

May 1, 1956

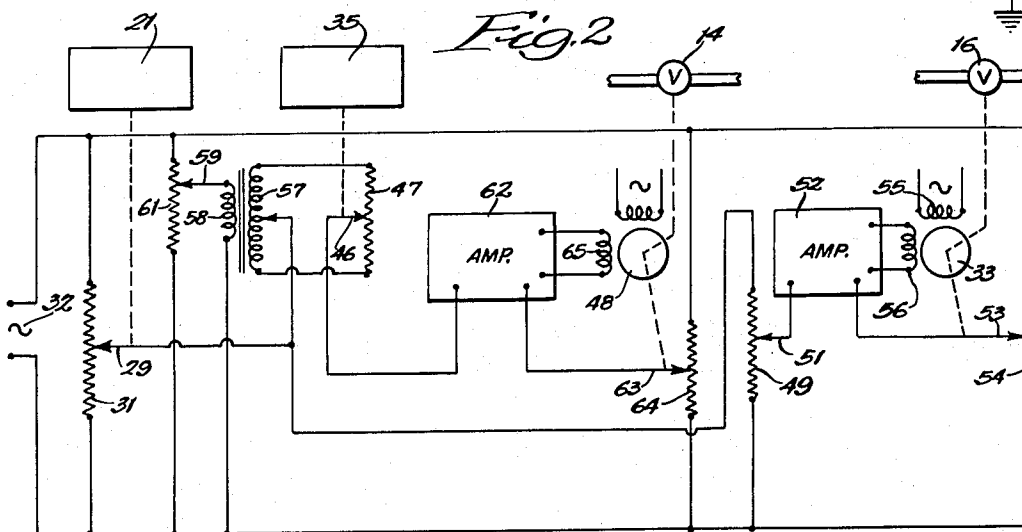
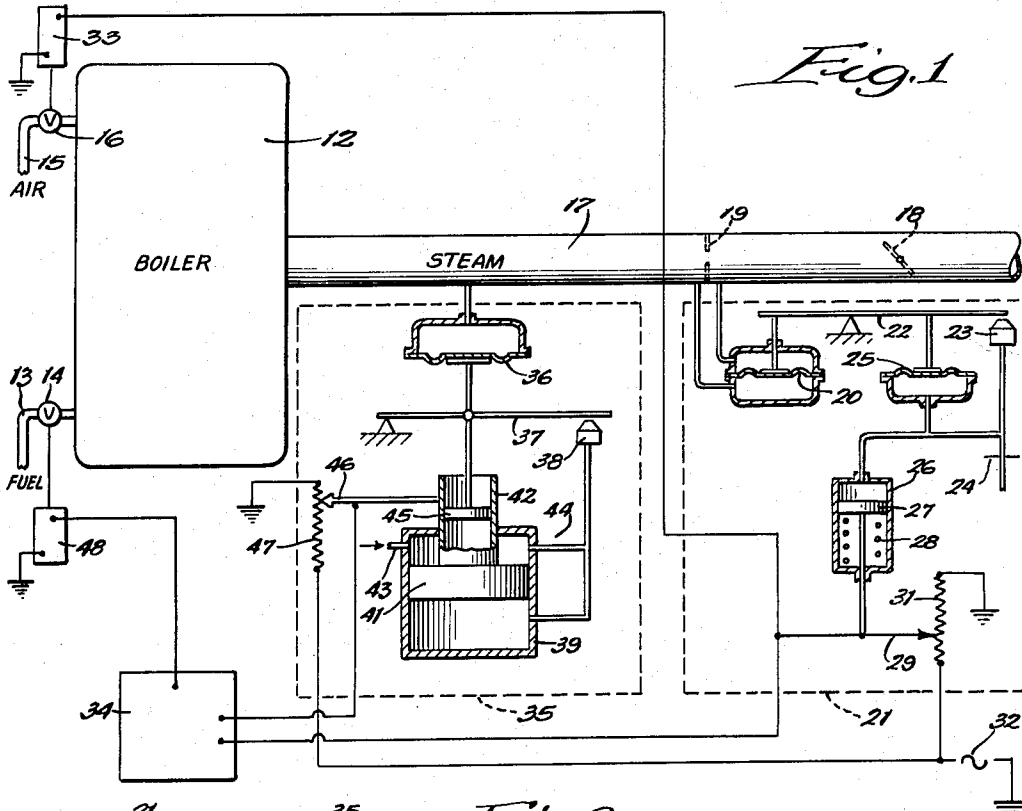
C. H. SMOOT

