsive to water level changes in the surge tanks, the individual regulators, in practice, would need to be extremely sensitive and precise in operation to prevent possible occurrence of cumulative errors in the regulation. For this reason, and to prevent operation of the regulation upon each tem-

porary and small variation in load, I prefer to utilize forces varying with the water levels in the surge tanks instead of the forces above enumerated as the controlling forces upon the regulators. Broadly, however, a force varying with the water level in a surge tank is in effect one varying with the load upon the turbine delivering condensate to that tank, for the level varies as a function of the turbine load, increasing and decreasing responsively with increasing and decreasing load but is not rapidly responsive to temporary small load variations. In Figs. 2 and 3 I have accordingly illustrated specific means which I employ for utilizing surge tank level variations in regulating the distribution of load between the pumping units of a feed water system. In Fig. 2 the pump regulator for each unit is shown as being provided with a loading force varied by a second regulator which in turn is movable in response to storage tank level variations. In Fig. 3 the pump regulator for each unit is shown as responsive to the pressure differential across a valve in the feed water line of that unit, which valve in turn is adjusted by a regulator responsive to the level variations in the storage tank from which the pump withdraws condensate as feed water.

Referring to Fig. 2, four high pressure boilers, indicated diagrammatically by the drums 1, receive feed water from the header 3 and deliver steam through a common header to two turbines 5. The condensate from one turbine is collected in the storage tank 11 and from the other turbine in the tank 11', from which tanks it is withdrawn as feed water by the pumps 7 and 7' respectively. Pump 7 is driven by an electric motor 14, which has a resistance 13 in its armature circuit adjusted by a regulator 22. Regulator 22 is preferably of the type in which auxiliary power means are brought into operation upon departure from equilibrium of the balance lever 23 acted upon by controlling forces. In the particular embodiment illustrated, regulator 22 comprises a pivoted balance lever 23 carrying a member 24 to which is attached a throttle valve 25 adapted to vary the leakage of actuating fluid from a chamber 26. Tending to tip lever 23 in a counter-clockwise direction is a spring 27 attached at one end to the lever 23 and slidably mounted in a fixed runway 29. A motor 30 by means of suitable reduction gearing varies the position of rack 28, and hence the tension of spring 27 in response to the operation of a regulator 31 responsive to the water level in the storage tank 11. Opposing the tension of the spring 27 upon the lever 23 is a force varying with the pressure in the header 3 as transmitted to a chamber 32 by a pipe 33. Chamber 32 is closed by a diaphragm 34 connected to the lever by a rod 35 and to a fixed part of the regulator by a compression spring 36. A power piston 37, movable in response to the pressure in chamber 26, carries a piston rod 38 to which is linked a pivoted arm 39 adapted, through suitable linkage, to vary the resistance 13. The upper surface of piston 37 is open to the atmosphere and carries a weight 40 tending to lower the piston against the pressure acting on the lower side thereof. Actuating fluid under pressure is supplied to chamber 26 from a pipe 41 provided with a restricted orifice 42 and connected to any suitable source of pressure (not shown). To prevent hunting of the regulator, piston rod 38 carries at its upper end a cup or dash-pot 43 cooperating with a piston 44 slidable therein and carried by member 24. To insure

that variations in pressure in chamber 32 will cause proportionate travel of piston 37, and therefore proportionate increments or decrements of resistance 13, springs 45 are connected between the movable elements 24 and 43 to give a stabilizing force upon the lever 23 varying with the position of piston 37. A regulator 22' is arranged to control the speed of pump 7' in response to the pressure in header 3 and in response to the tension of a spring 27' adjusted by a regulator 31' responsive to the water level in storage tank 11'. It is not believed necessary to describe regulator 22' in detail as it is similar in all respects to regulator 22 and as the various elements thereof have been indicated by the same reference numerals but with primes attached thereto as are the corresponding elements in regulator 22.

Assuming for the present that no load change occurs upon either turbine and that the turbines are under equal load, then the tensions of spring 27 and 27' will be equal and may be considered as constant forces acting upon levers 23 and 23' respectively. The pressures in chambers 32 and 32' will be equal as each is equal to that in the header 3. Under these circumstances the regulators 22 and 22' insure equal division of the load between the two pumping units. This will be readily apparent when it is noted that each balance lever 23 and 23' is subjected to three forces, viz., one due to the tension of spring 27 or 27', one due to the pressure in the header 3, and one due to the tension of springs 45 or 45'. The tension of springs 45 or 45' is a measure of the rate at which the pump 7 or 7' is operating, for the pump operation depends upon the position of the rheostat arm which in turn depends, as does the tension of springs 45 or 45', upon the position of the power piston within the regulator. As under the assumed equal load conditions on the turbines, the tensions of springs 27 and 27' are equal, and as the pressures in chambers 32 and 32' are equal, it follows that unless the pumps 7 and 7' are running at equal rating one or the other of balance levers 23 or 23' will be out of balance due to unequal tensions of springs 45 and 45'. The balance lever on the regulator for which ever pump is operating at the wrong speed will therefore tip to vary the leakage from chamber 26 or 26' to therefore unbalance the pressures on the power piston, causing it to move in a direction to equalize the tensions of springs 45 and 45' and at the same time to correspondingly change the speed of the pump to the desired value.

