

Sept. 1, 1936.

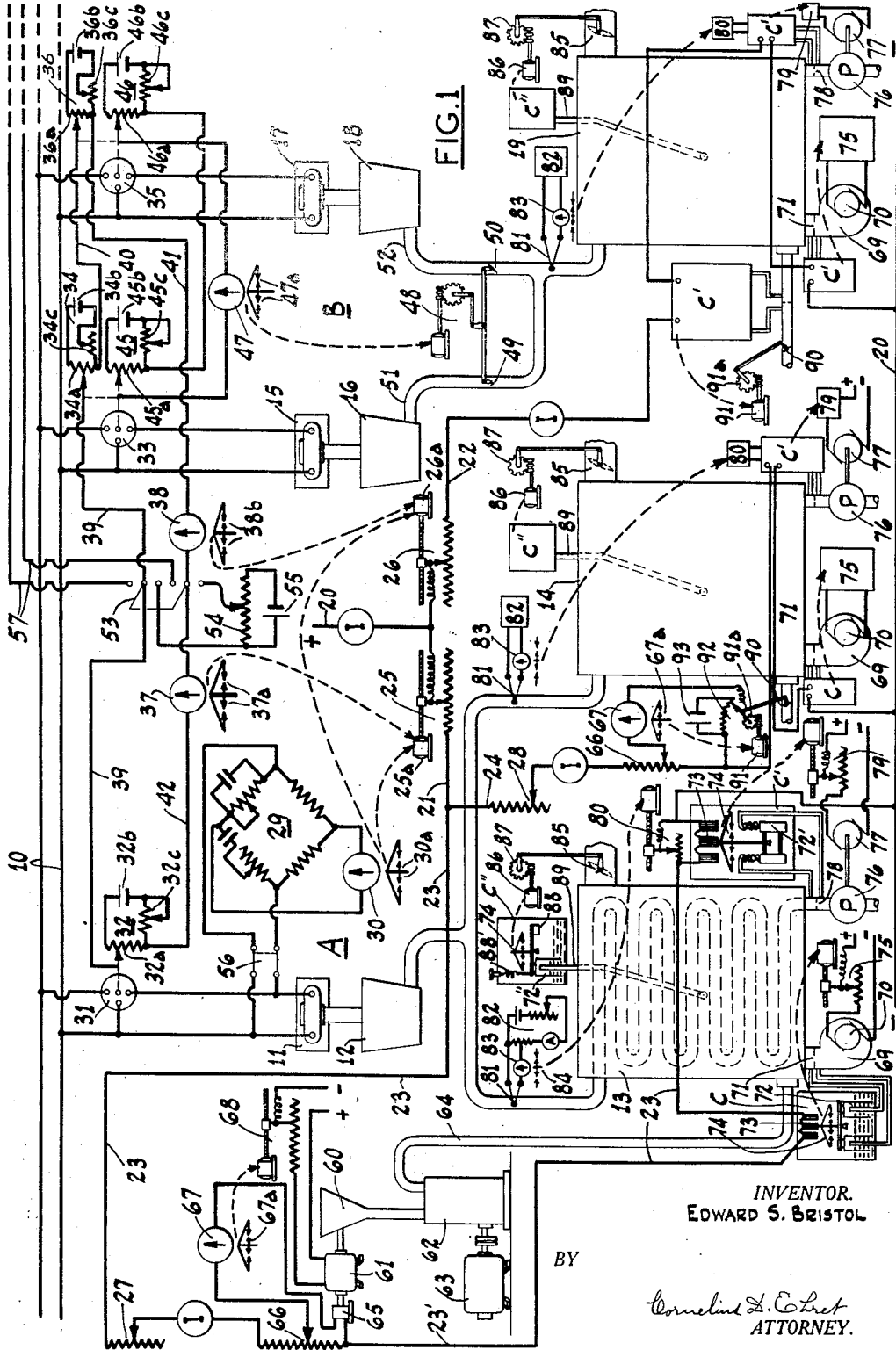
E. S. BRISTOL

2,053,061

COMBUSTION CONTROL SYSTEM

Filed Aug. 9, 1934

3 Sheets-Sheet 1



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COMBUSTION CONTROL SYSTEM

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FIG. 1a

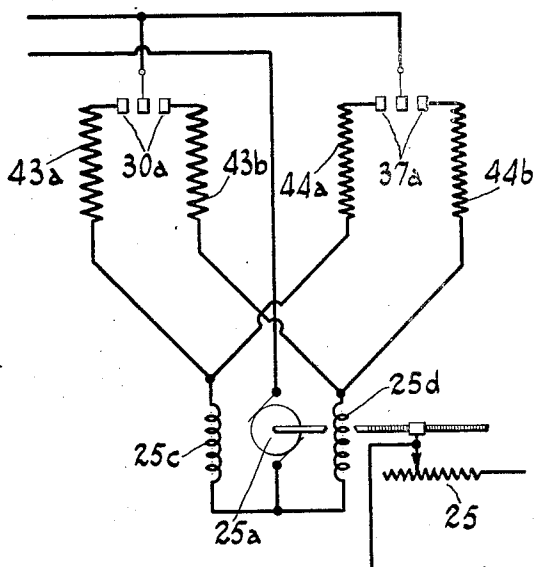


FIG. 2a

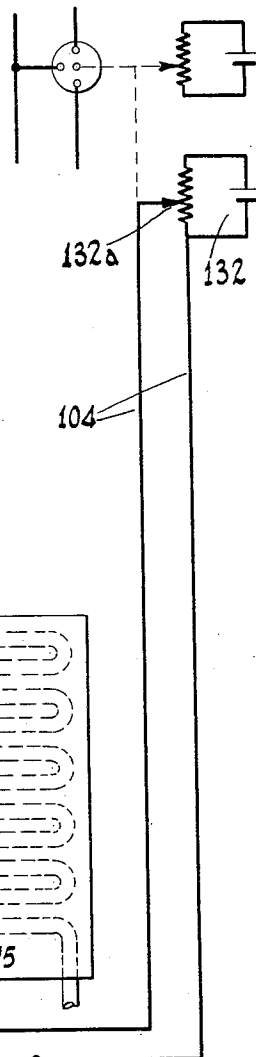
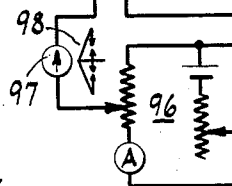
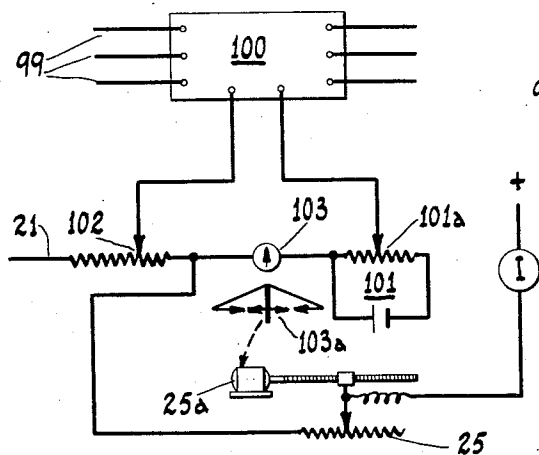