2,743,869

COMBUSTION CONTROL SYSTEM

Filed June 3, 1953

2 Sheets-Sheet 1



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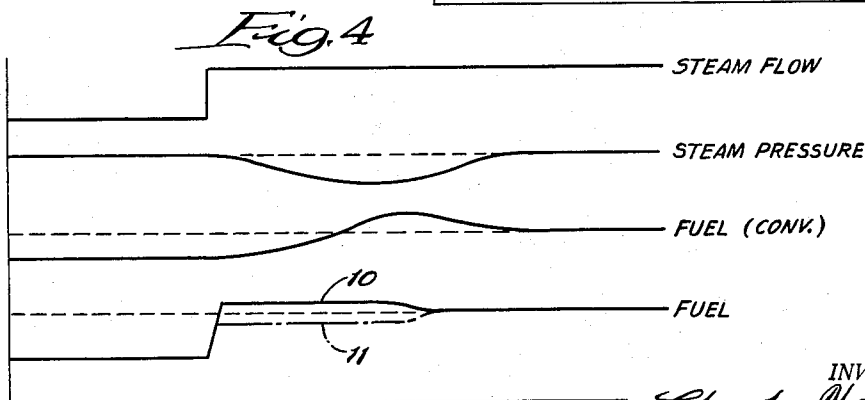
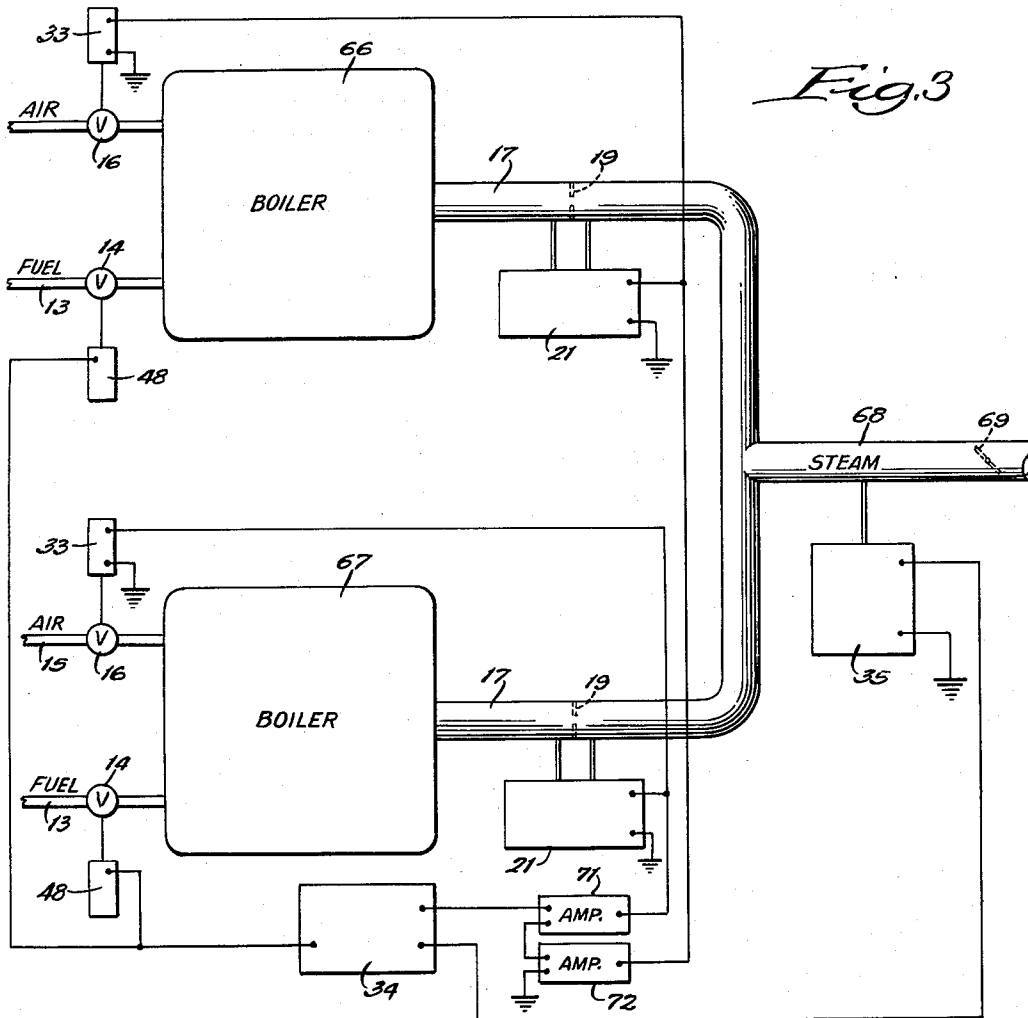
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1

