Oct. 25, 1949. C. F. BIRCHLER ET AL 2,485,999

CONTROL SYSTEM FOR ELECTRIC-STEAM GENERATORS

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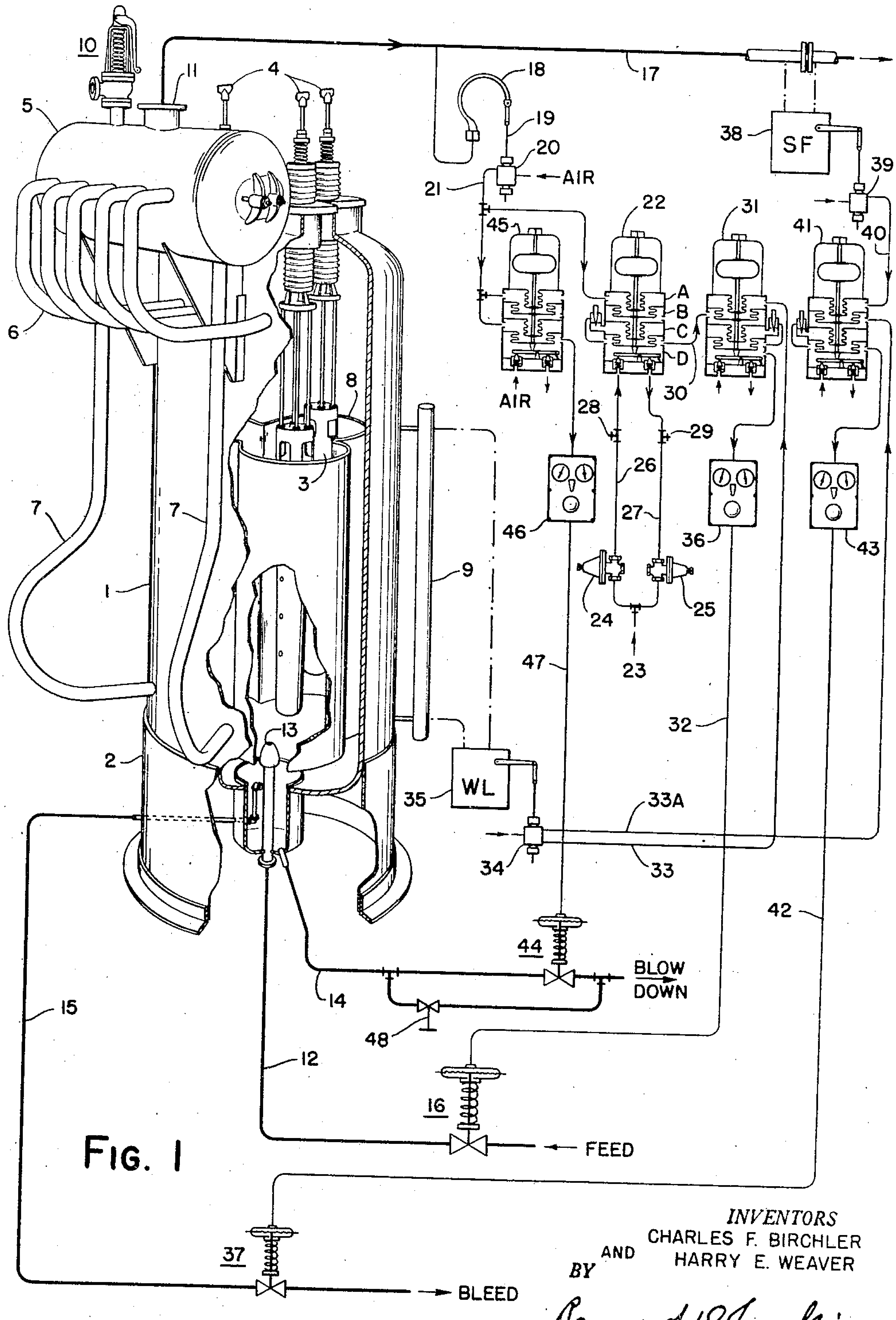

FIG. I

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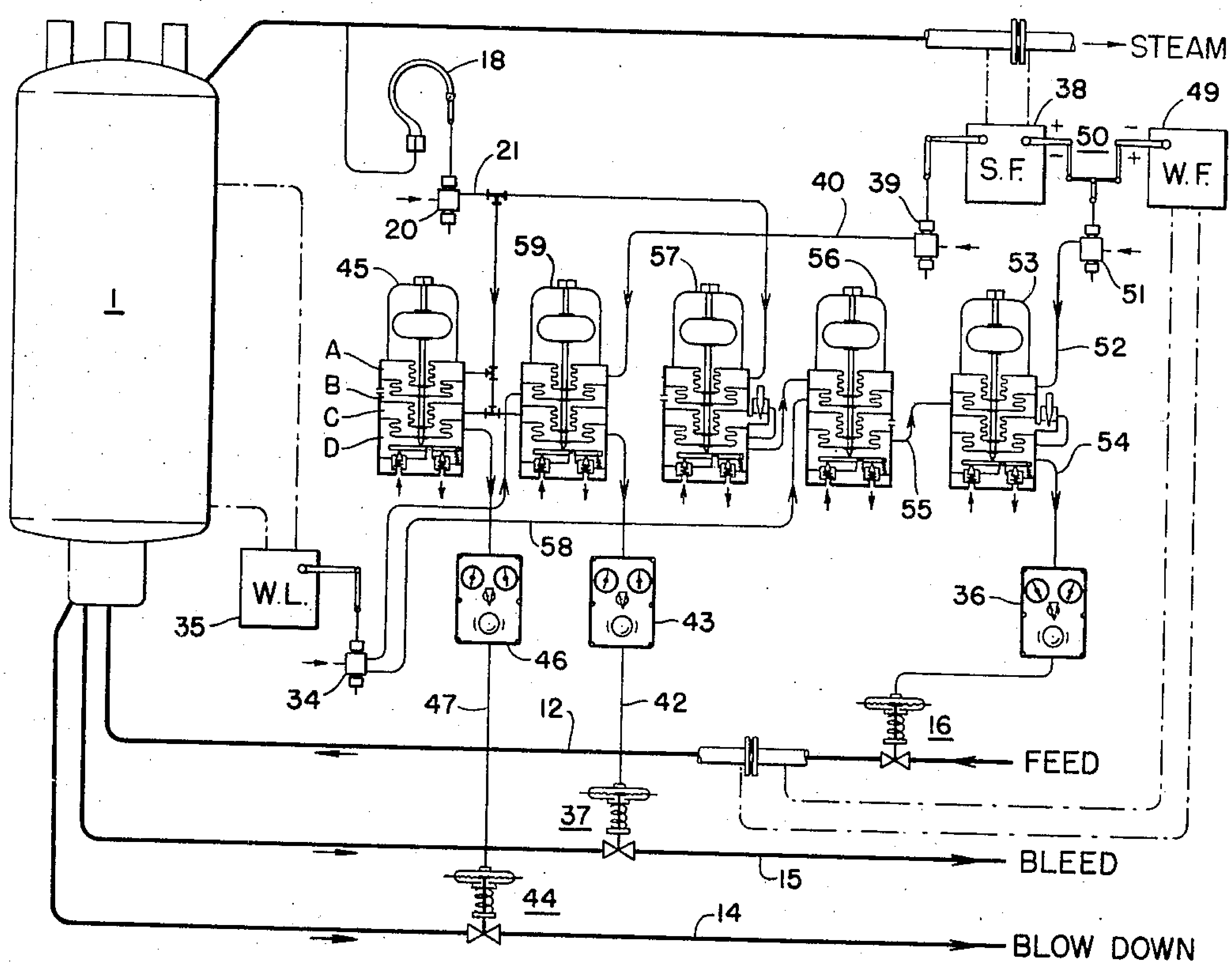