FIG. 3



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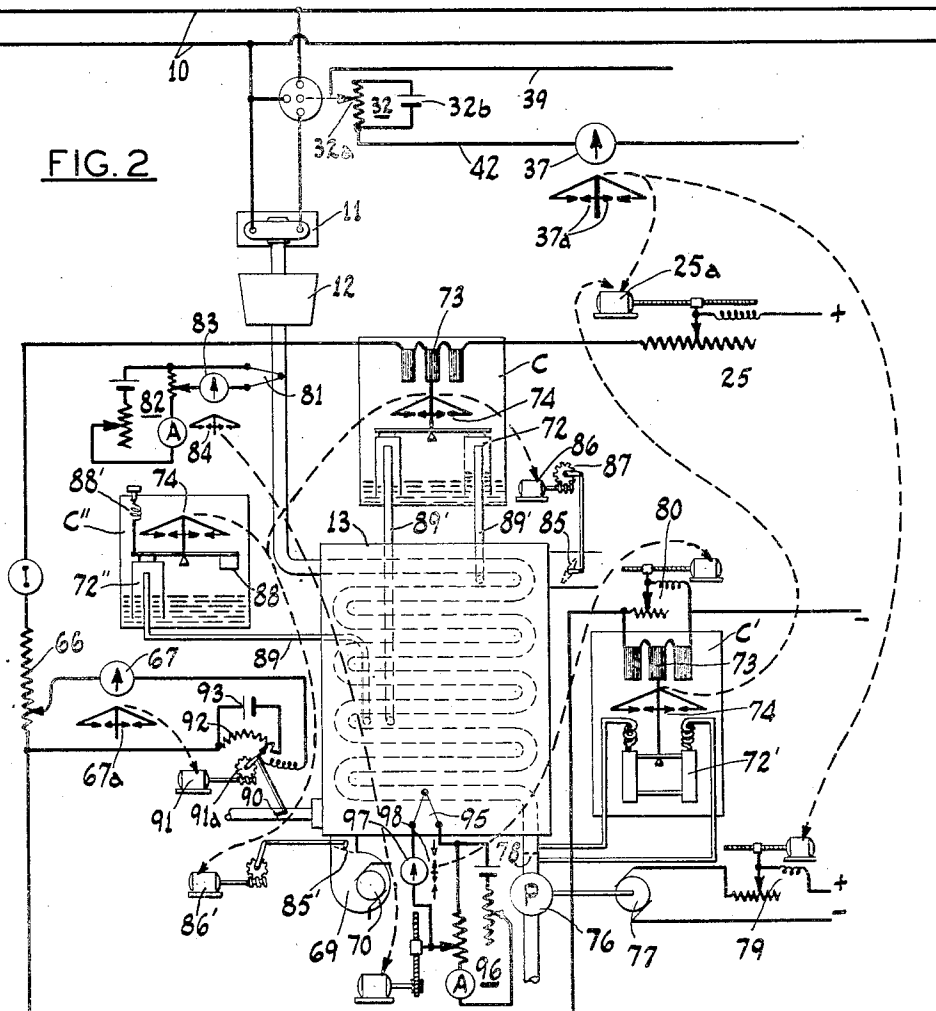
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3 Sheets-Sheet 3

FIG. 2



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## UNITED STATES PATENT OFFICE

2,053,061

## COMBUSTION CONTROL SYSTEM

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Application August 9, 1934, Serial No. 739,123

32 Claims. (Cl. 290—2)

My invention relates to new and improved combustion control systems and more particularly to such systems suitable for application to the control of fluid-driven prime mover systems including electric generating apparatus.

While my invention is of general application, it is particularly useful in systems including boilers having small thermal storage capacities, for example, those of the type known in the art as "flash tube boilers." In this type of apparatus it is desirable to maintain a close correspondence between the factors entering into the production of the motive fluid, for example, fuel, air, and water or other fluid, in spite of variations in load upon the system within a wide range. For instance, with a limited water storage capacity, it is obvious that the rate of supply of feed water to the boiler must be closely correlated with the rate of combustion in order to prevent an excessive rise in steam temperature or pressure occasioned by a deficiency of water, or, on the other hand, an excessive lowering of steam temperature or pressure by an excess of water.

A combustion control system embodying my invention is illustrated as applied to a fluid-driven prime system comprising a fluid-driven prime mover, a boiler for supplying motive fluid thereto, and an electric generator driven by the prime mover. My combustion control system includes means for establishing a master control force, preferably an electric current, varied primarily in accordance with the frequency of the current generated by the system and, secondarily, in accordance with the electrical power output of the generator, as compared with the power output of one or more other generators included in the same or connected systems. The primary control may be relatively quick-acting, rapidly to correct any deviations in frequency of the system from normal, while the secondary control may be relatively slow-acting and effective to prevent a gradual or continuous shifting of the system load between the several generators connected thereto. As an alternative, the primary control may be in response to the load on the system which may be correlated with any desired regulating or controlling force.

The master control current thus established may be employed to control one or more of the following factors of combustion or other operating conditions of the system: the delivery of fuel to the boiler; the forced draft or induced draft of the boiler; the supply of feed-water which, in turn, may be modified by a device responsive to the temperature of the boiler outlet steam, to

act as a check upon the correspondence in the rate of combustion and the rate of supply of water, and/or by a device responsive to the temperature of the water within the flash tube of the boiler; the flow of furnace gases. As an addition or alternative, the flow of furnace gases may be controlled by a device responsive to the pressure within the combustion chamber to maintain such pressure substantially constant, either by controlling the stack damper or the speed of a motor driving a forced draft fan. In case the system includes a prime mover supplied by two or more boilers, the master control current may be divided and adjusted either manually or automatically in proportion to the loads which it is desired the several boilers shall carry, and the branch currents then employed to regulate the control factors of the several boilers.

In each case the factor controlled, such, for example, as the supply of air, fuel, motive fluid or the like, is preferably metered; that is, it is employed to produce a control effect which is a measure of the factor and is compared with the master control current or other control means to produce an exact correspondence between the several operating factors of the system under each condition of load on the system, thus insuring optimum operating conditions. Such an arrangement is to be contrasted with a system in which the various controlling devices are varied proportionally and in which the non-linear characteristics of the several controlling devices or the non-linear relations between the several controlling factors for optimum operating conditions are completely disregarded and which, therefore, results in unbalanced conditions and unsatisfactory and uneconomic operation of the system as a whole.

For a better understanding of my invention, together with other and further features thereof, reference is had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

Referring to the drawings, Fig. 1 is a schematic diagram of a complete combustion control system embodying my invention; while Fig. 1a is a detail diagram of a portion of the control circuit of Fig. 1;

Fig. 2 is a similar diagram in which a master control current influences different control factors of the system; while Fig. 2a illustrates a further control feature which may be added to the system of Fig. 2;

Fig. 3 is a wiring diagram of a modified ar-

rangement for regulating the master control current.

