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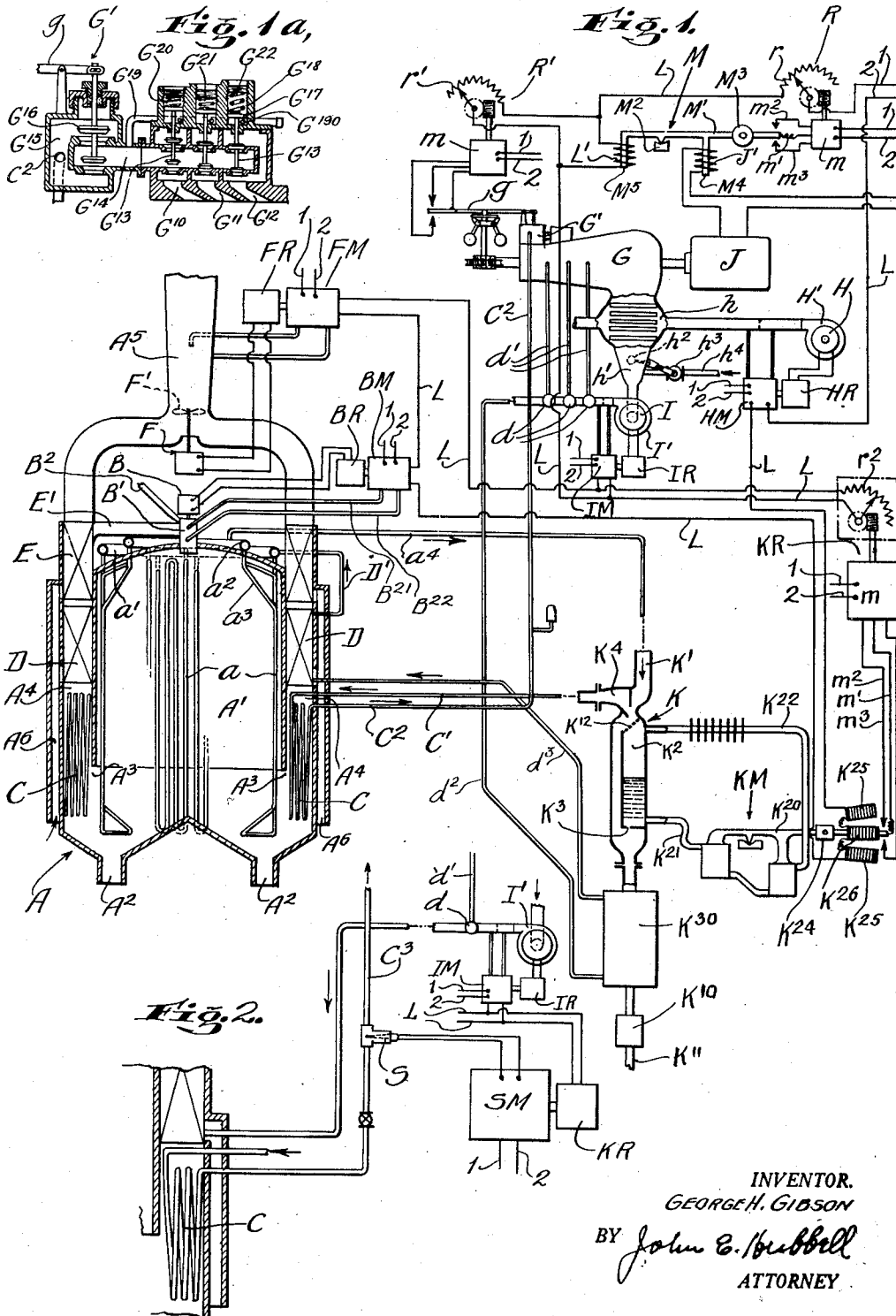
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2,042,838

COMBUSTION CONTROL

Filed June 22, 1929

2 Sheets-Sheet 1



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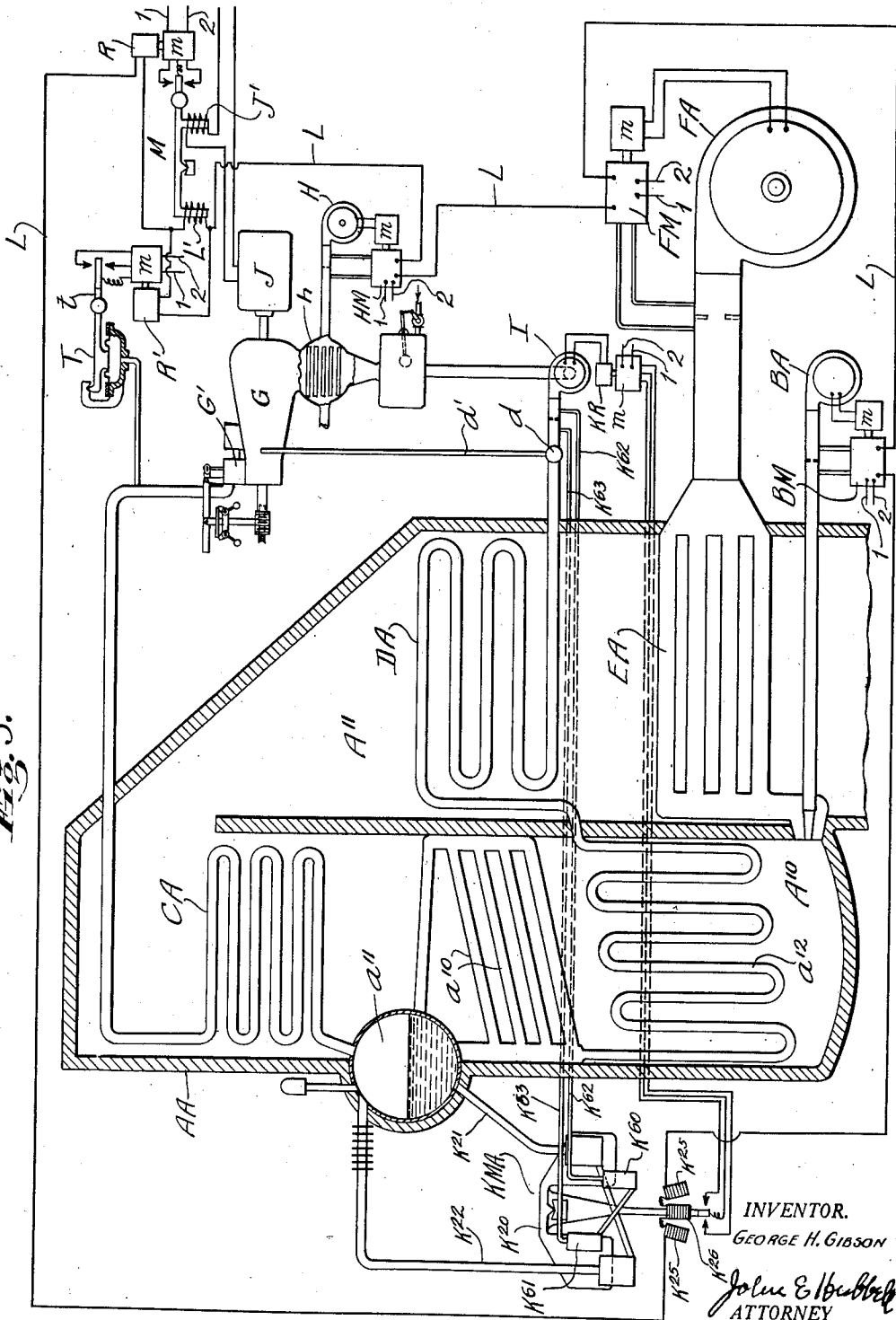
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Fig. 3.