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COMBUSTION CONTROL SYSTEM

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Application June 3, 1953, Serial No. 359,331

5 Claims. (Cl. 236—24.5)

This invention relates to combustion control systems and more particularly to a system for controlling the rate of combustion in a steam boiler to maintain substantially constant steam pressure and temperature.

It has heretofore been common practice to control the rate of fuel supply to a steam boiler in response to changes in the steam pressure. In such systems it is necessary to employ stabilizing means which introduce a time delay into the response of the system to changes in steam pressure to match the time delays inherent in operation of the boiler due to heat lag and the like.

It has also been proposed to control the fuel supply in response to steam flow but in such systems, it has been necessary to introduce time delay in order to obtain the necessary stability. Control in response to steam flow has furthermore been considered undesirable because the system is subject to errors in response which may be cumulative and may produce undesirable or even dangerous conditions.

It is highly desirable to effect control operations for the fuel supply as rapidly as possible upon a change in demand and without stabilizing time delays or even without waiting for the steam pressure to change. This is particularly true in modern boilers operating at extremely high temperatures and pressures and having relatively small storage capacity.

It is one of the objects of the present invention to provide a combustion control system in which the fuel supply is initially changed rapidly in response to changes in steam flow and is corrected relatively slowly in response to steam pressure.

Another object is to provide a combustion control system in which air supply to the boiler is controlled solely in response to steam flow and fuel supply is controlled in response to both steam flow and steam pressure.

Still another object is to provide a control system for a plurality of boilers in which the air supply to the boilers is controlled in response to steam flow from the respective boilers and the fuel supply for all of the boilers is controlled in response to the total steam flow and steam pressure.

A further object is to provide a control system which operates electrically to effect rapid and accurate control.

The above and other objects and features of the invention will be more readily apparent from the following description when read in connection with the accompanying drawing in which:

Figure 1 is a diagrammatic view of a combustion control system for a single boiler embodying the invention.

Figure 2 is a circuit diagram of the system.

Figure 3 is a view similar to Figure 1, showing a control system for a plurality of boilers, and

Figure 4 is a graph illustrating different control effects.

In a boiler or bank of boilers supplying steam to a variable load, such for example as a turbine, it is desirable that the steam supply be maintained at substantially constant pressure and temperature to supply variable

2

steam flows to the turbine as required. Steam flow is normally controlled by one or more valves which are adjusted solely in accordance with the demand and have no particular relationship to the operating condition of the boiler. As shown in Figure 4 by the upper line 10, the steam may remain constant over a substantial period and may change suddenly due to opening of the valve to an increased value which will then remain constant for an additional period. It will be noted that such changes may occur rapidly due to cutting one or more turbines into or out of operation as indicated by the sudden increase in steam flow shown in the upper line on Figure 4.

An increase in steam flow will normally produce a gradual decrease in steam pressure as indicated by the second steam pressure line in Figure 4. As the combustion rate of the boiler is increased to compensate for the increased load, the steam pressure will gradually build up to the desired value and so long as the control system is functioning properly and the load remains constant, will stay at that value.

The third line in Figure 4 illustrates the type of control effected by conventional control system which embodies stabilizing time delays and which may respond either to changes in steam pressure or in steam flow. As there shown, the fuel supply will remain constant so long as other conditions are constant and when the demand is increased by suddenly increasing the steam flow, the fuel supply will be gradually increased. The rate of increase will depend upon the stabilizing time delays employed in the control and may depend in part upon the change in pressure resulting from increased flow. Normally the fuel supply will increase to a value greater than that required to maintain the new flow and will then gradually be reduced to the correct value as indicated by the graph.