Referring now more particularly to Fig. 1 of the drawings, there is shown a generating system including my improved combustion control system and comprising a pair of units A and B connected to supply alternating current to a common load circuit 10. The unit A consists of an alternating current generator 11 driven by a suitable prime mover, such as a steam turbine 12, to which motive fluid is supplied by a pair of boilers 13 and 14. Similarly, the unit B comprises a pair of alternating current generators 15 and 17 driven by the turbines 16 and 18, respectively, supplied with motive fluid from a single boiler 19. While the boilers 13, 14 and 19 may be of any desired type, my invention is particularly suitable for use in systems embodying boilers having a relatively low thermal storage capacity, known in the art as "flash boilers."

In order to control the several factors entering into the production of motive fluid and its supply to the prime movers 12, 16 and 18, there is established a master control current for each of the units A and B. These control currents may be supplied from a suitable source of control power, such as a direct current circuit 20. The master control currents are established in control circuits 21 and 22 individual to the units A and B, respectively, while the control circuit 21 is, in turn, divided into circuits 23 and 24 individual to the boilers 13 and 14, respectively. The master control currents flowing in the circuits 21 and 22 are regulated to control the various factors of combustion and supply of motive fluid, as described more fully hereinafter, by means of a pair of adjustable resistances, such as motor-driven rheostats 25 and 26, respectively. Preferably, manually-controlled adjustable resistances 27 and 28 are included in the control circuits 23 and 24, respectively, to determine the distribution of load between the boilers 13 and 14. If desired, indicating instruments I may be included in the several control circuits, as the currents flowing in the circuits are measures of the load on the several boilers, as explained more fully hereinafter.

The master control currents flowing in the circuits 21 and 22 may be regulated by any suitable operating conditions of the system. In the arrangement of Fig. 1, they are regulated primarily in response to the frequency of the alternating current of the system supplied by generators 11, 15, and 17 to maintain this frequency substantially constant. To this end, there is provided a frequency-responsive network 29 one diagonal of which is connected to the alternating current circuit 10, while the other includes a contact-making instrument or galvanometer 30 provided with contacts 30a connected to control the motors 25a and 26a of the adjustable resistances 25 and 26, respectively, as indicated schematically by the dotted lines. This conventional interconnection between the controlling and controlled devices has been adopted throughout the drawings to avoid excessive complexity, as the particular controlling and controlled devices, per se, form no part of my invention. The frequency-responsive bridge 29, together with the contact-making instrument 30, may be of any of the several types well-known in the art, although I prefer to use a self-balancing bridge and contact structure, described in Wunsch Patent No. 1,751,538.

In addition, the master control currents may

be subjected to a secondary regulation in response to the division of the system load between the several generators 11, 15, and 17. There is illustrated in Fig. 1 an arrangement for maintaining a predetermined ratio between the electrical power output of the generator 11 and the sum of the power outputs of the generators 15 and 17. This apparatus comprises a contact making wattmeter 31 connected in the leads to generator 11 and operating to adjust a potentiometer 32 consisting of an adjustable potentiometer impedance 32a, a battery 32b and a calibrating impedance 32c. Similarly, a contact making wattmeter 33 is connected in the leads to the generator 15 and adjusts a potentiometer 34 consisting of similar elements, and a contact making wattmeter 35 is connected in the leads of the generator 17 and operative to adjust a potentiometer 36. The electromotive force derived from the potentiometer 32 is balanced against the sum of the electromotive forces of the potentiometers 34 and 36, and contact making instruments 37 and 38 are included in this balancing circuit individual to the units A and B, respectively. This balancing circuit may be traced from the potentiometer impedance 32a, conductor 39, potentiometer impedances 34a and 36a, conductor 41, instruments 38 and 37 and conductor 42. The instruments 37 and 38 may be of any suitable type of contact making ammeters or galvanometers, but are preferably of the type disclosed in Fig. 6 of Doyle Patent No. 1,918,021. By a proper proportioning of the circuit constants of the potentiometers 32, 34 and 36, any desired load distribution between the generator 11 and the generators 15 and 17 may be maintained.

The manner in which the primary and secondary control of the rheostats 25 and 26 is obtained will be clear from Fig. 1a of the drawings, in which the contacts 30a and 37a are those of the frequency-responsive instrument 30 and the load ratio responsive instrument 37, respectively. The motor 25a is provided with a pair of fields 25c and 25d of opposite polarity connected to be selectively energized from a suitable source, as determined by the calibration of the or 37a, or both. Included in the circuit of the contacts 30a are a pair of relatively low resistance devices 43a and 43b, while a pair of relatively high resistance elements 44a and 44b are connected in series with the contacts 37a. By means of such an expedient, if the instruments 30 and 37 operate in the same sense, one of the fields 25c and 25d is energized through a pair of resistors, for example, 43a and 44a, in parallel, so that the energization of the motor 25a is a maximum, and it will rotate at a maximum speed in the particular direction. In case either of the instruments 30 or 37 alone operates its contacts, the motor 25a will rotate at correspondingly reduced speed. In case the instruments 30 and 37 operate in an opposite sense, the fields 25c and 25d will be differentially energized, but the motor 25a will always operate in the direction indicated by the contacts 30a, when either of them is closed, since the smaller resistance is in this circuit.

A predetermined distribution of load between the generators 15 and 17 may be maintained by means of additional potentiometers 45 and 46 also adjusted by means of the contact making wattmeters 33 and 35, respectively. The potentiometers 45 and 46 are included in a balancing circuit in which is connected a contact making

instrument 47, the contacts 47a of which control a motor-operated valve mechanism 48 which adjusts valves 49 and 50 in the fluid conduits 51 and 52, respectively, in opposite senses to vary the distribution of motive fluid to the prime movers 16 and 18.

In case it is desired to change the primary regulation of the master control currents from the frequency-responsive network 29 to apparatus for maintaining constant load on the system, there is provided a switch 53 which, when operated into its lower position, connects the conductors 39 and 42 across a potentiometer 54 energized from a battery 55. In this case, a switch 56, included in the connections to the frequency-responsive network 29, is operated to open circuit position. Again, in case it is desired to control the output of the system from a remote point, either to maintain the output constant or to maintain a predetermined ratio between the output of the system and that of another connected or independent system, the switch 53 may be operated to its upper position, in which it connects the conductors 49 and 42 to the conductors 57 extending to the point of remote control.

In order to facilitate an understanding of my invention, the operation of the above described apparatus for regulating the master control currents of the two units will be explained before coming to the description of the apparatus by means of which the control currents effect the desired regulation of conditions of combustion in the boilers. Assume, for example, that the switch 53 is in the open position illustrated, that the load on the system suddenly increases and that the characteristics of the generators 11, 15, and 17 have a certain dissimilarity which causes the generator 11 to assume a greater proportion of the increase in the load than the generators 15 and 17. Because of change of frequency due to the sudden increase of load, the frequency-responsive network 29 will become unbalanced and the instrument 30 will close one of its contacts 30a to energize the motors 25a and 26a of the control rheostats 25 and 26, respectively. At the same time, the wattmeter 31 will adjust the setting of the potentiometer 32, and the wattmeters 33 and 35 will adjust the settings of the potentiometers 34 and 36, respectively, but the setting of the potentiometer 32 will be such that the electromotive force impressed upon the conductors 39 and 42 of the balancing circuit will be greater than the sum of the electromotive forces from the potentiometers 34 and 36, with the result that the instruments 37 and 38 become unbalanced to control their respective control rheostats in opposite senses. The instrument 37 will close one of its contacts 37a corresponding to that one of the contacts 30a closed by the instrument 30, for example, the left-hand contacts (Fig. 1a), to place the resistors 43a and 44a in parallel in the energizing circuit of the motor 25a. The motor 25a now operates at its maximum speed to adjust the control current flowing in the circuit 21 which, as described hereinafter, is effective to change the conditions of combustion by a proportionate amount and to increase the input of motive fluid to the prime mover 12 to correspond to the increase in load on the system.