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COMBUSTION CONTROL

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The general object of the present invention is to provide improved apparatus for and methods of generating steam. More specifically, the object of the invention is to provide methods and apparatus for generating steam characterized by the provisions made for maintaining close correspondence between the demand for steam and the rate of combustion of the fuel burned to generate the steam.

10 In the operation of steam generating apparatus the total heat requirement is proportional, in general, to the sum of a constant quantity plus a variable quantity which is in linear proportion to the steam load, the constant quantity representing heat radiation and other losses independent of the load. This relation between total heat requirement and load is sometimes referred to as the straight line law of boiler operation.

15 In proceeding in accordance with the present invention I provide a control system adapted to automatically vary combustion factors such as the supply of fuel and air for its combustion in automatic response to variations in a control force which is proportional to the sum of a constant quantity plus a quantity varying with the steam load. While the existence of the so-called straight line law of boiler operation has long been recognized, I believe the control system herein disclosed to be the first in which combustion control factors have been regulated primarily and directly in response to variations in a control force varied in direct accordance with the demand for heat as represented by said straight line law.

20 In preferred forms of the invention the above described primary regulation is supplemented by a secondary regulation controlling the pressure of the steam generated and serving in some cases to maintain a constant steam pressure, and in other cases to make the steam pressure vary in a predetermined manner as the steam load varies.

25 While general features of the present invention may advantageously be used with steam generating apparatus of various kinds, the invention is especially adapted for use with steam generating apparatus having a relatively small water storage capacity, as is the case with so-called flash boilers, and as is usually the case with apparatus generating steam at what are now called high pressures; i. e., pressures in the neighborhood of the critical temperature of steam and water. My present invention is especially well adapted for use in connection with boilers having little or no water storage capacity because the use of the invention makes it readily possible to accurately

proportion the boiler feed water supply to the steam output at all times which is highly desirable in the case of a boiler having relatively little water storage capacity.

30 In the preferred form of the invention for use in connection with a flash boiler, means are provided for passing water into the boiler at a rate which, while at all times approximately proportional to the rate of steam generation, exceeds the latter by a certain amount, providing for a continuous blow-off of concentrated water. Such purging of water from a flash boiler is desirable because it avoids objectionable concentration of foreign matter in the water held in the boiler, and eliminates or greatly minimizes the tendency to scale deposits in the boiler.

Advantageously, the means employed to effect the above described water purging operation serve also to condition the steam. In cases in which such water purging is not provided for, other steam conditioning provisions may be made.

35 The various features of novelty which characterize my invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, however, and the advantages possessed by it, reference should be had to the accompanying drawings and descriptive matter in which I have illustrated and described preferred embodiments of the invention.

Of the drawings:—

Fig. 1 is a diagrammatic representation of a steam power plant embodying one form of the present invention;

Fig. 1a is a sectional elevation of the turbine control valve mechanism shown in Fig. 1;

Fig. 2 illustrates a modified form of a portion of the apparatus shown in Fig. 1; and

Fig. 3 is a diagrammatic representation of a steam power plant of different type from that shown in Fig. 1 and embodying a modified form of the present invention.

40 In the form of the invention diagrammatically illustrated in Fig. 1, A represents a boiler furnace comprising a combustion chamber A' supplied with powdered fuel by a fuel feeder B' at a rate determined by the speed of the burner feed motor B. B² represents the fuel supply connection to the feeder B' from a fuel source (not shown). A² represent ash outlets from the bottom of the combustion chamber. The heating gases are discharged from the combustion chamber A' at A³ into a flue system shown as comprising a jacket or flue space A⁴ at the outer side of the combustion chamber. The space A⁴ is connected at its 55

upper end to a stack outlet A⁵. As diagrammatically shown, a superheater C, a feed water preheater or economizer D, and an air preheater E, are located in the flue space A⁴ so as to be successively traversed by the heating gases passing from the combustion chamber to the stack connection A⁵. Advantageously, as shown, the superheater C is arranged to receive a substantial amount of radiant heat from the chamber A', although a portion of the superheater is above the outlet passage A³, and the lower portion of the superheater is partly screened by the hereinafter described water tubes *a*.