FIG. 2

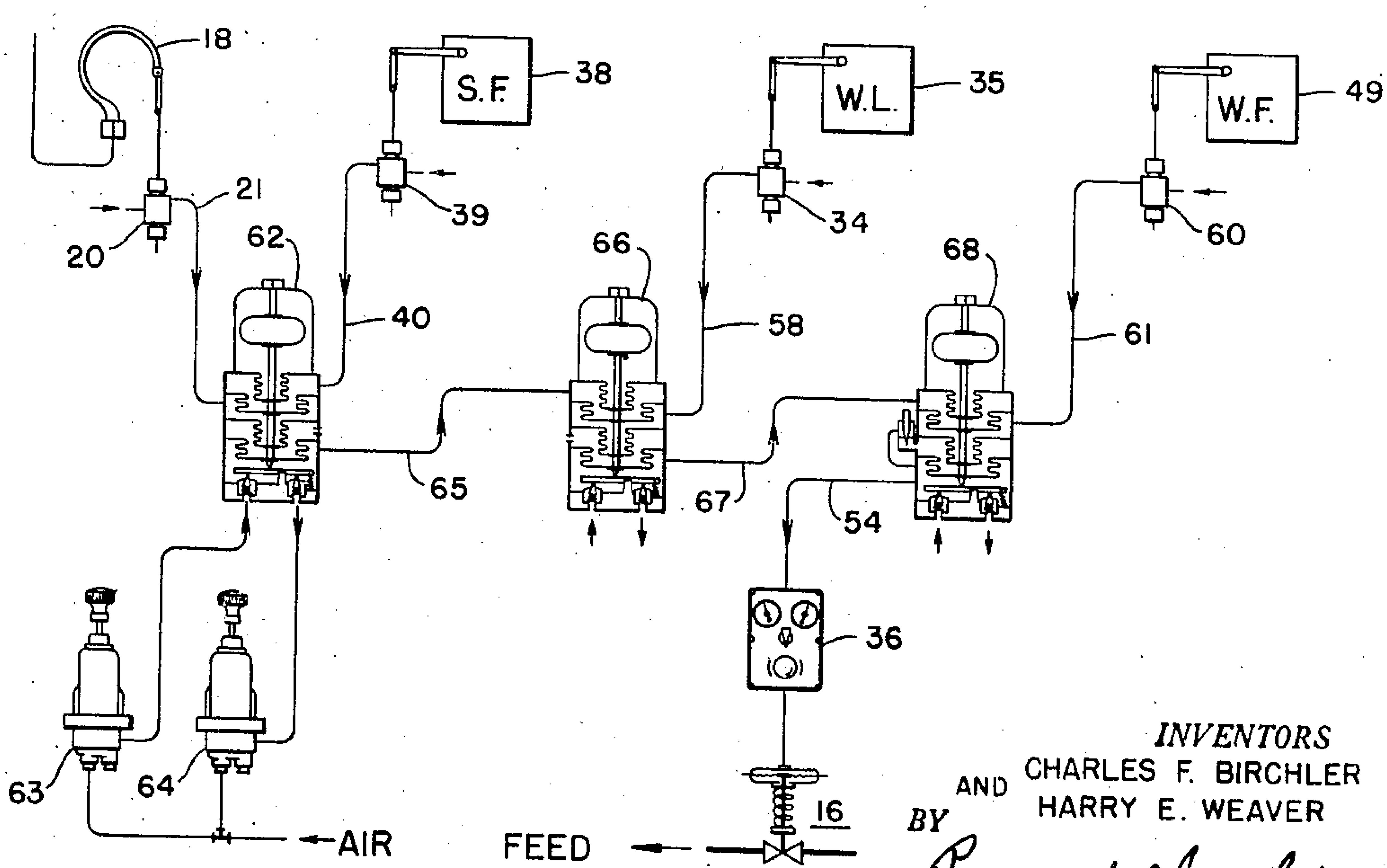

FIG. 3

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CONTROL SYSTEM FOR ELECTRIC-STEAM GENERATORS

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38 Claims. (Cl. 219—40)

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This invention relates to control systems and particularly to method and apparatus adapted to control the operation of a power producing apparatus such as an electrically heated vapor generator.

In certain localities where hydro-power is abundant, the price of electricity is low enough to make economical its use in vaporizing water into steam for process or heating uses. In the operation of such vapor generators problems of control arise which must be solved in order that the temperature and pressure of the produced steam will be of uniform optimum value under existing demand conditions and with full safety to life and generating apparatus.

It is an object of our invention to provide both method and apparatus of control for an electrically heated vapor generator.

We have as a further object the provision of a completely automatic control system for such a vapor generator.

Other objects will become evident upon a study of the specification, drawings and claims.

In the drawings:

Fig. 1 is a diagrammatic representation of one preferred embodiment of our invention applied to an electrically heated steam generator.