At the same time, the instrument 38 will close its opposite contacts, for example, its right-hand

contacts, so that the two fields of the motor 26a are differentially energized and the resultant field is sufficient to rotate the motor at only a very slow speed, if at all. In brief, the control current of unit A is increased very much more rapidly than the control current of the unit B to increase the power input to the generator 11 and bring the frequency of the system back to normal and, at the same time, to restore the division of load between the units A and B to its proper value.

In case the units A and B should assume the increase in load in the proper proportion, obviously the circuit including the potentiometers 32, 34, and 36 will remain in balance and the frequency-responsive network 29 will control the rheostats 25 and 26 similarly and to like extent. Again, in case the load on the system as a whole remains unchanged but the distribution between the units A and B changes for any cause, the frequency-responsive network will remain in balance, while the load distribution circuit, including potentiometers 32, 34, and 36 will become unbalanced to operate the instruments 37 and 38 in opposite senses. These instruments, in turn, energize the motor control rheostats 25 and 26 in opposite directions and to a similar extent, thus restoring the balance by the proper change in the control currents of the two units.

In case it is desired to control the power outputs of the units A and B to maintain a predetermined and adjustable load thereon, the switch 56 is opened, disconnecting the frequency-responsive network 29, while the switch 53 is operated to its downward position, connecting a portion of the potentiometer 54 between the conductors 39 and 42. The electromotive forces of the potentiometers 32, 34 and 36 are now compared with the constant, but adjustable electromotive force of the potentiometer 54 and the instruments 37 and 38 are operative to regulate the control currents in the circuits 21 and 22 through the rheostats 25 and 26, respectively, to maintain the power outputs of the generator 11 and the generators 15 and 17 at constant magnitudes, as determined by the calibration of the potentiometers.

Similarly, in case it is desired to control the outputs of the several generators from a remote point, either to maintain them at a constant adjustable value, or a value dependent upon the load on other units or systems, or other variable conditions or factors, the switch 53 is operated to its upper position in which the conductors 39 and 42 of the balancing circuit are connected to the conductors 57 extending to the point of remote control. An electromotive force representative of the controlling condition is impressed upon the conductors 57 at this remote point and the balancing circuit, including potentiometers 32, 34, and 36 and instruments 37 and 38 will operate to maintain the power output of the generators 11, 15, and 17 corresponding to the particular value of the controlling electromotive force obtaining at any given time.

In the system illustrated, the generators 15 and 17 are supplied by a common boiler 19 so that it is not possible to control the distribution of load therebetween by controlling the conditions of combustion in the boiler. Such control may be effected, however, by an auxiliary balancing circuit comprising a potentiometer 45 controlled also by the wattmeter 33 and a potentiometer 46 controlled by the wattmeter 35. The

potentiometers 45 and 56 are, in all respects, similar to those of the main balancing circuit and are connected in an auxiliary balancing circuit including a contact making instrument 47, which is effective, upon the occurrence of an improper division of load between the generators 15 and 17, to operate the motor-driven mechanism 48 to adjust the settings of the valves 49 and 50 in motive fluid conduits 51 and 52, respectively, to the prime movers 16 and 18.

The apparatus, by means of which the control currents, established as described above, regulate the conditions of combustion in the boilers of the units A and B, will be considered by reference to a particular boiler, for example, boiler 13. The portion of the master control current flowing in the circuit 23 regulates or controls devices for supplying fuel, air and motive fluid, such as water, to the boiler. The apparatus for controlling the supply of fuel to the boiler comprises a fuel-feeding device 60 driven by a motor 61, the fuel being delivered to a pulverizer 62 driven by a motor 63 and the pulverized fuel, together with a current of air, passing through a conduit 64 and into the combustion chamber of boiler 13. The motor 61 supplying the fuel to the boiler drives, also, an auxiliary tachometer generator 65, the electromotive force of which is balanced against that of a potentiometer 66 included in series with the master control circuit 23 which electromotive force is, of course, proportional to the control current. The balancing circuit includes a contact making instrument 67, the contacts of which control a motor operated rheostat in circuit with the fuel feed motor 61. The speed of the motor 61, and thus the electromotive force of the tachometer 65, is a direct measure of the fuel supplied to the boiler. By balancing this electromotive force against an electromotive force proportional to the master control current, it will be seen that the rate of fuel supplied is, at all times, proportional to the master control current. This balance is maintained by the instrument 67 which adjusts the speed of the motor 61 through the rheostat 68 to the proper value for maintaining the balance.

The air for supporting combustion is supplied to the combustion chamber of boiler 13 by means of a blower or fan 69 driven by a suitable motor 70. A device for producing a differential pressure dependent upon the rate of air supplied to the boiler, such as an orifice 71, is interposed between the fan 69 and the boiler. This differential pressure is applied to a bell-type manometer 72 of the controller C, the unbalanced moment of which is balanced by a current balance 73 provided with contacts 74 controlling a motor-operated rheostat 75 in circuit with the motor 70. As is well understood by those skilled in the art, the differential pressure acting upon the manometer 72 varies as the square of the rate of flow of the air through the orifice 71. The balancing force of the current balance 73 varies as the square of the master control current flowing in the circuit 23, so that a linear relation exists between the master control current and the rate of flow of air, when the controller C is balanced. This balance is maintained by means of the rheostat 75 which adjusts the speed of the motor 70 to that value for which the fan 69 supplies the proper amount of air for a given value of the master control current.

The motive fluid, such as water, is supplied to the boiler by means of a feed-water pump 76 driven by a motor 77. A differential pressure-

creating device, such as an orifice 78, is interposed between the pump 76 and the boiler 13, and the differential pressure thereacross is connected to the arms of a tilting manometer 72' of a controller C' which is similar to the controller C, except that the manometer 72' is adapted to respond to differences in liquid pressure, rather than gaseous pressure. The master control current flows also through the current balance 73 of the controller C' and, as in the case of the controller C, operates through a motor-driven rheostat 79 in the circuit of the motor 77 to maintain a linear relationship between the master control current and the rate of flow of motive fluid to the boiler 13.