The control effected by the present invention is indicated by the lowermost line on Figure 4. As shown, the fuel supply will be maintained constant as long as the flow and pressure conditions remain constant. As soon as the steam flow increases, the fuel supply will increase substantially instantaneously and proportionately in response to steam flow and will be adjusted to a new value approximating the desired rate of fuel supply for the new load conditions. This value may be either slightly above or slightly below the actual desired value as indicated by the solid line 10 or the dot-dash line 11. It has been found in actual practice that the fuel supply rate will normally be within less than 1% error from the desired rate so that only a very small correction is required to bring it to the desired rate. This correction is effected in response to steam pressure at a relatively low rate so that eventually the fuel supply will be brought to the exact value required to maintain the pressure at the desired value under existing load conditions.

While exact times for correction are variable with different installations, the conventional system has on the average required approximately 4 to 5 minutes to effect an 80% correction in fuel supply and 15 to 20 minutes to effect the final correction and bring the fuel supply back to the desired value. With the present invention 80% correction is effected in approximately 8 seconds and complete final correction is effected in less than 2 minutes. Therefore, the firing rate of the boiler is substantially instantaneously and proportionately adjusted to changes in demand so that the load is supplied with steam at the desired pressure and temperature even though the demand varies rapidly and relatively widely. Another important aspect is the safety provided by the rapid control of the firing rate in high pressure, high temperature boilers having a small storage capacity. With such boilers if the load is suddenly reduced materially or cut off, serious danger of explosion may result because the temperature and

pressure values may build up to dangerous levels before the firing rate can be adjusted. With the present invention, the firing rate is adjusted so rapidly that dangerous conditions are not allowed to build up so that a safe operation is provided.

Figure 1 illustrates application of the invention to a single boiler 12 which may be a high temperature, high pressure boiler having a relatively small storage capacity. Fuel is supplied to the boiler through any suitable supply means depending upon the type of fuel employed. For simplicity of illustration, the fuel supply means is indicated as a pipe 13, flow of fuel through which is controlled by a valve 14. Air may similarly be supplied by conventional forced or induced draft fans but for convenience of illustration, the air supply is indicated as a pipe 15 having a control valve 16 therein. Steam from the boiler flows through an outlet conduit 17 to any desired load such as a turbine or the like under the control of valve means indicated diagram at 18.

According to the present invention, the fuel and air supplies are controlled substantially instantaneously and proportionately in response to steam flow from the boiler. For this purpose the steam outlet conduit 17 is provided with a restriction 19 and the drop across the restriction is measured by connecting opposite sides thereof to the opposite sides of a diaphragm 20. The diaphragm 20 may form the sensing element of a control device 21 such as the transmitter more particularly described and claimed in my copending application Serial No. 268,378 filed January 26, 1952. As shown this transmitter includes a balanced beam 22 urged in one direction by the diaphragm 20 and controlling a nozzle 23 supplied with air through a restriction orifice 24. The regulated pressure produced by the nozzle 23 is transmitted to a balancing diaphragm 25 which acts on the beam 22 to rebalance it and is also transmitted to a fluid motor including a cylinder 26 having piston 27 slidable therein to be urged in one direction by a spring 28 and in the opposite direction by the regulated pressure. The piston will move to a position corresponding to a flow through the steam outlet conduit 17.

The transmitter produces a regulated controlling force which as shown is an electrical force regulated by moving a wiper 29 which is connected to the piston 27 over a resistance 31. The resistance 31 is connected across an alternating current source 32 so that the voltage to the wiper 29 will be proportional to the steam flow through the outlet conduit. The wiper 29 is connected directly to an electric motor 33 which is connected to the air control valve 16 to regulate the air supply solely in response to steam flow. The wiper 29 also is connected to a totalizing circuit 34.

Steam pressure is measured by a regulator indicated generally at 35 which includes a diaphragm 36 connected at one side to the steam outlet conduit 17 to sense the steam pressure therein. The diaphragm 36 is connected to a lever 37 movable toward and away from a nozzle 38 to control the pressure behind the nozzle.

A power element for the regulator includes a cylinder 39 having a differential piston 41 slidable therein. The piston includes a cylinder 42 extending through one end of the cylinder 39 and operating fluid such as liquid under pressure is supplied through an inlet 43 to the space above the differential piston. This space is connected through a restriction 44 to the nozzle 38 and also to the space beneath the piston 41. The cylinder 42 carries a piston 45 connected to the lever 37 as shown.