Fig. 2 diagrammatically represents a second embodiment of control directed to somewhat different operating conditions.

Fig. 3 constitutes a modification of Fig. 2.

Referring to the drawing, the particular unit being described and to which our control is applied, includes a vertically mounted drum or pressure chamber 1 supported on a base portion 2. Insulated through the upper head of the drum 1 and suspended therefrom are three electrodes 3, which may be of cast iron or other suitable material. Electrical power is applied to the electrodes as at 4 external to the drum 1.

External to and above the drum 1 is a dry drum 5 having steam riser tubes 6 and dry drum drain tubes 7. Enclosing the electrodes 3 and spaced therefrom is a clover-leaf neutral plate 8. Vertically positioned along the side of the drum 1 are the usual water column and gage glasses diagrammatically shown at 9. The dry drum 5 is provided with the usual safety valve 10 and with a main steam exit nozzle 11.

Water is fed to the unit through a feed pipe 12 terminating in a feed nozzle 13 centrally located in the lowermost portion of the main drum 1. To the lower portion of the drum is also connected a blowdown line 14 and a bleed line 15.

The terminals 4 are connected through the

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necessary electrical apparatus to a source of electrical power; the arrangement forming no part of the present invention. The problem with which our method and apparatus are concerned is the supply of water to the unit, the extraction of water therefrom, the maintenance of desired level of liquid within the drum 1, as well as the conductivity of the liquid within the drum; all in proper degree so that the vapor which is generated will satisfy the rate demand while maintaining the desired pressure.

In such a vapor generator, the heat for vaporizing the water is supplied by the passage of electric current through the water itself, from one electrode to another or to the neutral plate. Since the voltage of the power supply is constant, the energy consumed varies directly with the current, while the current varies inversely as the resistance of the path it travels. The resistance of the path, in turn, depends upon the cross-sectional area of the water conductor (path) and upon the specific resistance of the water itself. Inasmuch as the electrodes are fixed in position, the water area through which the current can pass is determined by the depth of immersion of the electrodes; i. e. the height of water within the boiler drum. The specific resistance of the water is a function of the concentration or amount of dissolved solids in the water and also of the temperature of the water.

Thus, in a boiler of this type, the amount of steam generated depends upon the amount of electric current passing through the water and this, in turn, depends upon the area of the path through the water and upon the conductivity (or resistivity) of the water to the passage of electric current therethrough. The water area through which the current can pass is determined by the depth of immersion of the electrodes. Therefore, if we maintain a constant specific resistance of the water, the amount of steam generated may be controlled by varying the level of the water in the boiler.

Thus in order to maintain a substantially uniform value of steam pressure, while satisfying the demand upon the boiler for quantity rate of steam generated, we are confronted with the problem of controlling the level of liquid within the boiler drum as well as the specific resistance of the water. A variation in any one, or all, of the three variables, namely, the amount of water within the boiler, its concentration of impurities, or its temperature, may cause a desirable or an undesirable variation in steam pressure and/or rate of steam generation.

The water fed to the unit will always contain a certain percentage of dissolved solids and particularly if the greater portion of water supplied is other than condensate. Inasmuch as the steam does not carry away salts or solids from the boiler there is a continuous tendency to build up the concentration of solids within the boiler water and thus to continually vary the resistivity to current passage through the water path. When operating at rated capacity the boiler hourly evaporates about ten times the water normally contained in it. In general, it may be said that if the conductivity of the water is maintained substantially uniform the rate of steam generation will vary with the water level. Conversely if the level is maintained substantially uniform then the rate of steam generation will vary with the concentration of dissolved salts in the boiler water. In order to keep the concentration of the water from gradually increasing (which would make inaccurate any functional relationship between water level and vapor generation) it is advisable to continually bleed some part of the highly concentrated water from the lower portion of the boiler drum in a controlled manner. If this is properly accomplished then a control of level within the drum is a control of rate of steam generation.

The interrelation of the effects of the operating variables may, however, cause disturbances in the primary control of level or of conductivity. For example, the conductivity of the water is not only a function of the amount of dissolved solids therein but is also a function of the temperature of the water.

By way of example: if there is an increase in demand upon the vapor generator the steam pressure will tend to fall. Assuming, for the moment, a uniform conductivity of the water then the increase in demand indicates a desirability of raising the level of water within the boiler and thus increasing the path for electric current and thereby increasing the rate of current dissipation and consequently the rate of steam generation. However a rapid increase in the rate of supply of water will tend to dilute the water within the boiler, thus lowering its conductivity, and at the same time will tend to cool the water within the boiler which also effects a lowering of its conductivity. Both of these adverse effects are opposite in nature to any increase in vapor generation desired by increasing the level and thus the area of conductor path. It is, therefore, apparent that a proper control must be judicious in regard to varying the level of water and must definitely take into account such adverse effects as have been mentioned.

Giving consideration to such disturbing influences as have been mentioned, which are effective principally under conditions of wide and rapid variations in demand, we have found that a somewhat different arrangement of control is preferable when operating under substantially steady load conditions than when operating under rapidly varying load demand. The arrangement of Fig. 1 is particularly directed to most efficient operation of a unit having substantially uniform load demand, although not limited thereto.

The primary functions accomplished by our control system, as depicted in Fig. 1, may be summarized as follows:

1. To so control the rate of admission of feed water to the unit as to maintain a uniform steam pressure, through varying the liquid immersion of the electrodes in relation to steam demand.

2. To so regulate the rate of bleed from the unit that the conductivity of the water remains substantially constant at all levels and rates of operation.

3. To prevent abnormal water level conditions by a control of blowdown.

Theoretically, with a constant voltage applied to the electrodes, and a uniform conductivity of the boiler water, the rate of steam generation will vary directly with the amount of immersion of the electrodes, i. e. the level of water in the boiler. Thus we desire a geared range between steam pressure (as an indication of demand upon the boiler) and water level, namely, a definite relation between level and load demand.