It may be desirable also to modify the rate of supply of water to the boiler in response to the temperature of the steam delivered by the boiler in order to prevent excessive variations in temperature and pressure of the steam. To this end, a motor-driven rheostat 80 is connected in parallel to the current balance 73 of the controller C' to by-pass a variable portion of the master control current therefrom. A thermocouple 81 is included in the outlet conduit of the boiler and is connected in circuit with an adjustable potentiometer 82 through a contact making instrument 83, the contacts 84 of which control the motor-operated rheostat 80. In case the temperature of the delivered steam rises above a predetermined value, the contacts 84 will control the rheostat 80 to change the point of balance of the controller C' to increase the rate of supply of water to the boiler and thus reduce its temperature to the desired value. Conversely, upon a decrease in the temperature of the boiler steam below a desired value, the ratio between the master control current and the rate of flow of feed water is changed to decrease the supply of feed water.

In certain cases, also, it is desirable to maintain the pressure within the combustion chamber of the boiler substantially constant, irrespective of variations in operating conditions, particularly variations in the supply of air to support combustion. This may be accomplished by means of a damper 85 located in the stack or flue of the boiler, the position of which is adjusted by means of a motor 86 through a suitable operating mechanism 87. The motor 86 is controlled by a controller C'' which is similar to the controller C except that it is provided with only a single pressure bell which is balanced against a weight 88 and a spring 88' rather than against a current balance. The pressure bell 72'' of the controller C'' is connected by means of a conduit 89 to the combustion chamber of the boiler and is thus subjected directly to the pressure therein. The contacts 74 of the controller C'' control the motor 86 to adjust the setting of the damper 85 to maintain the pressure in the combustion chamber at a predetermined value corresponding to balance of the controller C''. While separate sources of current are shown for the several motors controlling the supply of the several factors of combustion, for the sake of clarity, it will be apparent that these motors may be energized from any suitable source of direct or alternating current.

From the foregoing discussion, the cooperation of the several control devices for governing conditions of combustion in the boiler 13 will be readily understood. In brief, a linear relationship is established between the master control current and the rate of supply of fuel to the boiler; between this current and the rate of supply of air

to the boiler; and between this current and the rate of supply of feed water. By this means, the several factors entering into the operation of the boiler are controlled and varied rapidly and proportionately to maintain optimum conditions of combustion and generation of steam. The proportionality is maintained to a high degree of accuracy, since, in the control of each of these factors, the control current is balanced against an effect which is a direct measure of the factor, as contrasted with certain arrangements of the prior art in which the controlling force acts upon a number of control devices which are solely motive devices and which may have widely dissimilar control characteristics. In addition, in order to secure optimum conditions of combustion and generation of steam, the ratio of the master control current to the rate of supply of feed water is modified to maintain the temperature of the generated steam within predetermined limits and the pressure obtaining in the combustion chamber of the boiler is maintained at a substantially constant magnitude.

The control devices for regulating the conditions of combustion in the boiler 14 are, in all respects, similar to those of the boiler 13 with the exception of the device C controlling the rate of supply of fuel to the boiler and, with this exception, are illustrated schematically in order to simplify the drawing. The apparatus for controlling the supply of fuel to the boiler, in this case, is suitable for the control of fluid fuel, such as gas, oil or the like, and comprises a valve 90 included in the fuel inlet to the boiler, the position of which is adjusted by a motor 91 through a suitable mechanism 91a. The mechanism 91a also adjusts the setting of a potentiometer 92 supplied from a suitable source, such as a battery 93, the adjustable contact of the potentiometer 93 being mechanically interconnected with the operating arm of the valve 90. The potentiometer 92 is connected in a balancing circuit including the resistance 66 traversed by the master control current in the circuit 24 and a contact making instrument 67, the contacts 67a of which control the motor 91. In the operation of this control apparatus, in case the electromotive force derived from the potentiometer 66 differs from that derived from the potentiometer 92, the instrument 67 will indicate an unbalance and operate its contacts 67 to energize the motor 91, which varies the setting of the potentiometer 92 to restore the balance. The motor 91 coincidentally changes the setting of the valve 90 and the calibration of the mechanism is such that the rate of flow of fluid through the valve 90 varies linearly with the master control current in the circuit 24. In other respects, the operation of the combustion control apparatus of the boiler 14 is similar to that described above.

Again, the combustion control apparatus associated with the boiler 19 is similar to that of the boiler 14 with the exception that the motor-operated valve 90—91 is controlled by a controller C' identical to the controller C' associated with the boiler 13. The manner in which it maintains a linear relationship between the master control current flowing in the circuit 22 and the rate of flow of fuel through the valve 90 is identical to that described above in connection with the boiler 13 in which a linear relation is maintained between the master control current in the circuit 23 and the rate of supply of feed water.

In Fig. 2 is shown a system in which the master control current, established as in arrangement of

Fig. 1, regulates conditions of combustion in a modified manner. In this system the load-ratio responsive instrument 37 operates directly upon the motor-operated rheostat 25 to regulate the master control current and also operates directly upon the motor-operated rheostat 79 controlling the feed water pump 76—77. This may be termed the primary control. In this case, the master control current is also readjusted to correspond accurately with the rate of flow of feed water by means of the control device C', which is connected across the orifice 78 in the inlet to the feed water to the boiler. The device C', responsive to the rate of flow of feed water, is connected to control the motor-operated rheostat 25 jointly with the load-ratio instrument 37, as in the arrangement of Fig. 1a, and thus serves to balance this rate against the master control current. This may be termed the secondary control. The master control current as thus established flows through the potentiometer 66 which cooperates with a potentiometer 92 and the indicating instrument 67 to adjust the valve 90 in the conduit supplying fluid fuel to the boiler, to maintain a linear relation between the control current and the rate of supply of fuel to the furnace, as in the control of the boiler 14.

In the system of Fig. 2, a modified control apparatus is utilized to maintain a correct flow of gases through the furnace and a correct furnace pressure. This apparatus comprises a control device C connected to spaced points of the combustion chamber of the furnace through conduits 89' and thus responsive to the rate of flow of the combustion gases through the boiler. The differential pressure between these points is balanced against the control current which flows through the current balance 73 of the device C. The contacts 74 of this device control a motor 86', which determines the setting of a damper 85' interposed between the forced draft fan 69 and the furnace, and varies the setting of the damper 85 through the motor-operated mechanism 86—87 to maintain the flow of combustion gases proportional to the master control current.

This control of the rate of air flow may be modified to maintain the pressure within the combustion chamber substantially constant by means of the control device C' connected to the combustion chamber through the conduit 89. The pressure existing at this point is balanced against the weight 88 and spring 88' and the contacts 74 of the device C' control the motor operated damper 85'—86' in the air inlet to the boiler jointly with the controller C. The control of the motor-operated damper 85'—86' by the device C is preferably a primary control and is more rapid than that under the influence of the device C'. This primary and secondary control may be effected by an arrangement similar to the one illustrated in Fig. 1a. In this manner, the devices C and C' cooperate to maintain a flow of combustion gases through the furnace proportional to the master control current and, in addition, to maintain the pressure in the combustion chamber substantially constant.