In the operation of this regulator an increase in steam pressure will move the lever 37 toward the nozzle 38 to increase the pressure back of the nozzle and cause the differential piston 41 to rise. This will occur even though the pressure below the piston as controlled by the nozzle 38 is less than that above the piston due to the larger effective area on the lower side of the piston. Movement of the differential piston is transmitted through the dash-

pot formed by the cylinder 42 and piston 45 to the lever 37 to move the lever away from the nozzle 38. Liquid will leak gradually past the piston 45 so that as long as the steam pressure is at a higher value than desired, the differential piston 41 will continue to rise slowly as determined by the rate of leakage past the dashpot piston. In this way a stabilizing time delay is introduced into response of the regulator and in the normal use of such regulators, the rate of adjustment is set to compensate for time delays inherent in response of the boiler.

In the present system the movement of the differential piston controls the position of a wiper 46 over a resistance 47 which is connected to the source 32 in parallel with the resistance 31. The wiper 46 is connected to the totalizing circuit 34 so that the output of the totalizing circuit will depend upon both steam flow and steam pressure. The totalizing circuit output is connected to the fuel control valve 14 to control the fuel supply to the boiler.

The electrical components of the Figure 1 are illustrated in detail in the circuit diagram of Figure 2. As best shown in this diagram the wiper 29 is connected across a resistor 49 having manually adjustable wiper 51 slidable therealong. The wiper 51 is connected to one input terminal of an amplifier 52 whose other input terminal is connected to a wiper 53 movable over a resistance 54 which is connected across the source 32. The motor 33 as shown is a two-phased reversible motor having power winding 55 connected to a suitable source such as at source 32 and having a control winding 56 connected to the output terminals of the amplifier 52. The motor 33 is mechanically connected to the valve 16 to adjust it and is also connected to the wiper 53 to move it over the resistance 54.

The wiper 51 may be manually adjusted to set the fuel air ratio and is normally left in a fixed position of adjustment after being once properly set. As long as the voltage at this wiper which will be varied in response to movement of the wiper 29 is equal to the voltage at the wiper 53, the motor 33 will remain stationary. Upon movement of the wiper 29 the amplifier will supply voltage of one phase or another to the motor control winding 56 and will cause the motor to run in a direction to adjust the wiper 53 to rebalance the voltage and simultaneously to adjust the valve 16 to a new position corresponding to the position of the wiper 29. It will be seen that this operation is effected very rapidly so that the air supply will be adjusted rapidly to correspond to steam flow as measured by the control device 21.

The wiper 29 is also connected to the mid point of a transformer secondary winding 57. The transformer includes a primary winding 58 supplied with voltage from a wiper 59 movable over a resistance 61 which is connected across the source 32. The transformer secondary winding 57 is connected directly across the resistance 47 and the wiper 46 thereon is connected to one of the input terminals of an amplifier 62. The circuit elements just described constitute the totalizing circuit 34.

In this circuit when the wiper 46 is centered on the resistor 47 or occupies the same position in this resistor as does the tap from wiper 29 to winding 57, the voltages will be balanced and the voltage impressed on the input terminal of amplifier 62 will equal the voltage of wiper 29. However, if the wiper 46 is displaced by the regulator 35, the voltage impressed on the amplifier input terminal will be equal to the algebraic sum of wiper 29 and the voltage developed due to displacement of wiper 46. The regulator 35 is set to maintain the wiper 46 at the center of the resistance 47 when the steam pressure is at the desired value so that the steam pressure effect is present only when the steam pressure is above or below the desired value.

The other input terminal of the amplifier 62 is connected to a wiper 63 movable over a resistance 64 which is connected across the source 32. Motor 48 is controlled

5

through a control winding 65 connected to the amplifier 62 and is mechanically connected to the wiper 63 and valve 14 to adjust them.

It will be seen that in the operation of this portion of the system whenever the steam flow changes the wiper 29 will be quickly adjusted and will effect a rapid change in the fuel supply. If the steam pressure is not maintained at the desired value by this adjustment a slower follow-up adjustment will be effected through the regulator 35 and wiper 46 to bring the steam pressure back to the exact value desired.