The volume of draft through the combustion chamber A' is regulated by an induced draft fan F' which is driven at a regulated speed by a motor F. As shown, the main body of air for supporting combustion is drawn into the air inlets of the preheater E through a chamber space A⁶ at the outer sides of the portion of the space A⁴. The space A⁶ receives atmospheric air at its lower end at a rate dependent on the speed of the fan F'. The heated air from the preheater E passes to the burner B' through the preheater air outlet E' and thence to the combustion chamber.

Disposed along the wall of the combustion chamber A' are the tube elements *a* which form the boiler heating surface. As diagrammatically illustrated, each tube element *a* is a looped tube comprising a plurality of vertical sections extending from the top of the combustion chamber nearly to its lower end, the ends of each looped tube section being connected to external inlet and outlet headers *a*¹ and *a*². To facilitate close spacing of the vertical sections of the tube elements, and the avoidance of unduly sharp turns, the connections between the adjacent vertical sections of each element are in the form of rounded loops *a*³, the latter also serving to intercept heat radiated towards the top and bottom of the combustion chamber.

The inlet header *a*¹ receives the boiler feed water through a delivery pipe D' from the feed water heater D. Steam, or a mixture of water and steam, is discharged from the boiler outlet header *a*² through a pipe *a*⁴, which is connected to the steam inlet pipe C' of the superheater. In the particular form of the invention shown in Fig. 1, the pipes *a*⁴ and C' are connected through a steam and water separator and water purger K hereinafter described. The steam outlet pipe C² of the superheater leads to the inlet or throttle valve G' of a prime mover, shown as a turbine G, driving an electric generator J, and exhausting into a condenser *h*. Cooling water is forced through the condenser *h* at a regulated rate, by a circulating pump H' driven by a motor H. The boiler feed pump I', driven at a regulated motor rate by a motor I, draws water from the hot well *h*' of the condenser *h*, and forces it through stage heaters *d* supplied with bled steam from the turbine G through the conduits *d*'. From the stage heaters *d*, the water passes to the inlet of the economizer D preferably, and as shown, through the heat exchanger K³⁰. Make up water is supplied to the condenser hot well *h*' as required to maintain a normal water level therein, by means of a float *h*² responsive to the height of water level in the hot well, and controlling a supply valve *h*³, in the make up water supply pipe *h*⁴.

In the form of the invention illustrated in Fig. 1, various operation factors are automatically coordinated and controlled by a master controller M, and separate combustion factor controllers

subject to the control of the master controller. Conveniently, and as shown, the master controller M is of the electro-magnetic type and operates to maintain an electric current flow through a control circuit L, which is proportional in strength to the desired rate of combustion and which forms a control force acting on operation factor control devices BM, FM, HM, IM and KM as hereinafter set forth, to thereby keep the rate of combustion proportional to the strength of said current flow.

As diagrammatically shown, the master controller M comprises a lever M' fulcrumed at M², and subjected to two forces tending to turn the lever in the clockwise direction. One of these forces is a constant though regulable gravitational force, created by the counter weight M³ adjustably mounted on the master controller lever M'. In the normal use of the apparatus, the weight M³ is adjusted into the position in which its effect on the lever M is proportional to the average radiation and analogous heat losses of the boiler and turbine, which, as is generally recognized by those skilled in the art, are substantially constant over a wide load range. The second force tending to turn the master controller lever M' in the clockwise direction is proportional to the demand for steam as evidenced by the turbine load. This second force in the arrangement shown, is created by the magnetic interaction of a magnetic core M⁴ secured to the master controller lever M' and telescopically received in a solenoid coil J', the latter being connected in series in the circuit supplied with current by the generator J. The clockwise torque impressed upon the master controller lever M' by the counter weight M³ and the load coil J', is normally balanced by the opposing torque on the lever due to the magnetic interaction of a core M⁵ connected to the lever M' and a solenoid coil L' traversed by all or a regulated portion of the control current flowing through the control circuit L. As shown, the coil L' is normally traversed by a portion of the main control current, which portion is varied by the adjustment of a rheostat R'.

The master controller M normally maintains the proper control current flow through the circuit L by its action on a rheostat R which is automatically adjusted as conditions require, to increase and decrease the amount of resistance *r* connected in series with the control circuit L between the supply circuit conductors 1 and 2. As diagrammatically shown, the rheostat R is adjusted to vary the resistance *r* in circuit, by means of a reversible electric motor *m* energized from supply conductors 1 and 2 for operation in one direction or another accordingly as the master controller lever M' turns in one direction or the other from its normal neutral position. When the control current in the circuit L exceeds the required value, the lever M' turns in the counter clockwise direction, and thereby closes an energizing circuit for the motor *m*, including contact conductors *m*' and *m*². The motor *m* then turns in the direction to increase the amount of resistance *r* in the control circuit. Conversely, when the master controller lever M' turns in the clockwise direction, the second energizing circuit for the motor *m*, including conductors *m*' and *m*³, is closed, and the motor *m* then operates in the direction to reduce the amount of resistance *r* in the control circuit L.

If, as a result of change in operating conditions, the speed of the turbine G departs from its normal value, the corresponding tilting move-

ment of the speed governor lever g not only operates the throttle valve G' to increase or decrease the steam supply of the turbine as required to check the variation from the normal speed, but also effects an adjustment in the control current flowing in the circuit L which tends to increase or decrease the steam pressure as required to enable the turbine to carry its load at the normal speed. Such adjustment in the control current is effected by the rheostat R' . The latter is similar to the rheostat R of the master controller, and includes a reversible motor m controlled by the speed governor lever g , exactly as the motor m of the rheostat R is controlled by the master controller lever M' . On an increase in turbine speed, the motor m of the rheostat R' is operated to increase the amount of resistance r' in shunt to the master controller coil L' , thereby increasing the current flow through the latter. This reacts through the master controller to decrease the strength of the control current flowing through the circuit L and thereby, as hereinafter explained, reduces the rate of combustion and hence the pressure of the steam generated. Conversely, on a decrease in the turbine speed, the motor m of the rheostat R' is energized to decrease the amount of resistance r' in shunt to the coil L' , with the result that the master controller then increases the strength of the control current, and thereby increases the rate of combustion and the pressure of the steam generated. With the described operation, the throttle valve G' normally occupies the same intermediate position for all loads, the steam pressure being automatically adjusted as required to permit the partially open throttle valve to pass whatever steam is required to carry the existing turbine load.