The control of the feed water in this instance is modified by a device such as a thermocouple 95, responsive to the temperature of the water in the flash tube of the boiler near the inlet but displaced therefrom sufficiently to register a temperature appreciably above the inlet temperature and affording an indication of the outlet temperature of the boiler, assuming a predetermined

thermal gradient through the boiler. The electromotive force of the thermocouple 95 is balanced against that of potentiometer 96 through a contact-making instrument 97, the contacts 98 of which control a motor-operated rheostat connected to by-pass a variable portion of the master control current from the current balance of the instrument C'. Since the thermocouple 95 is placed relatively near the inlet of the boiler, it responds quickly to any change in the rate of flow of feed water, as evidenced by a change in temperature, to modify the action of the controller C' to adjust the rate of flow of feed water and maintain the temperature of the fluid outlet of the boiler approximately constant.

The regulating action of the thermocouple 95 is, in turn, modified by a thermocouple-potentiometer arrangement 81-84 similar to that of Fig. 1, which changes the setting of the potentiometer 96 in response to changes in temperature of the steam delivered by the boiler. The thermocouple 81 operates with a considerable time-delay because of the time required for the water to pass through the tube of the boiler, which may amount to a period of several minutes. Thus, the thermocouple 95 furnishes a rapid and approximate control of the feed water to maintain a constant output temperature, while the thermocouple 81, with a time-delay, modifies the action of the thermocouple 95 to secure more accurate regulation of this temperature.

In some instances, it may be found that the thermal gradient through the boiler, as determined by the number and location of the turns of the flash tubes and their spacing with respect to the combustion chamber, will vary with variations in load on the boiler, in some instances increasing, while in others decreasing. To compensate for this variation in thermal gradient, the secondary control of the feed water by the thermocouple 95 may be modified as shown in Fig. 2a. In this case, an additional load-ratio potentiometer 132 is provided having an adjustable contact 132a movable with the contact 32a. The adjustable electromotive force from this potentiometer is impressed upon conductors 104, which are included in series with the circuit of the thermocouple 95 and serve to introduce therein an electromotive force varying with load. By a proper calibration of the potentiometer 132, the electromotive force thereof may be made to compensate for variations in the temperature, as registered by the thermocouple 95, from that corresponding to a predetermined thermal gradient through the boiler.

In Fig. 3 is illustrated diagrammatically a circuit which may be utilized in lieu of the load responsive control of the motor-operated rheostat 25 of Fig. 1. This circuit is shown as applied to a 3-phase alternating current circuit 99, the power output of which is measured by a wattmeter 100 which is preferably of the thermoelectric type generating a thermoelectromotive force proportional to the power output of the circuit in which it is included. This electromotive force of the device 100 is balanced against the sum of the electromotive forces of a potentiometer 101 and a potentiometer 102 included in series with the circuit of the master control current. The balance of these two opposing electromotive forces is determined by a contact making instrument 103, the contacts 103a of which control the motor 25a of the motor-operated rheostat 25 included in the master control circuit 21.

The circuit arrangement of Fig. 3 is operative

to vary the proportionality between the power output of the circuit 99 and the master control current in the circuit 21 and, at the same time, to provide for a component of the master control current dependent only upon a constant adjustable value which may be representative of the losses of the system, which are substantially independent of the load thereon. Under normal operating conditions, the action of this load control circuit is similar to that of Fig. 1. A departure of the load on the circuit 100 from that corresponding to the given value of the master control current unbalances the circuit, including the potentiometers 101, 102 and the device 100, and the instrument 103 controls the motor-operated rheostat 25 to vary the master control current to restore the balance and to change the conditions of steam generation to correspond to the new load condition. In case it should be desired to change the master control current for a given load, as might be required, for example, by a change in turbine efficiency or for other change in the operating conditions of the system, the adjustable contact of the potentiometer 102 is moved, increasing or decreasing the proportion of the electromotive force of the potentiometer 102 introduced into the balancing circuit. On the other hand, in case the operating conditions of the system should change so that the heat losses of the system are changed, the constant component of the electromotive force may be adjusted by adjusting the contact 101a of the potentiometer 101, which varies the electromotive force of the potentiometer 101. By these means the proportionality between the load upon the unit and the variable component of the master control current may be varied without varying the relative magnitude of the electromotive force representative of the constant losses of the system, while this latter quantity may be independently adjusted to take into consideration variations in operating conditions of the system.

While I have illustrated and described alternative apparatus for regulating the master control current of a combustion control system in response to several operating conditions of the system or combinations thereof, and numerous control devices responsive to the master control current for governing the conditions of combustion in the system, it will be apparent to those skilled in the art that my invention is not limited to the examples specifically illustrated and described, but embodies also other combinations of the devices and apparatus to meet the requirements of a particular system, and also such other changes and modifications as fall within the true spirit and scope of my invention.

What I claim is:

1. A combustion control system for a fluid-driven prime mover system including a prime mover, a boiler for supplying motive fluid thereto and an electric generator driven thereby, comprising means for establishing a master control current, means for regulating said control current in accordance with variations in frequency of the current output of said generator, means for modifying the action of said regulating means in accordance with the electrical power output of said generator, and a plurality of control devices individually regulated by said control current for governing conditions of combustion in said boiler.

2. A combustion control system for a fluid-driven prime mover system including a prime mover, a boiler for supplying motive fluid thereto and an electric generator driven thereby, com-

prising means for establishing a master control force, relatively quick-acting means for regulating said control force in accordance with variations in frequency of the current output of said generator, relatively slow-acting means for modifying the action of said regulating means in accordance with the electrical power output of said generator, and a plurality of control devices individually regulated by said control force for governing conditions of combustion in said boiler.

3. A combustion control system for a prime mover system including a prime mover, an electric generator driven thereby, and boiler means for supplying motive fluid to said prime mover; comprising means for controlling said boiler means including relatively quick-acting means responsive to the frequency of the current output of said generator and relatively slow-acting means responsive to the electrical power output thereof and acting independently of said frequency responsive means whereby the condition of combustion of said boiler means is controlled primarily to maintain constant frequency and secondarily to maintain a predetermined load characteristic.

4. A combustion control system for a fluid-driven prime mover system including a prime mover, a boiler for supplying motive fluid thereto and an electric generator driven thereby, comprising means for establishing a master control force, means for regulating said control force including a frequency-responsive network energized from said generator, means for modifying the action of said regulating means including means responsive to the power output of said generator, and a plurality of control devices individually regulated by said control force for governing conditions of combustion in said boiler.

5. A combustion control system for a fluid-driven prime mover system including a plurality of units each consisting of a fluid-driven prime mover, a boiler for supplying motive fluid thereto and an electric generator driven thereby, said electric generators being connected in parallel, comprising means for establishing master control forces individual to said units, means for coincidentally regulating said control forces in response to system frequency, means for individually modifying the action of said regulating means on said control forces in accordance with the relative power outputs of said generators, and a group of control devices cooperating with each boiler and regulated by the control force of its respective unit for governing the conditions of combustion in said boiler.

6. A combustion control system for a fluid-driven prime mover system including a plurality of units each consisting of a fluid-driven prime mover, a boiler for supplying motive fluid thereto and an electric generator driven thereby, said electric generators being connected in parallel, comprising means for establishing master control currents individual to said units, a frequency-responsive network energized from said generators and means controlled thereby for coincidentally regulating said control currents, potentiometer impedances individual to said units and connected in a control circuit, means responsive to the electrical power output of each of said generators for adjusting a connection to an impedance of its respective unit, an instrument individual to each of said units included in said control circuit for regulating its respective master control current, and a group of control devices cooperating with each boiler and regulated by the control current of its respective unit for

governing conditions of combustion in said boiler.