Referring now to Fig. 1, it will be seen that a feed water control valve **16** is positioned conjointly responsive to steam pressure and water level, so that as the steam pressure drops, indicating an increasing demand or steam outflow, the rate of water supplied to the boiler will be increased in proportion to deviation of steam pressure from the desired value or standard. Should there be fluctuations in feed water pressure, the feed water flow will fluctuate accordingly, so that a measure of water level is used to modify the primary steam pressure effect so as to maintain the level at a proper value. In effect, this two-element control maintains a definite water level for a given load demand. As steam pressure decreases (indicating increased steam outflow) the rate of water supply will be increased proportionately to the deviation of steam pressure from standard. The electrodes are subject to wearing away or scaling up, with consequent variation in steam generation rate per inch of submergence. Steam pressure as an element in the control of feed water supply has the advantage of correcting for such changes in the relationship between level and rate of steam output.

Connected to the steam outflow conduit **17**, we show a Bourdon tube **18** sensitive to pressure of the steam and arranged to vertically position the stem **19** of a pneumatic pilot valve **20**, which is adapted to establish in the pipe **21** an air loading pressure bearing a definite relation to pressure of the steam in the conduit **17**. Such a pilot valve is disclosed and claimed in the patent to Johnson 2,054,464. The loading pressure thus established in the pipe **21** is applied to the A chamber of a standardizing relay **22** which may be of the type disclosed and claimed in the patent to Gorrie 2,098,914.

Air under pressure is supplied to the relay **22** through reducing valves **24** and **25** from a source **23**. The reducing valves supply air at selected reduced pressures to the pipes **26** and **27** in which are located bleed valves **28** and **29** each having an adjustable bleed orifice to the atmosphere. The pipes **26** and **27**, beyond the bleed valves **28**, **29** join the inlet and outlet connections of the D chamber of relay **22**. By way of example, the pressure in the pipe **26**, between elements **24** and **28**, may be 25 p. s. i., while the pressure in the pipe **27** between elements **25** and **29** may be 5 p. s. i.

Variations in the loading pressure established by the pilot **20**, effective in the chamber A, produce a control pressure in the chamber D to which is connected the pipe **30**. Chamber B is open to the atmosphere while chamber C is interconnected with chamber D by an adjustable bleed connection. The result is that for any change in the loading pressure applied to chamber A, the control pressure in chamber D will be initially varied in proportional amount with a slow folblow-up effected by the bleed from chamber D to chamber C.

We desirably limit the water level in the boiler drum to a maximum and a minimum value irrespective of steam pressure conditions. When the loading pressure from the relay **22** to the relay **31** reaches either a minimum or a maximum value, as determined by the setting of the two pressure reducing valves **24**, **25**, no further change in loading pressure from the relay **22** can be applied to the relay **31**. Under such conditions the water level controller **35** assumes precedence over the steam pressure controller **18** and maintains the water level in the boiler drum within the desired limits without regard to steam pressure changes. Thus the boiler is prevented from flooding or from becoming empty.

In order to limit the maximum and minimum values of the control pressure applied to pipe **30** we limit the maximum air pressure in the pipes **26** and **27** through adjustment of the elements **24**, **25**, **28** and **29**. Assuming that a maximum pressure of 25 p. s. i. is available in the pipe **26** through the bleed valve **28** and to the inlet of the chamber D then this is the maximum control pressure which can be applied to the pipe **30** when the inlet valve is open and the outlet valve is closed. Under a reverse extreme condition, when the inlet valve is closed and the outlet valve is open, the elements **25** and **29** are so adjusted that the pressures within the chamber D cannot decrease below a minimum of say 5 p. s. i.

The pipe **30** connects to the B chamber of a differential standardizing relay **31** for establishing a control pressure in a pipe **32** leading to the feed control valve **16**. Connected to the A chamber of relay **31** is a pipe **33** in which is an air loading pressure established by a pilot valve **34** positioned by the water level measuring controller **35**. Thus the chamber A of relay **31** is continually subjected to a loading pressure representative of water level while the B chamber is subjected to the control pressure established by relay **22**. The resulting operation is that relay **31** will come to a balance condition when the actual water level is such that the rate of steam generation satisfies the demand and steam pressure is at the desired value. If steam pressure departs in either direction beyond predetermined limits the water level controller will have full control since the slightest unbalance in relay **31** will be able to obtain full movement of the feed valve **16** in either direction.

Interposed in the pipe **32** we provide a selector valve **36** similar to the type disclosed and claimed in the patent to Fitch 2,202,485; thus providing a possibility for remote manual or automatic selective control of the valve **16**.

In order to maintain uniform concentration of dissolved solids in the boiler, and thereby a uniform value of water conductivity, a continuous bleed system is provided. In the bleed line **15** we indicate a control valve **37** actuated conjointly responsive to water level within the drum **1** and to rate of steam outflow. Primarily the rate of bleed should be proportioned to the rate of steam outflow for that is the rate at which the concentration of the boiler water is increasing. However, for a given water level in the boiler drum, there should be a given steam flow produced. If there is a greater or lesser amount of steam outflow than that theoretically produced for a given water level in the drum it is due in part at least to a greater or lesser concentration of dissolved solids in the boiler water which of course varies the current carrying capacity of the water between the electrodes. Some effect will of course be had by variation in temperature of the water within the boiler drum. Therefore, by controlling the bleed valve **37** both from water level and from steam flow the correct concentration of dissolved solids should be maintained in the boiler drum.

At **38** we indicate a measuring controller sensitive to the rate of steam outflow through the conduit **17**. Controller **38** positions the movable element of a pilot valve **39** to establish in the pipe **40** a loading pressure representative of rate of steam outflow. The pipe **40** is connected to the A chamber of a differential standardizing relay **41**; to the B chamber of which is applied the loading pressure within a pipe **33**A. Thus within the relay **41** we continually compare a loading pressure representative of steam outflow rate with a loading pressure representative of water level, to establish a resultant control pressure in the pipe **42** for positioning the bleed valve **37**. Interposed in the pipe **42** is a selector valve **43** providing the possibility of hand or automatic control of the valve **37**.

It will be observed that the water level (WL) effect is applied to the B chamber of relay **41**, while the steam flow (SF) effect is applied to the A chamber. From a balance condition; an increase in pressure in the A chamber so positions the valves of the D chamber as to increase the pressure therein, resulting in a positioning of valve **37** in an opening direction. On the other hand, an increase in pressure in the B chamber results in a closing movement of valve **37**.

Assume a steady load condition with water level corresponding to steam outflow, steam pressure as desired, and bleed rate properly proportioned to output rate.