Advantageously, provisions are made for securing the required turbine speed regulation with a relatively small total range of steam pressure variation, thereby avoiding both inefficiently low steam pressures at light loads, and steam pressures high enough to be dangerous or otherwise objectionable at heavy loads. To this end, for example, the turbine control valve mechanism G' may be of the form shown in Fig. 1a wherein nozzle valves G^{13} control communication each between a corresponding turbine inlet nozzle G^{10} , G^{11} or G^{12} , and the main valve chest delivery chamber G^{14} . Communication between the delivery chamber G^{14} and the main valve chest inlet chamber G^{15} , to which the steam supply pipe C^2 opens, is controlled by the main valve member G^{16} which has its stem connected to the lever g of the speed governor. Each of the valves G^{13} has its stem connected to a piston G^{17} working in a corresponding piston chamber G^{18} formed in the valve chest. Springs G^{20} , G^{21} , and G^{22} located in the outer ends of the chamber G^{18} and acting against the corresponding pistons G^{17} , tend to hold the valves G^{13} in the positions in which they close communication between the valve delivery chamber G^{14} and the corresponding nozzles G^{10} , G^{11} and G^{12} . The valve closing tendency of said springs is opposed by the steam pressure in the chamber G^{14} transmitted to the inner ends of the chambers G^{18} by the conduit G^{19} and ports G^{190} .

The parts are so proportioned that as the steam pressure in the chamber G^{14} progressively increases from a certain minimum value the valve G^{13} controlling the nozzle G^{10} will first open, the valve G^{13} controlling the nozzle G^{11} will next open, and the valve G^{13} controlling the

nozzle G^{12} will open last. This result is secured with the arrangement shown in Fig. 1a wherein the pistons G^{17} are all of the same diameter, by making the springs G^{20} , G^{21} and G^{22} of progressively increasing stiffness.

With the control valve mechanism shown in Fig. 1a, on any change in turbine load and consequent change in turbine speed, the corresponding opening or closing movement of the main valve G^{16} will decrease or increase the pressure drop between the main valve chambers G^{15} and G^{14} , and correspondingly increase or decrease the steam pressure in the chamber G^{14} . This pressure change in the chamber G^{14} , transmitted to the inner ends of the piston chambers G^{18} , produces an adjustment in the position of one or more of the valves G^{13} , which, by increasing or decreasing the supply of steam passing to the turbine through one or more of the nozzles G^{10} , G^{11} and G^{12} , tends to restore the turbine speed to its normal value. At very light turbine loads, the valves G^{13} controlling the nozzles G^{11} and G^{12} will be closed, and the remaining valve G^{13} will be in an intermediate position, in which the supply of steam to the nozzle G^{10} is partly throttled. At intermediate load conditions, the inlet to the nozzle G^{10} will be wide open, the inlet to the nozzle G^{12} will be closed, and the inlet to the nozzle G^{11} will be throttled more or less. At heavy loads the inlets to the nozzles G^{10} and G^{11} will be wide open, and the inlet to the nozzle G^{12} will be throttled more or less. As those skilled in the art will readily understand, with the parts of the valve mechanism described properly proportioned and adjusted, the range through which the pressure at which steam is supplied by the pipe C^2 to the inlet chamber G^{15} varies, as the turbine load varies between its minimum and maximum values, may thus be kept suitably small.

The steam and water separator and purger K , and the controller KM associated therewith, operate to continuously purge from the boiler circulating system a portion of the water supplied thereto, the amount of water so purged being in proportion to the strength of the current flowing in the control circuit L . The device K , in the form diagrammatically shown, has a water inlet K' , receiving water and steam through the boiler outlet pipe a^4 . The water entering the device K through the inlet K' is received in a chamber K^2 provided with an orifice or discharge opening K^3 at its lower end. The water passing through the latter, enters a trap K^{10} from which it is automatically discharged through the outlet K^{11} . Steam separating from the water passing through the device K , passes out of the steam space of the latter through the steam outlet K^4 , into the superheater inlet pipe C' .

Advantageously, a screen K^{12} is provided at the upper end of the chamber K^2 to prevent solid matter entering the purger through its inlet K' from passing into the chamber K^2 . Preferably, as shown, the screen K^{12} is inclined, so that solid matter deposited on the screen may be washed off of the latter by the incoming water. The solid matter washed off the screen K^{12} passes down through the heat exchanger K^{30} , and thence into the discharge trap K^{10} .

The amount of water discharged through the orifice K^3 is approximately proportional to the square root of the head of water in the chamber K^2 , and means are provided for varying the speed of the boiler feed pump I as required to make the water delivered to the separator K through

the pipe K^1 proportional to the control current flowing through the circuit L. To this end, the controller KM comprises a tilting manometer K^{20} of the U-tube sealing liquid type, having one pressure chamber or leg connected by a flexible pipe K^{21} to the chamber K^3 adjacent the lower end of the latter, and having its other leg or pressure chamber connected by a flexible pipe K^{22} to the chamber K^2 adjacent the upper end of the latter. The pipe K^{22} while connected to the steam space of the device K will normally be filled with water of condensation. With the described arrangement the pressure transmitted to the manometer by the pipe K^{22} will exceed that transmitted to the manometer by the pipe K^{21} by an amount which diminishes as the height of water level in the chamber K^2 increases. The tilting manometer is shown as provided with a counter-balance K^{24} , normally adjusted to hold the manometer in a neutral intermediate position when the chamber K^2 contains no water.