7. A combustion control system for a fluid-driven prime mover system including a prime mover, a plurality of boilers for supplying motive fluid thereto and an electric generator driven thereby, comprising means for establishing a master control force, means for regulating said control force in accordance with variations in frequency of the current output of said generator, means for modifying the action of said regulating means in accordance with the electrical power output of said generator, a plurality of control systems energized in multiple from said control force, and a group of control devices cooperating with each of said boilers for governing conditions of combustion therein, each group of control devices being included in one of said control systems, and means for adjusting the distribution of force between said multiple systems to effect a corresponding load distribution between said boilers.

8. A combustion control system for a prime mover system including a plurality of fluid-driven prime movers, a boiler for supplying motive fluid thereto and a plurality of electric generators individually driven by said prime movers and connected to a common circuit, comprising means for establishing a master control force, means for regulating said control force including a frequency-responsive network energized from said generators, a plurality of control devices individually regulated by said control force for governing conditions of combustion in said boiler, and means responsive to the power outputs of said generators for adjusting the distribution of motive fluid from said boiler to said prime movers.

9. A combustion control system for a prime mover system including a plurality of units, one including a fluid-driven prime mover, a boiler for supplying motive fluid thereto and an electric generator driven thereby and another including a plurality of prime movers, a single boiler for supplying motive fluid thereto and a plurality of electric generators individually driven by said prime movers, all of said electric generators being connected to a common circuit, comprising means for establishing master control forces individual to said units, means for coincidentally regulating said control forces in response to system frequency, means for individually modifying the action of said regulating means on said control forces in accordance with the relative power outputs of the generators of said units, means responsive to the power outputs of the generators of said second-named unit for adjusting the distribution of motive fluid from its respective boiler to the several prime movers thereof, and a group of control devices cooperating with each boiler and regulated by the control force of its respective unit for governing the conditions of combustion in said boiler.

10. A combustion control system for a fluid-driven prime mover system including a prime mover, a boiler for supplying motive fluid thereto and an electric generator driven thereby, comprising means for establishing a master control current, means for regulating said control current in accordance with an operating condition of the system, a plurality of devices for controlling the supply of air, fuel, and motive fluid to said boiler, control means individual to said supply control devices and responsive jointly to said control current and to the supply of media as controlled by their respective devices, and means responsive

solely to the pressure within the combustion chamber of said boiler for modifying the action of said air supply control device.

11. A combustion control system for a fluid-driven prime mover system including a prime mover, a boiler for supplying motive fluid thereto and an electric generator driven thereby, comprising means for establishing a master control current, means for regulating said control current in accordance with an operating condition of the system, a plurality of devices for controlling the supply of air, fuel, and motive fluid to said boiler, control means individual to said supply control devices and responsive jointly to said control current and to the supply of media as controlled by their respective devices, and means responsive solely to the pressure within the combustion chamber of said boiler for varying the resistance to flow through the combustion chamber of the products of combustion to maintain said pressure substantially constant.

12. A combustion control system for a fluid-driven prime mover system including a prime mover, a boiler for supplying motive fluid thereto and an electric generator driven thereby, comprising means for establishing a master control current, means for regulating said control current in accordance with an operating condition of the system, a plurality of devices for controlling the supply of air, fuel, and motive fluid to said boiler, control means individual to said supply control devices and responsive jointly to said control current and to the supply of media as controlled by their respective devices, and means for maintaining substantially constant the pressure within the combustion chamber of said boiler comprising a stack damper and means responsive solely to said pressure for controlling the setting of said damper.

13. A combustion control system for a fluid-driven prime mover system including a prime mover, a boiler for supplying motive fluid thereto and an electric generator driven thereby, comprising means for regulating said control current in accordance with variations in frequency of the current output of said generator, means for modifying the action of said regulating means in accordance with the electrical power output of said generator, and a plurality of devices for controlling the supply of air, fuel, and motive fluid to said boiler, and control means individual to said supply control devices and responsive jointly to said control current and to the supply of media as controlled by their respective devices.

14. A combustion control system for a fluid-driven prime mover system including a prime mover, a boiler for supplying motive fluid thereto and an electric generator driven thereby, comprising means for establishing a master control force, means for regulating said control force in accordance with the electrical power output of said generator, a plurality of control devices individually regulated by said control force for governing conditions of combustion in said boiler, and means responsive to the supply of motive fluid to said boiler for modifying the action of said regulating means on said control force.

15. A combustion control system for a fluid-driven prime mover system including a prime mover, a boiler for supplying motive fluid thereto and an electric generator driven thereby, comprising means for establishing a master control force, means for regulating said control force in accordance with the electrical power output of said generator, a plurality of control devices in-

dividually regulated by said control force for governing conditions of combustion in said boiler, means responsive solely to the electrical power output of said generator for controlling the supply of feed water to said boiler, and means responsive to the supply of feed water to said boiler for modifying the action of said regulating means on said control force.

16. A combustion control system for a fluid-driven prime mover system including a prime mover, a boiler for supplying motive fluid thereto and an electric generator driven thereby, comprising means for establishing a master control current, means for regulating said current in accordance with an operating condition of the system, a plurality of devices for controlling the flow of combustion gases through said boiler and the supply of fuel and motive fluid thereto, control means individual to said devices and responsive jointly to said control current and the factors controlled by their respective devices, a device for controlling the supply of air to said boiler, and control means cooperating with said last-named device responsive jointly to the pressure in the combustion chamber of the boiler and to the control means associated with the device for controlling the flow of combustion gases.

17. A combustion control system for a fluid-driven prime mover system including a prime mover, a flash tube boiler for supplying motive fluid thereto and an electric generator driven thereby, comprising means for establishing a master control force, means for regulating said force in accordance with an operating condition of the system, a plurality of devices for controlling the flow of combustion gases through said boiler and the supply of fuel thereto, control means individual to said devices and responsive jointly to said control force and the factors controlled by their respective devices, means for regulating the supply of motive fluid directly in accordance with said operating condition of the system, means responsive to the temperature within said boiler near the inlet thereof for modifying the action of the control means of the motive fluid supply control device, and means responsive to the load on said generator for modifying the action of the temperature responsive means to compensate for changes in thermal gradient through said boiler with changes in load.

18. A combustion control system for a fluid-driven prime mover system including a prime mover, a flash tube boiler for supplying motive fluid thereto and an electric generator driven thereby, comprising means for establishing a master control force, means for regulating said force in accordance with an operating condition of the system, a plurality of devices for controlling the flow of combustion gases through said boiler and the supply of fuel thereto, control means individual to said devices and responsive jointly to said control force and the factors controlled by their respective devices, means for regulating the supply of motive fluid directly in accordance with said operating condition of the system, a thermocouple disposed in said boiler near the inlet thereof and connected to modify the action of the control means of the motive fluid supply control device to maintain the temperature of the fluid output of said boiler approximately constant, and means for introducing into the circuit of said thermocouple an electromotive force varying with the load on said generator to compensate for changes in thermal gradient through said boiler with changes in load.