An increase in steam demand occurs. Steam flow increases and steam pressure drops. Feed water rate is increase (relay **31**) to raise the level, thus increasing the electrode immersion, and increase the current path. Pressure within the A chamber of relay **41** increases immediately and before any change in pressure in the B chamber (from WL) can occur. This results in an increase of pressure within the D chamber and consequently an opening motion of bleed valve **37**. Subsequently, as the rate of feed is increased (by relay **31**) the rising water level will result in an increase in pressure in the B chamber of relay **41**. When the unit stabilizes at the new rate of vapor outflow, water level and feed rate corresponding thereto, and optimum steam pressure; the relay **41** will have come to a balance condition with the bleed rate properly proportioned to the new conditions of inflow and outflow.

On the other hand, should steam demand decrease, steam pressure will rise, feed input rate will decrease, pressure within chamber A of relay **41** will decrease, and bleed valve **37** will move in a closing direction.

Thus it will be seen that the bleed rate is proportioned to the vapor outflow or load upon the unit and consequently to the rate of supply of feed water; with a continual check-back from level within the boiler.

In addition to the high and low water level limits, described in connection with the relay **22**, we provide an emergency blowdown system including a blowdown valve **44** interposed in the blowdown pipe **14** and under control of steam pressure through the agency of a relay **45**. The relay 45 assists the steam pressure controller in maintaining steam pressure within desired limits on a sudden decrease in steam demand. Normally the blowdown valve 44 is closed. Should a sudden decrease in steam outflow occur it may not be possible for the water level in the boiler to be immediately evaporated down to that value corresponding to the required steam output of the boiler, through closing down the feed water valve 16 under the dictates of the rising steam pressures and water level. The steam pressure would then increase beyond the standard and the master loading pressure in pipe 21 would also increase above the standard value. When increased sufficiently above standard, depending upon the adjustment of relay 45, the blowdown valve 44 will start to open up so as to assist in dropping the level of water in the boiler drum, and thus decrease the rate of steam generation so as to bring the steam pressure back to the normal value.

The loading pressure within the pipe 21 is applied to both the A and C chambers of the relay 45 while the opposing chamber B is left open to the atmosphere. Thus the loading pressure is doubly effective in positioning the supply and bleed valves of chamber D of the relay. The initial spring loading adjustment of the relay is such that the pressure within the pipe 21 is not effective in positioning the valves of the relay 45 until after a predetermined high loading pressure is attained, representative of a predetermined high steam pressure acting on the Bourdon tube 18.

Thus it is seen that the blowdown valve 44 is normally closed and is opened only under what may be termed an emergency condition of high steam pressure when it is desired to more rapidly relieve water from the boiler drum than is possible by merely shutting off the supply line 12 and waiting for the level to be lowered through evaporation of that water which is still in the boiler.

Interposed in the pipe 47 is a selector valve 46 which joins the D chamber of relay 45 to the blowdown control valve 44 and allows the possibility of hand or automatic control of the latter. In order that the boiler may be blown down manually we provide a manually operable valve 48 bypassed around the control valve 44.

In general, the control system of Fig. 1 provides that the greater the depth of submersion the greater the contact area of the boiler water with the heating units becomes and consequently the greater the steaming rate of the unit will be. There is, of course, a desirable maximum and minimum level of water in the boiler not to be exceeded.

The steam pressure controller has two principal functions:

1. To control or maintain water level in the boiler to maintain steam pressure within desired limits at different loads.

2. To open the blowdown valve in the event that the steam pressure increases beyond a predetermined high value. Blowdown valve 44 is normally closed and opens only upon emergency high pressure. For instance, the doubling relay 45 is so adjusted that for an increase of say 25–35 p. s. i. loading pressure from pilot 20 the output of the relay will cover the range of 5–25 p. s. i. for opening valve 44.

The water level controller 35 functions to simultaneously open both the feed water valve 16 and the bleed valve 37 as rating (steam flow) increases and subsequently, as the operating water level in the generator is increased. Although called a water level controller its essential function serves primarily to maintain an increase in rate of fresh feed water flow as boiler demand increases and also to stabilize the action of the steam pressure controller in the operation of the feed water valve.

Water concentration is controlled from two variables, namely, water level and steam flow. These two variables open the bleed valve and also the feed valve with an increase in unit output to maintain concentration within the desired operating limits.

In Fig. 2 we show diagrammatically a modification of the arrangement of Fig. 1 and which is adapted more particularly to rapidly fluctuating load demands upon the unit. In Fig. 2 we have used the same reference numerals for elements which are identical with those previously described in connection with Fig. 1. On both of these drawings the arrows on the various control pipes indicate the direction of application of loading pressure, i. e. from a controller to a relay or from a relay to a controlled valve.

In the arrangement of Fig. 2, we again indicate a control of the feed inlet valve 16 from a measure of steam pressure modified by an indication of level of water within the boiler drum. Additionally, the valve 16 is under the control of a comparison of steam outflow rate with water inflow rate.

For comparing the rate of steam outflow with the rate of water inflow, we show the steam flow controller 38 and a water flow controller 49 adapted to position a comparing linkage 50 for positioning a pilot valve 51. The usual adjustments are provided in the individual flow controllers so that desired proportionality may be established between the two rates of flow. The + and − signs adjacent the linkage 50 indicate the direction of motion of the controller arms of the steam flow meter and of the water flow meter for an increase or a decrease in rate of flow. When desired proportionality between the rate of vapor outflow and the rate of water supply is attained, the linkage 50 will be in such a position (regardless of the actual value of the rates) that the pilot 51 will establish a predetermined loading pressure within a pipe connection 52. Should the interrelation between steam flow and water flow depart from desired proportionality the loading pressure within the pipe 52 will be greater or lesser than the predetermined value.

The loading pressure within the pipe 52 is imposed upon the A chamber of a differential or comparison and standardizing relay 53 whose output from the D chamber, is applied to the pipe 54 and therefrom imposed upon the valve 16 for positioning the same. To the B chamber of the relay 53 we apply a loading pressure, through the pipe 55, originating in the D chamber of a relay 56 which is a comparison relay for comparing pressures representative of steam pressure and water level.