When the chamber K^2 is partly filled with water, the resultant displacement of the mercury or other sealing liquid subjects the manometer to a torque tending to tilt the manometer in the clockwise direction. This torque is normally balanced by the electro-magnetic interaction of stationary coils K^{25} and a floating coil K^{26} carried by the tilting manometer. The coils K^{25} and K^{26} are connected in series in the control circuit L. In the normal balanced condition of the manometer K^{20} , the rate of water discharge through the port K^3 will be proportional to the strength of the current flowing through the coils K^{25} and K^{26} , since the square of velocity of the discharge of the water through the port K^3 will be proportional to the height of the water level in the chamber K^2 , while the electro-magnetic interaction of the coils K^{25} and K^{26} will be proportional to the square of the strength of the electric current flowing through those coils.

In accordance with the present invention the flow of water through the port K^3 is normally held proportional to the strength of the current flowing in the circuit L, by the action of the controller KM on the boiler feed pump motor I. The speed of the latter is directly and primarily controlled, as hereinafter described, by a controller IM connected into the control circuit L, but normally only a fractional portion of the current flowing in the control circuit L, passes into and acts upon the controller IM. The balance of the control current passes through a shunt about the controller IM which includes the resistance r^2 forming a part of a rheostat KR which is controlled by the controller KM. As diagrammatically shown, the rheostat KR includes a reversible motor m connected through a worm and gear to the pivoted rheostat switch arm. The motor m is energized for rotation in one direction or the other by means of contact conductors m' , m^2 and m^3 which close one or the other of the two actuating circuits of the motor, when the tilting manometer K^{20} turns away from its neutral position in one direction or the other, exactly as one or the other of the energizing circuits for the motor m of the master controller M is energized by a tilting movement of the master controller lever M' .

When the height of water level in the chamber K^2 diminishes relative to the magnetic interaction between the coils K^{25} and K^{26} , the manometer K^{20} tilts in the counter-clockwise direction, and the motor m of the rheostat KR is energized to increase the amount of resistance

r^2 in circuit. Since the latter is in shunt to the controller IM, the effect of increasing the amount of resistance r^2 in circuit is to increase the portion of the control current passing through and acting on the controller IM. The latter thereupon increases the speed of the boiler feed pump motor I, with the result that more water is passed through the boiler and into the chamber K^2 . Conversely, when the height of water level in the chamber K^2 exceeds the normal amount, the manometer K^{20} tilts in the clockwise direction and thereby energizes the motor m of the rheostat KR to diminish the amount of resistance r^2 in circuit. This diminishes the portion of the control current flowing through the controller IM and thereby diminishes the rate at which water is passed into the boiler with the ultimate result of diminishing the rate at which water is discharged through the port K^3 .

Advantageously, provisions are made for recovering available heat from the water passing through the port K^3 and ultimately discharged by the trap K^{10} . To this end, in the arrangement shown, a heat exchanger K^{30} is interposed between the separator K and the trap K^{10} . As shown, this heat exchanger is employed to increase the temperature of the water passing from the stage heaters d through the pipe d^2 to the heat exchanger K^{30} and passing from the latter through the pipe d^3 to the economizer D.

Each of the previously mentioned controllers BM, FM, IM and HM, may be identical in form with the controller KM. As shown, the controllers BM, FM, IM and KM comprise motor operating rheostats BR, FR, IR and MR which may be each identical with the rheostat KR forming a part of the controller KM. The rheostat BR is employed to regulate the speed of the fuel feed motor B, 1 and 2 representing the current supply conductors to the motor. The pipes B^{21} and B^{22} provide means for impressing on the controller BM a differential pressure proportional to the square of the rate at which fuel is supplied to the combustion chamber. When said differential pressure diminishes or increases relative to the strength of the electric current flowing in the circuit L, the controller BM adjusts the rheostat BR to correspondingly increase or decrease the speed of the motor B, and thus bring the rate of fuel feed into the desired proportion with the strength of the control current.

Similarly, the controllers FM and HM operate through the corresponding motor controllers FR and HR to increase and decrease the speeds of the motors F and H as required to maintain the volume of draft and the rate of condenser cooling water flow, each proportional to the strength of the control current. The controller IM operates like the other operation factor controllers, to maintain the desired ratio between the flow of feed water discharged by the pump I and the portion of the control current acting on the controller IM. As previously explained, the rate at which feed water is supplied to the boiler, is varied as required to make the discharge of water through the separator K and trap K^{10} proportional to the rate of combustion. This control, however, is in the nature of a secondary control. So long as the desired amount of water is being purged through the separator K, the controller IM operates primarily and solely to keep the supply of feed water in proportion to the strength of the control current then flowing through the circuit L. As previously explained, the lever M' of the master controller M is acted upon by two

forces tending to turn the lever in the clockwise direction and to the action of an opposing force tending to turn the lever counter clockwise as seen in Fig. 1. Of the two forces tending to turn the lever M' in the clockwise direction, one, due to the counter-weight M^3 , is a normally constant force which may be adjusted by adjustment of the weight M^3 toward or away from the fulcrum of the lever M' to the value required to make its effect on the lever correspond to the constant heat radiation and other boiler furnace and turbine heat losses. The second force tending to turn the lever M' clockwise is due and directly proportional to the electric current flow through the coil J' , and is approximately proportional to the electrical load on the electrical generator J and to the mechanical load on the turbine G which drives the generator J , and to the useful load on, or useful heat supplied by, the steam generator which supplies the steam by which the turbine G is operated. But for the variations in boiler furnace, turbine and electrical generator efficiencies, variations in the temperature and pressure of the steam supplied to the turbine G , and variations in the delivery voltage of the electric generator J , the action of the current flow through the coil J' would be in constant proportion to the loads on the turbine and the electric generator and to the useful boiler furnace load. In the normal operation of a suitable designed power plant of the form shown in Fig. 1, said variations in efficiency, etc. are not great enough to prevent the strength of the current flow through the coil J' from being in approximately constant proportion to the electric load on the generator J , to the mechanical load on the turbine G , to the useful load on the steam generator, and to the useful load on the steam power plant considered as an entity.

The master controller has no control of the forces tending to turn the lever M' clockwise except indirectly as and in consequence of the fact that the proper operation of the master controller contributes to the maintenance of conditions enabling the plant to carry its load. The master controller, however, directly controls the current flow through the coil L' , and, through its action on the motor m of the rheostat R , increases or decreases said current flow as required to normally hold the balance lever M' in its intermediate position in which it is out of engagement with either of the motor terminals m^2 and m^3 of the rheostat R .