Under unequal load conditions on the turbines, the tensions of springs 27 and 27' will be different, thus insuring balance upon the respective balance levers of the regulators only when the tension of springs 45 and 45' are correspondingly different and the pumps are consequently operating at the required different ratings.

The means for varying the tensions of springs 27 and 27' in response to the ratings upon the turbines comprise the regulators 31 and 31' and the parts associated therewith. It will be sufficient to describe but one of the units, the other being identical therewith.

Regulator 31 is substantially similar to regulator 22. It comprises the pivoted balance lever 46 carrying the member 47 from which depends the throttle valve 48 arranged to vary the actuating pressure beneath the power piston 49 upon an unbalance of the lever. The control-

ling forces upon lever 46 comprise a force varying with the difference in pressure between two chambers 52 and 53 separated by a diaphragm connected to the balance lever, a constant force introduced by a weight 54 and a stabilizing force due to the tension of a spring 55. Spring 55 is connected to a rack 55a vertically movable in a fixed guide by means of a motor 50 and suitable gearing. Chamber 52 is connected to a constant level device 56 comprising a closed chamber within which is a partition 57 and to which through a pipe 58 is supplied a small stream of water sufficient to maintain water up to the top of the partition 57. A pipe 59 connects the device 56 with the surge tank 11 above the water level therein to permit water flowing over partition 57 to drain into the tank and to insure equal pressures above the surface of the water in the tank and in the device. With this arrangement, the pressure in chamber 52 will be that due to a constant head of water while the pressure in chamber 53 will be that due to the variable head of water in tank 11. The difference in pressure in chambers 52 and 53 will thus vary inversely with the water level in tank 11, which level itself varies as a function of the load upon the turbine 5 supplying condensate thereto through pipe 60. An increase in turbine load will therefore be felt upon regulator 31 as a reduction in the force tending to turn lever 46 in a clockwise direction. Valve 48 will, therefore, be slightly raised to decrease the pressure beneath piston 49 and to therefore cause this piston to descend until the power arm carried thereby closes the circuit of motor 30 to cause it to operate in a direction to lower rack 28 and to thereby increase the tension of spring 27 and simultaneously to close the circuit of motor 50 in parallel with motor 30 to cause it to operate in a direction to raise rack 55a and to thereby decrease the tension of spring 55 until equilibrium of forces upon lever 46 is restored and the circuits of motors 30 and 50 is broken. The tension of springs 50 and 27 will therefore be varied by amounts dependent upon the level change in tank 11. The increased tension of spring 27 thereupon causes operation of regulator 22 in a direction to increase the speed of pump 7 to prevent further water level change.

Similarly a variation in the rating of the turbine supplying condensate to the storage tank 11' causes unbalance of regulator 31' when the changed rating of the turbine has been reflected in a water level change in tank 11', unbalance of regulator 31' operates to vary the tension of spring 27' in a direction and magnitude sufficient to cause regulator 22' to vary the speed of pump 7' to compensate for the change in turbine rating.

In the arrangement illustrated in Fig. 3, the regulators 61 and 61' responsive respectively to the water level in storage tanks 11 and 11' operate upon unbalance of their respective balance levers 62 and 62' to adjust valves 63 and 63' at the outlet of pumps 7 and 7' respectively. Regulators 64 and 64' operate in response to the pressure differentials across the valves 63 and 63' respectively to adjust the speeds of pumps 7 and 7' to maintain the pressure differentials constant and to thereby vary the feed water supply proportionately with the setting of these valves. In the particular modification illustrated in Fig. 3, the differentials across valves 63 and 63' include the preheaters 65 and 65' with the low pressure side of the differentials being taken from the header

3 which insures an equal pressure in pipe 66 and chambers 80 and 80'. The regulator 61 operates the valve 63 by means of a link 68 connecting the power arm 69 of the regulator with a floating lever 70 to which the pistons of a pilot valve 71 and relay cylinder 72 are likewise connected; the piston of the relay cylinder 72 being connected to the movable element of the valve 63. The structure of regulator 61 is substantially the same as that of regulator 22 of Fig. 2, and its connections to the storage tank 11 and constant level device 56 through which water level changes disturb the balance upon lever 62 are identical with those above described in connection with regulator 31. The structure of regulator 64, while in most respects similar to that of regulator 61, differs therefrom in the omission of stabilizing springs between the movable parts of the dash-pot 73. Such springs are omitted because with the particular connections to this regulator when the pump 7 is operating at the desired speed the controlling force applied to the balance lever 74 is constant and it is desired that the piston of the regulator take whatever position is necessary to maintain this force constant; this force being the difference in pressure between the outlet of the pump and the maximum boiler drum pressure in pipe 66.