Figure 3 illustrates application of the invention to two similar boilers 66 and 67, each of which may be identical to the boiler 12 and may operate in a similar manner. For simplicity of description, elements in the system of Figure 3 corresponding to identical elements in Figures 1 and 2 are indicated by the same reference numerals. As shown the steam outlet lines for the two boilers combine in a single steam header, flow through which is controlled by a steam valve 69.

Each boiler has a steam flow responsive control device 21 connected across an orifice 19 in its individual steam outlet conduit 17 and the air supply for each boiler is controlled individually solely in response to the control force developed by the corresponding control device 21. In addition, the output voltages of the two control devices are connected to amplifiers 71 and 72. The amplifiers are interconnected as illustrated to provide a single output voltage equal to the sum of the two voltages and this single output voltage is supplied to the totalizing circuit 34 in the same manner as the voltage from the wiper 29 of Figures 1 and 2. The amplifiers 71 and 72 are employed to prevent cross feeding between the two control devices 21 and it will be apparent that any other desired type of circuit arrangement which will totalize the two voltages and will prevent cross feeding may be employed.

The regulator 35 is connected to the steam header 68 to be responsive to steam pressure therein and its output voltage is supplied to the totalizer 34 in the same manner as in Figures 1 and 2. The output voltage from the totalizer 34 is connected to both of the motors 48 in parallel so that the fuel to both of the boilers is controlled in exactly the same manner in response to the total steam flow and the steam pressure. Thus the loads on the boilers are maintained the same or in a desired ratio where the boilers may be of different sizes.

It will be understood that in the same manner the control system might be expanded to a greater number of boilers than two. In all cases the air flow to the boilers is controlled solely in response to the individual steam flows therefrom and the fuel supply to the boilers is controlled jointly by steam flow with a slower correction in response to steam pressure.

While the invention has been illustrated in detail in connection with two typical installations, it will be apparent that these are for the purpose of illustration only and are not to be taken as a definition of the scope of the invention, reference being had for this purpose to the appended claims.

What is claimed is:

1. A combustion control system for a steam boiler having fuel and air supply means and a steam outlet comprising a first control device responsive to flow of steam through the steam outlet and constructed to produce a first control force changing substantially instantaneously and proportionately with changes in steam flow, a second control device responsive to steam pressure in the steam

6

outlet and constructed to produce a second control force proportional to steam pressure, means in the second control device to introduce a time delay into response of the second control force to changes in steam pressure, means responsive to the first control force to control supply of fuel and air to the boiler, and a connection from the second control device to the fuel control means to modify control of the fuel supply in response to the second force.

2. A combustion control system for a steam boiler having fuel and air supply means and a steam outlet comprising a first control device responsive to flow of steam through the steam outlet and constructed to produce a first control force changing substantially instantaneously and proportionately with changes in steam flow, a second control device responsive to steam pressure in the steam outlet and constructed to produce a second control force proportional to steam pressure, means in the second control device to introduce a time delay into response of the second control force to changes in steam pressure, control means for the air supply means responsive solely to the first control force, and control means for the fuel supply means responsive to both the first and second control forces.

3. A combustion control system for a steam boiler having fuel and air supply means and a steam outlet comprising an electrical control device responsive to flow of steam through the steam outlet to produce a first voltage substantially instantaneously proportional to steam flow, a second electrical control device responsive to steam pressure in the steam outlet to produce a second voltage proportional to variations of steam pressure from a normal value, means in the second control device to introduce a time delay into response of the second voltage to changes in steam pressure, means to control the air supply means responsive solely to the first voltage, and means to control the fuel supply means responsive to the algebraic sum of the first and second voltages.

4. A combustion control system for a plurality of steam boilers each having fuel and air supply means and a steam outlet and having the steam outlets connected in a common header comprising a first control device for each boiler substantially instantaneously proportionately responsive to flow of steam through the steam outlet to produce a first control force, a second control device common to all of the boilers and responsive to the steam pressure in the header to produce a second control force, means in the second control device to introduce a time delay into response of the second force to changes in steam pressure, control means for the air supply means of each boiler responsive respectively to the first forces to control the supply of air to the individual boilers, means to total the first forces, and control means responsive to the total of the first forces and to the second force to control the fuel supply means of all of the boilers.

5. The system of claim 4 in which the control devices are electrical and the control forces are electrical voltages.

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