The current flow through the control circuit L is a main or master control force which controls the boiler furnace rate of combustion and maintains the latter in constant proportion to said force. Said force controls the rate of combustion by the action on the controllers BM and FM which operate in a well known manner to make the rate of fuel supply and the rate of combustion air supply or volume of draft each proportional to said control force. Through the controller HM the rate of flow of condenser cooling water is kept in constant proportion to the main control force and hence to the rate of combustion. The controller IM tends to maintain the rate of feed water supply proportional to the main control force and to the rate of combustion. The action of the controller KM which increases and decreases the rate of feed water supply as required to maintain the rate at which water is purged by the device K in constant proportion to the master control force and hence to the rate of combustion.

But for its inclusion of the rheostat R controlled by the turbine speed governor lever g , the control system shown in Fig. 1 would tend when properly calibrated or adjusted, to supply steam at constant pressure to the inlet of the turbine G . The turbine governor provisions of Fig. 1, illustrated in detail in Fig. 1a, are of such character, as to require an increase in steam pressure with turbine load to avoid an objectionable decrease in turbine speed from then occurring. On an increase in load and resultant initial decrease in speed of the turbine, the turbine speed governor lever g not only operates the throttle valve G' to thereby directly increase the steam pressure in the valve chest chamber G^{14} , but also energizes the motor m of the rheostat R' to decrease the amount of resistance in the shunt about the coil L' , thereby increasing the current flow through the shunt and momentarily diminishing the current flow through the coil L' . The momentary reduction in current flow through the coil L' unbalances the master controller lever M' , which thereupon actuates the motor m of the rheostat R as required to increase the current flow through the coil L' to the value needed to hold the lever M' in its normal neutral position. The net effect of the adjustments of the resistance R' and R just described, is to increase the strength of the current flowing through the control circuit L . This increase in the main control force correspondingly increases the rate of combustion as required to increase the steam pressure at the turbine inlet in accordance with the increase in turbine load. Conversely on a decrease in turbine load and resultant increase in turbine speed, the rheostats R' and R are actuated to diminish the main control force and rate of combustion as required to reduce the steam pressure at the turbine inlet in accordance with the decrease in turbine load.

In the arrangement shown in Fig. 1, the separator and purger K , and the control provisions associated therewith comprise means for regulating the supply of feed water to the boiler as required to continuously supply steam to the inlet of the superheater C which is saturated but free from excessive moisture. The saturated steam condition at the superheater inlet maintained with the apparatus shown in Fig. 1, is not the only constant steam condition which may be maintained by the use of the general principles of the invention set forth herein. For example, in some cases it may be desirable to dispense with the purger and separator K , and to impose a secondary control effect on the feed water supply means effective to insure a constant steam temperature in the superheater outlet. A modification for this purpose, of the apparatus shown in Fig. 1, is illustrated in Fig. 2. In the latter figure, S represents a thermo-couple or analogous device responsive to the temperature of the steam passing away from the superheater C through the superheated steam delivery pipe C^3 . The temperature responsive device S acts through a controller SM to determine what portion of the total control current flowing in the circuit L , is impressed on the boiler feed pump controller IM . The controller SM may include a rheostat KR like the rheostat KR of Fig. 1, which is actuated by the controller SM to increase or decrease the rate at which boiler feed water is supplied to the boiler by the pump I' , as the superheated steam temperature to which the device S responds, rises above or falls below a predetermined value.

As has been stated, certain general features of

the invention herein disclosed may be employed to advantage in connection with boilers which are not flash boilers. One such use of the invention is illustrated in Fig. 3 wherein the boiler AA is shown as a cross drum horizontal water tube boiler, a^{10} representing the boiler tubes, and a^{11} the steam and water drum. As shown in Fig. 3, the walls of the combustion chamber A^{10} below the tubes a^{10} are cooled by tubes a^{12} through which the water is passed from the economizer DA into the boiler proper. In the construction shown in Fig. 3, the superheater CA is a convection type heater located above the boiler water tubes, and the heating gases after passing over the superheater CA pass down through a chamber A^{11} in which they give up heat first to the economizer DA, and then to the air heater EA. In the particular construction shown in Fig. 3 the boiler is heated by the combustion of gaseous fuel supplied by a fan BA, and the rate of combustion is controlled by varying the speed of the fan BA and the speed of a blower FA which passes air into the combustion chamber A^{10} through the air preheater EA.

The arrangement shown in Fig. 3 comprises a turbine G, condenser h, generator J, master controller M, pump H as in Fig. 1, and the master controller M controls the pumps BA, FA and H through controllers BM, FM and HM connected to the control circuit L as in Fig. 1. In Fig. 3 the rheostat R' controlling the variable shunt about the coil L' instead of being controlled by the speed governor lever g, is controlled by the lever t of a device T responsive to the pressure at which steam is supplied to the turbine. The device T serves to vary the resistance in shunt to the coil L' as required to increase and decrease the control current when the steam pressure impressed upon the device T diminishes below or rises above a predetermined value.

In the arrangement shown in Fig. 3, the control of the boiler feed pump I is made jointly dependent on the strength of the control current and on the accumulation of water in the steam and water drum a^{11} of the boiler by a controller KMA which serves to increase the accumulation of water in the steam and water drum as the rate of combustion and steam generation increases.