In operation, when the load is equally divided between turbines 5 and 5', the water in tanks 11 and 11' will be at substantially equal levels and will subject the regulators' 61 and 61' to equal controlling forces. The power arms 69 and 69' will be shifted therefore through equal areas to such position as will cause the stabilizing springs of regulators 61 and 61' to apply forces to the balance levers 62 and 62' sufficient to counterbalance the forces due to the water levels in tanks 11 and 11'. Valves 63 and 63' will thus be opened by equal amounts and consequently, if the balance levers 74 and 74' are in equilibrium, pumps 7 and 7' must be delivering equal quantities of feed water through the pipes 75 and 75'. If now, the load upon turbine 5 is increased while that upon turbine 5' is unchanged, the level in tank 11 will gradually rise due to the greater supply of condensate from the turbine 5. This will decrease the pressure differential acting upon lever 62, causing it to tip in a counter-clockwise direction and to thereby reduce the pressure beneath the power piston of the regulator, which piston will then descend until the increased tension of the stabilizing springs compensates for the decreased downward force of the pressure differential due to water level. The downward movement of the power piston above described carries with it the power arm 69 which, through rod 68 and floating lever 70, lowers the piston of the pilot valve 71 until the fluid supply pipe 76 is placed in communication with the pipe leading to the lower end of the relay cylinder and the drain pipe 77 is placed in communication with the pipe leading to the upper end of the cylinder with the result that valve 63 is opened by an amount corresponding to the travel of the piston 78 permitted before the floating lever 70 closes the pilot valve by pivoting about rod 68. The opening of valve 63 reduces the pressure transmitted to chamber 79 and results in a tipping of lever 74 in a direction to cause a downward movement of the power piston of regulator 64 and a corresponding decrease in the armature resistance of the motor driving pump 7, which movement continues until the increased speed of pump 7 restores the pressure in chamber 79 to its

former value. If by the above operation the rating of pump 7 is not increased proportionately to the increased rating of turbine 5, the water level in tank 11 will continue to rise and regulator 61 will open valve 63 to a greater extent to cause a further increase in the rating of the pump. Conversely a reduction in either turbine load results in a partial closure of valve 63 or 63' and a consequent decrease in the speed of the associated pump. Variation in the pressure in the water-header 3 such that the pressure in pipe 66 is raised or lowered operates similarly on each regulator 64 and 64', causing equal changes in the speed of pumps 7 and 7', an increased pressure in pipe 66 causing a corresponding increase in the speed of each pump and a decreased pressure in pipe 66 causing a corresponding decrease in the speed of each pump.

When centrifugal pumps are acting in parallel at light load they tend to be unstable in their action and will not divide evenly the quantity of water delivered to a common pressure. This instability is caused by the fact that the pressure from no load up to a certain light load increases somewhat with the quantity of water, so that the pump which happens to take the greater supply of water also generates a greater pressure, which in turn chokes the other pump and reduces the quantity of water which it delivers. The valves 63 and 63' in Fig. 3 introduce a pressure opposed to the pump, which varies with the quantity of water and opposes this unstable tendency by giving to the combination of pump and valve a reduction in pressure overall with an increase in quantity of water, which permits the pumps to work in parallel with their even division, and a stabilized division in the quantities of water being handled, so that these valves are virtually water volume regulators which impose on the pumps the necessary relative water volumes even at light loads when the pumps would be unstable and otherwise virtually uncontrollable.

I have now described three embodiments of my invention. In each embodiment means are provided for automatically and independently varying the operation of each feed water pumping unit of a boiler plant in response to the rating of or load upon the turbine supplying condensate to that unit and for automatically and conjointly varying the operation of all of the pumping units in response to the pressure in the feed water header. In the preferred embodiment of the invention, the regulation of the pumping units is arranged to be directly responsive to forces varying with the level variations in the surge tanks associated with pumping units.

I believe it to be broadly novel to so regulate the distribution of feed water between the various pumping units of a boiler plant as to insure equalization of the storage water in the various surge tanks and to utilize in such regulation forces varying with the water levels in such tanks or with the load upon the individual turbines. Furthermore I believe it to be broadly novel to introduce in the regulation of feed water pumping units opposing pressures for stabilizing the loads between pumps operating in parallel.