19. A combustion control system for a fluid-driven prime mover system including a prime mover, a flash tube boiler for supplying motive fluid thereto and an electric generator driven thereby, comprising means for establishing a master control force, means for regulating said force in accordance with an operating condition of the system, a plurality of devices for controlling the flow of combustion gases through said boiler and the supply of fuel thereto, control means individual to said devices and responsive jointly to said control force and the factors controlled by their respective devices, means for regulating the supply of motive fluid directly in accordance with said operating condition of the system, a thermocouple disposed in said boiler near the inlet thereof and operating quickly to modify the action of the control means of the motive fluid supply device to maintain the temperature of the fluid output of said boiler approximately constant, a thermocouple disposed in the fluid outlet of said boiler and operating with a time delay to modify the action of said first thermocouple to maintain more accurately the temperature of the fluid output of said boiler, and means for introducing into the circuit of said first thermocouple an electromotive force varying with the load on said generator to compensate for changes in thermal gradient through said boiler with changes in load.

20. A combustion control system for a fluid-driven prime mover system including a prime mover, a boiler for supplying motive fluid thereto and an electric generator driven thereby, comprising means for establishing a master control current, means for regulating said current in accordance with an operating condition of the system, a plurality of devices for controlling the flow of combustion gases through said boiler and the supply of fuel thereto, control means individual to said devices and responsive jointly to said control current and the factors controlled by their respective devices, means for regulating the supply of motive fluid directly in accordance with said operating condition of the system, means responsive to the temperature within said boiler near the inlet thereof for by-passing a variable portion of said control current from the control means of the motive fluid supply control device, and means responsive solely to the temperature of the fluid output of said boiler for modifying the action of said last-named means.

21. In a combustion control system, means for establishing a master control current for governing conditions of combustion, means for producing an effect varying with an operating condition of said system, means for producing an effect varying with said control current, means for producing an adjustable constant effect, means for regulating said control current to maintain the first of said effects proportional to the sum of the other two, and means for varying the factor of proportionality and at the same time maintaining the relative magnitude of said constant effect.

22. In a combustion control system, means for establishing a master control current for governing conditions of combustion, means for producing an electrical effect proportional to an operating condition of said system, means for producing an electrical effect constant in magnitude, means for deriving an electrical effect proportional to said control current, means controlled by said electrical effects for regulating said control current to balance the effect derived from said operating condition and the sum of the other

two effects, and means for independently varying said last-named two effects.

23. In a combustion control system, means for establishing a master control current for governing conditions of combustion, means for producing an electromotive force proportional to the electrical power output of said generator, a potentiometer impedance energized from a source of constant electromotive force, a second potentiometer impedance energized by said control current, a circuit including an electroresponsive device for comparing said first electromotive force with the sum of those across said potentiometer impedances, means including said electroresponsive device for regulating said control current to balance said circuit, means for independently adjusting the settings of said potentiometer impedances, and means for adjusting the value of said constant electromotive force.

24. A system comprising a prime mover, an alternator driven thereby, a boiler for supplying motive fluid to said prime mover, means for producing a control force, means responsive to the frequency of the current generated by said alternator for regulating said control force, and a plurality of control devices regulated by said control force for governing conditions of combustion in said boiler.

25. A system comprising a prime mover, an alternator driven thereby, a boiler for supplying motive fluid to said prime mover, means for producing a control force, means responsive to the frequency of current generated by said alternator for regulating said control force, means responsive to the output of said alternator for modifying said control force, and a plurality of control devices regulated by said control force for governing conditions of combustion in said boiler.

26. An electric power system comprising a generator, a prime mover therefor, boiler means for supplying motive fluid to said prime mover, means for producing an effect varying as a function of the system load, means for producing an effect varying as a function of the generator output, and means jointly responsive to said effects for varying the rate of production of motive fluid by said boiler means.

27. An electric power system supplied from generating units each comprising a generator, a prime mover therefor, and boiler means for supplying motive fluid to the prime mover, separate means for individually controlling the rate of production of motive fluid by the individual boiler means, means responsive to system load for effecting operation of said control means, and means responsive to the outputs of said generators for effecting operation of said control means to effect predetermined division of load between said units.

28. An electric power system supplied from generating units each comprising a generator, a prime mover therefor, and boiler means for supplying motive fluid to the prime mover, means responsive to the outputs of said generators, and means controlled by said responsive means individually to control the rate of production of motive fluid by said individual boiler means to accord with predetermined division of load between said generators.

29. A system comprising a generator, a prime mover therefor, boiler means for supplying motive fluid to the prime mover, means producing an effect varying as a function of the output of said generator, means producing a standard effect, and means jointly responsive to said effects for

controlling the rate of production of motive fluid by said boiler means to maintain a predetermined relation of the magnitudes of said effects.

30. An electric power system supplied from  
 5 generators having individual prime movers and  
 a common boiler for supplying motive fluid to  
 said prime movers, means responsive to the sys-  
 tem demand for changing the rate of production  
 of motive fluid by said boiler, means producing  
 10 effects each varying as a function of the output  
 of one of the generators, and means responsive  
 to said effects for varying the distribution of  
 motive fluid from said boiler to said prime movers  
 to effect predetermined division of load between  
 15 said generators.

31. An electric power system comprising boil-  
 ers, one or more prime movers supplied with  
 motive fluid from each of said boilers and indi-  
 vidual thereto, alternators individually driven by  
 20 said prime movers, means responsive to changes  
 in system frequency for similarly varying the rate  
 of production of motive fluid by said boilers,  
 means producing effects each varying as a func-  
 tion of the output of one of said alternators, and  
 25 means responsive to said effects for individually

varying the rate of production of motive fluid by  
 said boilers to maintain a predetermined relation  
 between the outputs of the alternators associated  
 with the different boilers.

32. An electric power system comprising boil-  
 ers, one or more prime movers supplied with  
 motive fluid from each of said boilers and indi-  
 vidual thereto, alternators individually driven by  
 said prime movers, means responsive to changes  
 in system frequency for similarly varying the  
 10 rate of production of motive fluid by said boilers,  
 means producing effects each varying as a func-  
 tion of the output of one of said alternators,  
 means responsive to said effects for individually  
 varying the rate of production of motive fluid by  
 15 said boilers to maintain a predetermined rela-  
 tion between the outputs of the alternators asso-  
 ciated with the different boilers, and means res-  
 ponsive to said effects to vary the distribution  
 of motive fluid to prime movers supplied from a  
 20 common boiler to maintain a predetermined rela-  
 tion between the outputs of alternators associated  
 with the same boiler.

EDWARD S. BRISTOL.

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# CERTIFICATE OF CORRECTION.

Patent No. 2,053,061.

September 1, 1936.

EDWARD S. BRISTOL.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 2, second column, line 46, for the syllable and words "tudes, as determined by the calibration of the" read of direct current through either the contacts 30a; page 7, first column, line 14, claim 3, strike out the semicolon after "mover"; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 16th day of March, A. D. 1937.

(Seal)

Henry Van Arsdale  
 Acting Commissioner of Patents.