As shown, the controller KMA comprises a tilting manometer K^{20} including differential pressure chambers connected to the steam and water drum a^{11} by pipes K^{21} and K^{22} , respectively below and above the water level therein. In addition, the tilting manometer structure comprises differential pressure chambers K^{60} and K^{61} , connected at their lower ends for the passage between the chambers of a suitable sealing liquid. The upper end of the chamber K^{60} is connected to the delivery pipe from the feed pump I at the high pressure side of an orifice therein by a pipe K^{62} , and the upper end of the chamber K^{61} is connected by a pipe K^{63} to the delivery pipe at the discharge side of the restricted orifice in the last mentioned pipe. The coils K^{25} and K^{26} of the controller KMA electro-magnetically interact to subject the tilting manometer K^{20} to a clockwise torque. The differential pressure impressed on the manometer through pipes K^{62} and K^{63} as the flow of feed water increases, tends to tilt the manometer K^{20} in the counter clockwise direction. The differential pressure imposed on the manometer through pipes K^{21} and K^{22} tends to tilt the manometer in a clockwise direction as the level of the water in the boiler drum

falls. When the moment impressed upon the balance by the solenoids K^{25} and K^{26} plus the moment impressed upon the balance through the pipes K^{22} and K^{21} is greater than the moment due to the differential pressure transmitted through the pipes K^{62} and K^{63} , the balance will tilt in a clockwise direction thereby closing the energizing circuit for the motor M of the rheostat KR which causes the latter to be adjusted to speed up the feed pump I. This will increase the flow of feed water and hence the differential pressure set up at the orifice in the feed line. This in turn will increase the moment exerted by the chambers K^{60} and K^{61} until the manometer of controller KMA is returned to its normal neutral position.

Conversely, when the sum of the moments due to the solenoids K^{25} and K^{26} and to the differential pressure transmitted through pipes K^{21} and K^{22} are less than the moment due to the rate of flow of feed water, the speed of the pump I will be reduced until equilibrium of the balance is reestablished. The solenoids K^{25} and K^{26} and the chambers K^{60} and K^{61} are so proportioned that in order to maintain equilibrium of the balance when the correct amount of water is being fed to correspond to the control current in the circuit L, a high water level will be required in the drums a^{11} at high rates of steaming and a low level at low rates of steaming. The water thus stored in the drum a^{11} at high rates of steaming serves to compensate for the space occupied by steam bubbles in other parts of the boiler at high rates of steaming, and on the other hand avoids having so large an amount of water in the boiler at low rates of steaming that the water level in the the drum a^{11} will rise to an inconvenient height when the rate of steaming is suddenly increased.

While in accordance with the provisions of the statutes, I have illustrated and described the best form of embodiment of my invention now known to me, it will be apparent to those skilled in the art that changes may be made in the form of the apparatus disclosed without departing from the spirit of my invention as set forth in the appended claims and that in some cases certain features of my invention may be used to advantage without a corresponding use of other features.

Having now described my invention what I claim as new and desire to secure by Letters Patent is:—

1. The method of furnace control which consists in maintaining a control force approximately proportional to the sum of a constant quantity corresponding to the furnace heat losses and a variable quantity proportional to the furnace heat utilization, and varying the rate of combustion in the furnace as said force varies.

2. The method of regulating the rate of combustion in a boiler furnace which consists in maintaining a control force approximately proportional to the sum of a constant quantity and a quantity varying in linear proportion with the rate of steam generation, modifying said control force to correct for departures in the pressure of the steam generated from a predetermined standard, and varying the rate of combustion in correspondence with changes in said control force.

3. The combination with a steam generator, of a prime mover utilizing the steam generated by said generator, means for regulating the rate at which heat is supplied to said generator comprising—

ing a master controller maintaining a control force, means for subjecting said master controller to said control force and to two opposing forces, one of which is a constant and the other of which is proportional to the prime mover load.

4. In a steam power plant, the combination with a steam generator, of a prime mover utilizing the steam generated, a combustion control system regulating the supply of heat to said generator including means responsive to a plant load condition and tending to make the rate of steam generation proportional to the prime mover load, and means responsive to variations in the prime mover speed tending to increase and decrease the rate of heat supply as the prime mover speed rises above or falls below a normal value.

5. In a combustion control system, control mechanism actuated by a control force and means for maintaining said control force comprising a master controller and means for subjecting said master controller to the action of a force proportional to said control force and to the opposing action of two forces, one of which is a constant and the other of which is approximately proportional to the rate of heat utilization.

6. In a steam power plant, the combination with a steam generator, of a prime mover utilizing the steam delivered by said generator, means for supplying heat to said generator including control provisions comprising means tending to increase and decrease the rate of steam generation as the plant load requirements increase and decrease and other means cooperating with the first mentioned means to increase and decrease the pressure of the steam generated as said requirements increase and decrease.

7. In a steam power plant, the combination with a steam generator, of a prime mover utilizing the steam delivered by said generator, means for supplying heat to said generator including combustion control provisions comprising means responsive to the prime mover load requirement tending to increase and decrease the rate of heat supply as the prime mover load increases and decreases, and means responsive to the speed of the prime mover also tending to increase and decrease the heat supply as the prime mover speed decreases and increases.

8. In a steam power plant, the combination with a steam generator, of a prime mover utilizing the steam generated by said generator, and combustion control provisions comprising means responsive to a prime mover load condition tending to make the rate of steam generation proportional to the prime mover load and other means responsive to another plant condition cooperating with the first mentioned means to increase and decrease the pressure of the steam as the prime mover load increases and decreases.

9. The combination with a steam generator, of feed water supply means and controlling mechanism for the latter tending to maintain a feed water supply rate proportional to the rate of evaporation in said generator, and means responsive to variations in the wetness of the steam generated for varying the rate of water supply.

10. In a steam generating plant, the combination with a steam generator, of feed water supply means therefor, a combustion control system tending to maintain a rate of combustion approximately proportional to the rate of evaporation, and including control means for said feed water supply means, and means responsive to variations in the quality of the steam generated for varying the rate of feed water supply.

11. The combination with a steam generator normally supplied with feed water at a rate in excess of the evaporative capacity of the boiler and having an outlet for steam and water, of a separator connected to said outlet and having separate outlets for steam and water, means measuring the rate of water discharge from said separator and means measuring the rate at which feed water is supplied to said generator and cooperating with the first mentioned means to hold the last mentioned rate in a constant ratio to the rate of water discharge.