The steam pressure pilot valve 20 establishes in the pipe 21 a pressure representative of steam pressure and applies the same to the A chamber of a standardizing relay 57. To the A chamber of the relay 56 we apply the output pressure from the relay 57, while to the B chamber of relay 56 is applied (through the pipe 58) a pressure established by the water level pilot valve 34. Thus it will be seen that the relay 56 establishes a loading pressure in the pipe 55 representative of demand upon the vapor generator as indicated by steam pressure and modifies this effect by a pressure representative of the actual level of water within the boiler drum.

In the present embodiment, the rate of supply of water to the boiler drum is adjusted under the dictates of four variables in the operation of the unit. Under any steady load condition it is apparent that the rate of liquid inflow to the boiler should equal the rate of vapor outflow plus any bleed. There will be little effect upon the valve 16 from the steam pressure controller or from the water level controller inasmuch as under such steady load conditions these variables should not be fluctuating. However, should any of the variables tend to fluctuate, they will impose a correction upon the loading pressure within the pipe 54 and correspondingly correct the rate of water input to the boiler.

The steam flow controller and the water flow controller are each designed on a weight rate basis for proper comparison. Should there be a deviation in steam pressure, steam temperature, or feed water pressure, one or the other of these flow controllers may give a slightly incorrect representation of true weight rate. Thus, the comparison between the two might indicate a proper proportionality between weight rate of liquid inflow and weight rate of vapor outflow whereas actually the proportion would not be exactly correct. With the check back however from actual water level such discrepancy will be corrected. At the same time the modified control from steam pressure will be effective to take care of minor departures in steam pressure from the desired value.

When a change in load (for example an increase in steam demand) occurs, this will show up in an increase of the steam flow and a corresponding decrease in steam pressure. As previously mentioned, the desired operation is to raise the water level on the electrodes to increase the rate of steam generation. The increased steam flow and the decreased steam pressure will act in the same direction to demand an increase in rate of feed water until the comparison between steam outflow rate and feed water input rate attains desired proportionality. If the water level has not reached the proper value to satisfy the new demand, the water level controller will impose its control upon the feed water valve 16. In general, the four variables, namely, steam outflow, water inflow, steam pressure, and water level will coact to properly position the feed input valve 16 to satisfy the steam demand upon the unit and maintain steam pressure substantially uniform. It will be appreciated that the various control instrumentalities, such as regulators, relays, pilot valves, etc, may be adjusted for sensitivity, range, limits, etc. Inasmuch as such adjustments are known, it does not appear to be necessary to go into the details thereof.

Fig. 2 shows a control of the bleed valve 37 conjointly from steam outflow, steam pressure and water level. A loading pressure representative of each of these three variables is algebraically added in a relay 59 from which a resultant control pressure is applied, through the pipe 42 and selector valve 43, to positon the valve 37.

It will be observed that in this arrangement the steam flow effect is applied to the A chamber of relay 59, the water level effect to the B chamber and the steam pressure effect to the C chamber. Under relatively steady load conditions the steam flow effect and water level effect offset each other so that the steam pressure variations substantially control the positioning of the bleed valve 37, one way or another from a throttled condition corresponding to the basic steam flow-water level dictates (load demand upon the unit).

Assuming, from a steady state condition, an increase in steam outflow with resulting decrease in steam pressure. Pressure within the A chamber increases while pressure within the C chamber decreases. The tendency is to offset each other so that no resultant positioning of the valve 37 occurs. No immediate change has occurred in water level so that the pressure in chamber B remains as before. Thus there is no immediate change of the rate of bleed in either direction.

As the increased rate of feed to the boiler results in an increase in water level the pressure within the B chamber increases, tending to counteract the increased pressure in the A chamber with the result that the C chamber pressure becomes more effective in positioning the valve 37. Inasmuch as the decreasing steam pressure lowered the pressure in the C chamber then the positioning of the valve 37 will be in a closing direction as water level is increased. This is proper to offset the dilution and lowering of temperature caused by the increased rate of feed and increased volume of water within the drum.

Following this action, as steam pressure rises, it opens the bleed due to an increase in pressure within the C chamber, until, when a steady state of operation is reached, the steam flow effect within the A chamber balances the water level effect within the B chamber and any variation in steam presssure effect within the C chamber controls the bleed valve; from a new opening condition representative of the new vapor outflow rate and corresponding water level.

It may be said, in general, that the arrangement of Fig. 2 for bleed valve control normally balances an effect from steam flow against an effect from water level and utilizes variations in steam pressure effect to continuously readjust the position of the bleed valve. The valve is under the conjoint control of the three variables whose effects are algebraically added within the relay 59.

As in Fig. 1, the control of the blowdown valve 44 is from the steam pressure pilot 20 acting through a doubling relay 45.

In Fig. 3 we illustrate a modification of Fig. 2. Herein we have shown diagrammatically the control of the feed water input valve 16 conjointly from the four variables steam pressure, steam flow, water level and water flow. In this illustration we have not shown, even diagrammatically, the boiler nor the control of blowdown or of the bleed valve which may be as described in connection with Fig. 1 or Fig. 2. The arrangement of Fig. 3 depicts a modification in the control of the feed water inflow valve, particularly useful under certain operating conditions. It may be said that in Fig. 3 an air loading pressure is established within the pipe 21 representative of steam pressure, an air loading pressure within the pipe 40 representative of weight rate of steam outflow, an air loading pressure within the pipe 58 representative of water level within the boiler drum, while an air loading pressure is established in the pipe 61 representative of weight rate of water feeding the boiler.

We apply the steam flow effect to the A chamber of a relay 62, to the B chamber of which we apply the steam pressure effect. Connected to the inlet and outlet valves of the relay 62 are load limiting relays 63, 64 performing the function of the elements 24, 25, 28 and 29 of Fig. 1. Thus the resultant effect, from the D chamber of the relay 62, as applied through the pipe 65, has a maximum and a minimum limit established by the adjustment of the relays 63 and 64.

The loading pressure resultant of steam pressure and steam flow, available in the pipe 65, is applied to the A chamber of a relay 66 for comparison with the water level effect available within the B chamber from the pipe 58. The output of the relay 66, available through the pipe 67, is applied to the A chamber of a standardizing relay 68, to the B chamber of which we apply the water flow effect through the pipe 61. The output of the relay 68 is available in a pipe 54 for positioning the feed valve 16.