The following is claimed:

1. In a boiler plant having a feed water header and provided with a plurality of feed water pumping units and with a plurality of steam utilizing devices, each unit receiving condensate from one device and delivering the same as feed water to the feed water header of the plant, a regulating

system for said units including in combination means for automatically and independently varying the operation of each unit in response to a function of the load upon the particular device

supplying condensate thereto and pressure responsive means for automatically and conjointly varying the load upon all of the units.

2. The regulating system for a boiler plant according to claim 1 wherein each of said devices supplies condensate to a storage tank from which it is withdrawn by the associated pumping unit and wherein the means for automatically and independently varying the operation of each unit in response to a function of the load upon the particular device supplying condensate thereto comprise means responsive to the water level in the associated storage tank.

3. In a boiler plant provided with a feed water header to which a plurality of pumping units deliver feed water under pressure and with steam utilizing devices each receiving steam from the boilers and each supplying condensate to one of said units, a regulating system for each unit comprising in combination a member adapted when moved to adjust the rate of operation of the unit, means responsive to a function of the load upon the utilizing device delivering condensate to that unit adapted to move said member and opposing means responsive to a function of the rate of flow from that unit adapted to move said member.

4. In a boiler plant of the type wherein a plurality of turbines receive steam from a common header and deliver condensate to separate storage tanks and wherein a plurality of pumping units, each withdraws condensate from one of said tanks and delivers it as feed water to a common header, a regulating system for said units comprising in combination a regulator for each unit including a balance adapted when disturbed from equilibrium to cause adjustment of the rate of operation of the pumping unit associated therewith, means for acting on the balance of each regulator with a force varying as a function of the water level in the associated storage tank whereby the rate of operation of the unit is increased with increase in water level and opposing means responsive to a function of the rate of flow from that unit adapted to move said balance member.

5. In a boiler plant including a plurality of boilers the combination comprising a turbine receiving steam from the boilers, a pumping unit including a variable speed pump adapted to receive water condensed from various stages of said turbine and to supply the same as feed water to a common feed water header for said boilers, a regulator for said pump adapted to vary the speed thereof, means varying with a function of the load on said turbine for acting upon said regulator in a direction to increase or decrease the speed of the pump with increase or decrease respectively of the turbine load, a second turbine receiving steam from said boilers and a pumping unit including a variable speed pump adapted to receive water condensed from various stages of said second turbine and to supply the same as feed water to the common feed water header

and a regulator for said second pump adapted to be acted upon by a force varying with a function of the load upon said second turbine and pressure responsive means for automatically and conjointly varying the pressure on said regulators.

6. In a boiler plant the combination comprising a turbine receiving steam from the plant, a storage tank receiving condensate from said turbine, a variable speed pump adapted to withdraw condensate from said tank and to deliver the same as feed water through a branch pipe to the common feed water header of the plant, a valve in said branch pipe, means for positioning said valve in response to the water level in said tank, and a regulator for said pump adapted to vary the speed of the pump to maintain constant the pressure differential across said valve.

7. The combination according to claim 6 including a second turbine and a storage tank and pump associated therewith to receive the condensate therefrom and to deliver the same as feed water through a second branch pipe to the feed-water header of the plant, a valve in said second branch pipe, means for positioning said valve in response to the level of the water in the storage tank associated with said second turbine, and a regulator for said second pump adapted to vary the speed thereof to maintain constant the pressure differential across the valve in said second branch pipe and pressure responsive means for automatically and conjointly varying the pressure on said regulators.

8. In a boiler plant provided with a feed water header to which a plurality of pumping units deliver feed water under pressure and with steam utilizing devices each receiving steam from the boilers and each supplying condensate to one of said units, a regulator for each unit including a balance member adapted when displaced from neutral position to vary the rate of operation of the associated unit, means for acting upon said member with a force varying with the load upon the utilizing device supplying condensate to the associated unit, means for acting on said member with a force varying as a function of the conjoint operation of all of said units and means for creating a third force normally maintaining said member in equilibrium under the action of said two first mentioned forces, and adapted upon operation of the regulator to vary said third force in a direction to return said member to neutral position.

9. In combination with a feed water system comprising a plurality of pumps delivering water to a common header and receiving water from separate sources in which the available supply is adapted to vary, means for varying the outlet pressure of each pump in response to the supply of water available in the source associated therewith, and a regulator for each pump responsive to the outlet pressure thereof and to a pressure varying with that in the common header whereby the operation of the pumps is stabilized and the quantity of water divided therebetween responsively to the supply available for each.

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