12. The combination with a steam generator normally supplied with feed water at a rate in excess of the evaporative capacity of the boiler and having an outlet for steam and water, of a separator connected to said outlet and having separate outlets for steam and water, said separator comprising discharge water measuring means, means responsive to the rate at which feed water is supplied to said generator and means controlled by the two previously mentioned means for regulating said rate to maintain it in approximate proportion to the rate of water discharge.

13. The combination with a steam generator normally supplied with feed water at a rate in excess of the evaporative capacity of the boiler and having an outlet for steam and water, of a separator connected to said outlet and having separate outlets for steam and water, said separator comprising water measuring means receiving the entering water and a screen for diverting from said means solids carried into said separator by the entering water and steam.

14. The method of regulating the rate of combustion in a boiler furnace which consists in maintaining a control force approximately proportional to the sum of a constant quantity and a quantity varying in linear proportion with the rate of steam generation, and varying the rate of combustion in correspondence with changes in said control force.

15. In a steam generating plant including a steam and water drum, the combination of feed water supply means therefor, a combustion control system setting up a control force proportional to the rate of evaporation and control means for said feed water supply means jointly responsive to said control force, to the rate of feed water supply and to the level of the water in said drum.

16. In combination a steam heater, a furnace supplying heat thereto, a combustion control system for said furnace including means responsive to the rate of flow of the steam which passes through said heater, means responsive to variations in a quantity which is approximately proportional to the rate of combustion tending to maintain an approximately constant ratio between the rate of combustion on the one hand and the rate of flow of steam plus a constant quantity on the other hand, and means responsive to the temperature of the steam at the heater outlet for adjusting said ratio.

17. In a steam generating plant including a steam and water drum, the combination thereof with of feed water supply means, a combustion control system for setting up a control force varying in accordance with variations in the rate of steam delivery from said drum, control means for said water supply means normally responsive jointly to said control force and to the rate of feed water supply, and means controlled by the level of the water in said drum for modifying the action of said supply means when said level passes above or below predetermined normal limits.

18. In a furnace control system, the combination of means maintaining a control force approximately proportional to the sum of a constant quantity corresponding to the normal furnace heat losses and a variable quantity proportional to the furnace heat utilization and means responsive to said force for varying the furnace rate of combustion in accordance with changes in said force.

19. The combination with a boiler furnace, of means for regulating combustion therein comprising means maintaining a control force approximately proportional to the sum of a constant quantity and a quantity varying in linear proportion with the rate of steam delivery from said furnace, means for modifying said control force to correct for departures in the pressure of the steam generated from a predetermined standard, and means responsive to said force for varying the rate of combustion in said furnace in correspondence with changes in said force.

20. The combination with a boiler furnace, of a control system regulating combustion therein and comprising means for maintaining a control force approximately proportional to the sum of a constant quantity and a quantity varying in linear proportion with the rate at which steam is generated by said furnace, and means responsive to said force for varying the rate of combustion in correspondence with changes in said force.

21. In a combustion control system, means responsive to the rate of useful heat delivery, means responsive to the rate of fuel feed, means responsive to the rate of supply of air for combustion, and means coacting with all of the previously mentioned means and including means for creating an effect proportional to the sum of two quantities one of which is a constant and the other of which is proportional to the first mentioned rate for supplying fuel and supplying air each at a rate proportional to said effect.

22. In combination with a vapor generator of the type having a water containing space of relatively small storage capacity to which water is normally supplied at a rate in excess of the rate at which steam is withdrawn from the generator, devices supplying fuel and air for its combustion to said generator, and controlling means for said devices including means responsive to the rate of fuel supply, means responsive to the rate of air supply, means responsive to the rate at which steam is withdrawn from the generator and cooperating means adjusting said devices as required to maintain definite minimum rates of air and fuel supply, when no steam is being withdrawn, corresponding to the furnace heat losses, and for increasing each of said supply, at other times, by an amount proportional to the rate at which steam is being withdrawn from the generator.

23. In combination with a vapor generator of the type having a water containing space of relatively small storage capacity to which water is normally supplied at a rate in excess of the rate at which steam is withdrawn from the generator, devices supplying fuel and air for its combustion

to said generator, and controlling means for said devices including means responsive to the rate of fuel supply, means responsive to the rate of air supply, means responsive to the rate at which steam is withdrawn from the generator and cooperating means adjusting said devices as required to make the rate of air supply and the rate of fuel supply each proportional to a quantity varying in proportion to the sum of the rate at which steam is withdrawn from the generator and a constant quantity.

24. The method of controlling the furnace of a steam generator having no substantial water storage capacity so that the rate of water supplied to the generator must be maintained in close correspondence with the rate of steam output at all times, which consists in maintaining a control force approximately proportional to the sum of a constant quantity corresponding to the furnace heat losses and a variable quantity proportional to the furnace heat utilization, and varying the rate of combustion in the furnace as said force varies.

25. The combination with a steam generator having no substantial water storage capacity so that the rate of water supplied to the generator must be maintained in close correspondence with the rate of steam output at all times, of a prime mover utilizing the steam generated by said generator, means for regulating the rate at which heat is supplied to said generator comprising a master controller maintaining a control force, means for subjecting said master controller to said control force and to two opposing forces, one of which is a constant and the other of which is proportional to the prime mover load.

26. In a steam power plant, the combination with a steam generator, having no substantial water storage capacity so that the rate of water supplied to the generator must be maintained in close correspondence with the rate of steam output at all times, of a prime mover utilizing the steam delivered by said generator, means for supplying heat to said generator including control provisions comprising means tending to increase and decrease the rate of steam generation as the plant load requirements increase and decrease, and other means cooperating with the first mentioned means to increase and decrease the pressure of the steam generated as said requirements increase and decrease.

27. The combination with a steam generator delivering steam at a variable rate and heated by the combustion of fuel and provided with water purging means, of feed water supply means including means responsive to the rate of steam delivery from said generator and also including means measuring the rate of water purging for supplying feed water to said generator at a rate in substantially constant proportion to said rate of steam delivery and in excess of the generator rate of steam generation, whereby a substantially constant fraction of the water fed to the generator is purged therefrom.

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