It will be evident from a study of Fig. 3 that the differential relay 62 continually interrelates pressures individually representative of the two operation variables first to show the effect of changes in demand upon the boiler, namely, steam pressure and steam outflow rate. Either or both of these operation variables may change, but normally they vary in opposite direction, i. e. an increase in steam outflow rate is accompanied by a decrease in steam pressure, and vice versa. Thus upon an increase in steam outflow the pressure within the A chamber of relay 62 will increase while the pressure within the B chamber will decrease. These effects are additive to increase the loading pressure output of the relay 62 through pipe 65 to the A chamber of relay 66, resulting in an increase in pressure within chamber A of relay 68 and in an opening of the feed valve 16.

The resultant effect of steam flow and steam pressure (in chamber A of relay 66) is modified in accordance with water level as imposed upon the B chamber. Likewise the pressure effect in the A chamber of relay 68 is modified by a pressure in the B chamber representative of water flow rate. Thus when the valve 16 is positioned to satisfy the dictates of steam pressure, steam flow and water level it should result in a rate of feed water admission to the boiler such as to satisfy said three variables. As a check upon the actual rate of water flow the water flow meter 49 establishes a loading pressure representative of water flow rate within the B chamber of the relay 68 and compares this against the effect established within the chamber A. If the proper rate of water admission is not attained due, perhaps, to fluctuations in feed water pressure, then the positioning of the valve 16 is modified responsive to the interrelation between the pressure effects within the chambers A and B of relay 68.

While we have chosen to illustrate and describe certain preferred embodiments of our invention, it will be understood that this is by way of explanation only and is not to be considered as limiting.

What we claim as new, and desire to secure by Letters Patent of the United States, is:

1. The method of operating a steam generator of the type wherein electric energy is dissipated in the water of the generator for vaporizing the water, which includes, continuously establishing a control effect representative of the pressure of the vapor generated, continuously establishing a control effect representative of the level of water within the generator and consequently of the area of the liquid path to be traversed by the electric current, and utilizing the two control effects conjointly to control the rate of supply of water to the generator.

2. The method of claim 1 wherein each of the control effects is a fluid pressure.

3. The method of claim 1 including the further step of continuously establishing a control effect representative of the rate of steam generation, and including this latter control effect in the conjoint control of the rate of supply of water to the generator.

4. The method of claim 1 including the further steps of continuously establishing a control effect representative of the rate of steam generation, continuously establishing a fourth control effect representative of the rate of feed water supply to the generator, and interrelating the four control effects to control the rate of supply of feed water.

5. The method of controlling the operation of an electric steam generator which includes, feeding the unit with water to form a pool in which the electrodes are immersed for vaporizing the water, determining the extent of immersion, obtaining a representation of the steam demand upon the unit, and continuously utilizing the values of these two variables in controlling the rate of feeding of water to the generator.

6. The method of claim 5 wherein the steam demand upon the unit is the rate of flow of steam discharged from the unit, and so controlling the rate of water supply to the unit that a predetermined relation will exist between submergence of the electrodes and rate of steam outflow.

7. The method of claim 5 wherein the steam demand is represented by pressure within the generator, and rapidly blowing down or discharging water from the pool to decrease electrode immersion when steam pressure exceeds a predetermined value.

8. The method of controlling the operation of an electric steam generator which includes, feeding the unit with water to form a pool in which the electrodes are variably immersed for vaporizing the water, determining the extent of immersion, determining the rate of steam outflow from the generator, determining the pressure within the generator, continuously controlling the rate of feed of water to the unit in response to the extent of immersion and the steam pressure, bleeding water from the pool at a rate dependent upon the rate of steam outflow to control the conductivity of the water in the pool, and rapidly blowing down or discharging water from the pool to decrease electrode immersion when steam pressure exceeds a predetermined value.

9. The method of claim 8 including the step of limiting the immersion of the electrodes between predetermined high and low limits.

10. The method of controlling an electric steam generator supplied with liquid under pressure and having provision for bleeding liquid from the generator at a controllable rate for regulating the conductivity of the water within the generator, which includes, continuously developing a control effect representative of load demand upon the unit, and utilizing the control effect in establishing the rate of bleed.

11. The method of controlling an electric steam generator supplied with liquid under pressure and having provision for bleeding liquid from the generator at a controllable rate for regulating the conductivity of the water within the generator, which includes, controlling the rate of bleed

responsive to departure of desired interrelation between rate of steam outflow and liquid level in the generator, and modifying such control in response to steam pressure.

12. The method of controlling an electric steam generator supplied with liquid under pressure for variably immersing the heating electrodes, which includes, separately obtaining effects representative of steam pressure, rate of steam outflow, rate of water inflow and liquid level relative to the electrodes; and continuously regulating the rate of supply of liquid to the generator conjointly responsive to such effects.

13. The method of claim 12 including the further step of first proportionately comparing the rate of water inflow to the rate of steam outflow and then utilizing any discrepancy from desired porportionality in modifying the control of liquid feed from both steam pressure and water level.

14. The method of claim 12 including the further step of bleeding water from the generator at a rate controlled conjointly responsive to steam pressure, rate of steam outflow and water level.

15. The method of controlling an electric steam generator supplied with liquid under pressure for variably immersing the heating electrodes, which includes, continuously producing a control effect conjointly representative of steam pressure and steam outflow rate, as an indication of load demand upon the generator, modifying the control effect upon departure of water level from that which is dictated by load demand, controlling the rate of liquid supply by the modified control effect, and continuously checking back from the actual rate of liquid supply to see if it is as dictated by the modified control effect.

16. The method of controlling an electric steam generator supplied with liquid under pressure for variably immersing the heating electrodes, which includes, controllably bleeding water from the generator for maintaining substantially constant the conductivity of the water by temporarily varying the rate of bleed in opposite sense to a change in rate of steam outflow, followed by a proportioning of the rate of bleed to the rate of steam outflow.

17. The method of controlling an electric steam generator supplied with liquid under pressure for variably immersing the heating electrodes, which includes, normally maintaining a liquid level varying with demand upon the unit, feeding water to the unit in proportion to steam outflow, and controlling a bleed of water from the unit directly proportional to steam outflow rate and to water level and inversely proportional to steam pressure so as to maintain conductivity substantially uniform.

18. In combination with an electric steam generator having provisions for supplying feed water thereto, means sensitive to water level within the generator, means sensitive to steam pressure within the generator, and a single control valve regulating the rate of supply of feed water and adapted to be positioned through the coactive agency of said means.

19. In combination with an electric steam generator having provisions for supplying feed water thereto, means establishing a fluid control pressure representative of steam pressure within the generator, means establishing a fluid control pressure representative of water level within the generator, and a single means continuously responsive to said two fluid pressures adapted to control the rate of feed water supply.

20. The combination of claim 19 including means establishing a third fluid control pressure representative of the rate of steam outflow, said means which controls the rate of feed water supply being continuously responsive to all three fluid control pressures.

21. The combination of claim 19 including means establishing a third fluid control pressure representative of the rate of steam outflow, and means establishing a fourth fluid control pressure representative of the rate of water inflow, said means which controls the rate of feed water supply being continuously responsive to all four fluid control pressures.

22. Apparatus for controlling the operation of an electric steam generator including in combination, means continuously producing a control effect representative of demand upon the generator, means continuously producing a control effect representative of water level, and control means continuously regulating the rate of supply of water to the generator responsive to the two mentioned control effects.

23. The apparatus of claim 22 wherein the control effects are fluid pressures.

24. The apparatus of claim 22 including means continuously producing a control effect representative of the rate of steam generation, said three control effects arranged to conjointly actuate the said control means.

25. In combination with an electric steam generator having provisions for supplying feed water thereto, means determining the rate of steam outflow from the generator, means determining the level of water within the generator, and control means responsive to said two determining means and adapted to so control the rate of feed water supply that a predetermined relation will exist between the rate of steam outflow and the amount of submergence of the electrodes.

26. In combination with an electric steam generator having provisions for supplying water thereto to form a pool in which the electrodes are variably immersed for vaporizing the water, means establishing a fluid control pressure representative of steam pressure within the generator, means establishing a fluid control pressure representative of water level within the generator, control means adapted to regulate the rate of supply of water responsive to both said fluid control pressures, and means arranged to rapidly discharge water from the generator when steam pressure exceeds a preternined value.

27. In combination with an electric steam generator having means supplying water thereto to form a pool in which the electrodes are variably immersed for vaporizing the water, a first means determining the extent of immersion, second means determining the rate of steam outflow from the generator, third means determining the pressure of the steam generated, means continuously controlling the rate of supply of water to the unit in response to the first means and the third means, means bleeding water from the pool at a rate dictated by the second named means to control the conductivity of the water in the pool, and blowdown means arranged to rapidly discharge water from the pool when the third means determines an excessive steam pressure.

28. The combination of claim 27 including means limiting the immersion of the electrodes between predetermined high and low limits.

29. Apparatus for controlling an electric steam generator having means supplying water thereto to form a pool in which the electrodes are

variably immersed for vaporizing the water, which includes in combination, a controller for the water supply means, a liquid level responsive device arranged to normally actuate the controller in accordance with liquid level within the generator, and pressure responsive means subjected to the pressure of the generated vapor and adapted to modify the actuation of the controller by the level responsive device.

30. Apparatus for controlling an electric steam generator having means supplying water thereto to form a pool in which the electrodes are variably immersed for vaporizing the water and having means for bleeding water from the pool at a controllable rate for regulating the conductivity of the water in the pool, which includes in combination, means sensitive to rate of steam outflow from the generator, and means positioned by said sensitive means controlling the bleeding means.

31. Apparatus for controlling an electric steam generator having means supplying water thereto to form a pool in which the electrodes are variably immersed for vaporizing the water and having means for bleeding water from the pool at a controllable rate for regulating the conductivity of the water in the pool, which includes in combination, means sensitive to rate of steam outflow from the generator, means sensitive to the extent of immersion of the electrodes, comparison means responsive to said two sensitive means continuously determining the interrelation between rate of steam outflow and immersion of the heating electrodes, said comparison means adapted to regulate the bleeding means, and means sensitive to pressure within the generator arranged to modify the effect of the comparison means upon the bleeding means.

32. Apparatus for controlling an electric steam generator supplied with water under pressure for variably immersing the heating electrodes, which includes in combination, a plurality of means separately sensitive to steam pressure, to rate of steam outflow, to rate of water inflow and to liquid level relative to the electrodes; and means continuously regulating the rate of liquid supply conjointly responsive to said plurality of sensitive means.

33. The combination of claim 32 including means for bleeding water from the generator, and control means for positioning said bleeding means conjointly responsive to the steam pressure, rate of steam outflow and water level sensitive means.

34. Apparatus for controlling an electric steam generator supplied with water under pressure for variably immersing the heating electrodes, which includes in combination, means continuously producing a control effect conjointly representative of steam pressure and steam outflow rate, as an indication of load demand upon the generator, means sensitive to water level within the generator continuously modifying said control effect upon departure of electrode immersion from that which is dictated by load demand, apparatus sensitive to such modified control effect and adapted to control the rate of supply of water to the generator, means continuously producing a control effect representative of actual rate of water supply to the generator, and comparison means comparing the last mentioned control effect with the said modified control effect arranged to further modify said modified control effect.

35. The combination of claim 34 wherein the control effects are fluid pressures.

36. Apparatus for controlling an electric steam generator supplied with water under pressure to form a pool of water in the generator in which the electrodes are variably immersed for vaporizing the water and having means for bleeding water from the pool at a controllable rate for regulating the conductivity of the water in the pool, which includes in combination, control means for regulating the rate of bleed from the pool, and means sensitive to the rate of steam outflow from the generator for positioning the control means, the rate sensitive means so arranged that upon change in rate of steam outflow the control of bleed will first be in opposite sense to the change in rate of steam outflow followed by a positioning of the bleed control means in the same sense as the change in rate of steam outflow.

37. The method of controlling an electric steam generator supplied with liquid under pressure and having provision for bleeding liquid from the generator at a controllable rate for regulating the conductivity of the water within the generator, which includes, continuously developing a control effect representative of rate of steam outflow from the unit, and utilizing the control effect in establishing the rate of bleed.

38. The method of operating a vapor generator of the type wherein electric energy is dissipated in the liquid of the generator for vaporizing the liquid, which includes, continuously establishing a first pneumatic control pressure varying in value with the pressure of the vapor generated, continuously establishing a second pneumatic control pressure varying in value with the level of liquid within the generator and consequently with the area of the liquid path to be traversed by the electric current, and continuously regulating the rate of supply of liquid to the generator conjointly responsive to both the pneumatic control pressures.

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