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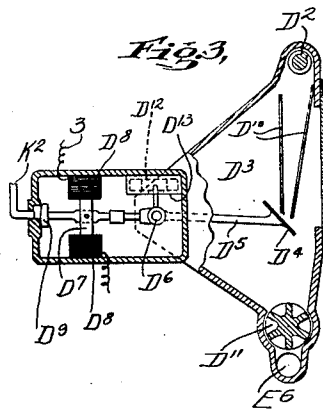
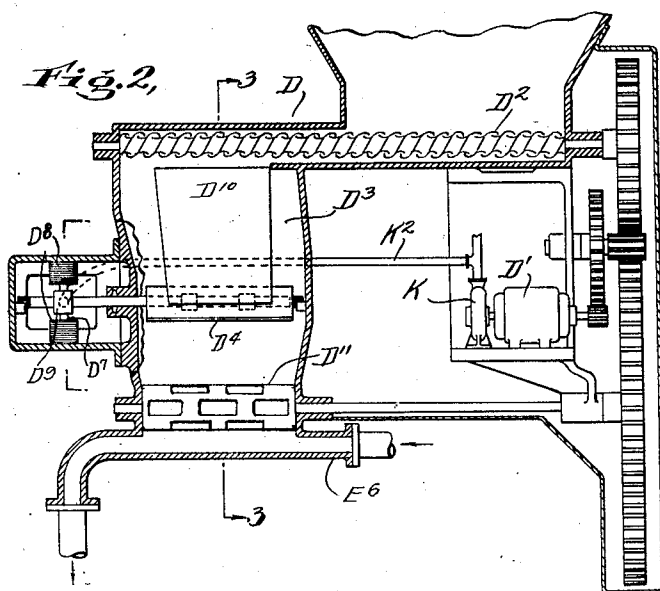
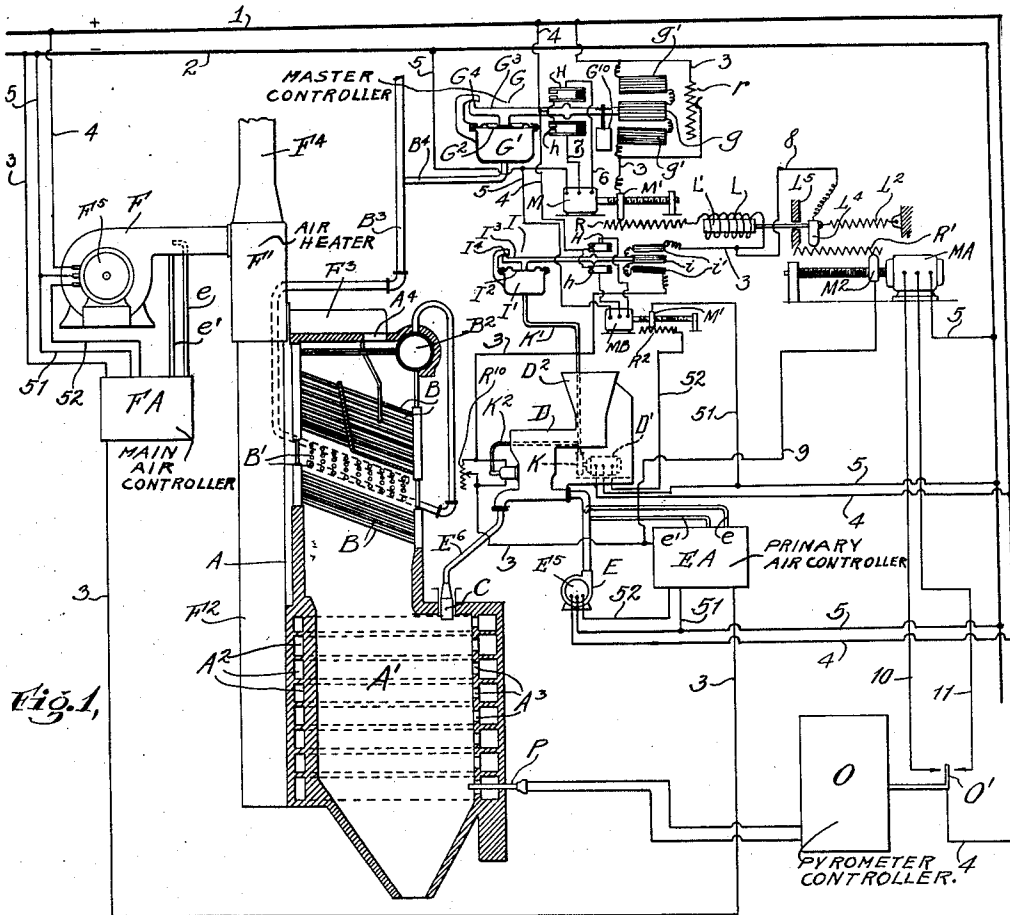
G. H. GIBSON

1,820,939

COMBUSTION REGULATION

Filed Aug. 4, 1926

2 Sheets-Sheet 1



Sept. 1, 1931.

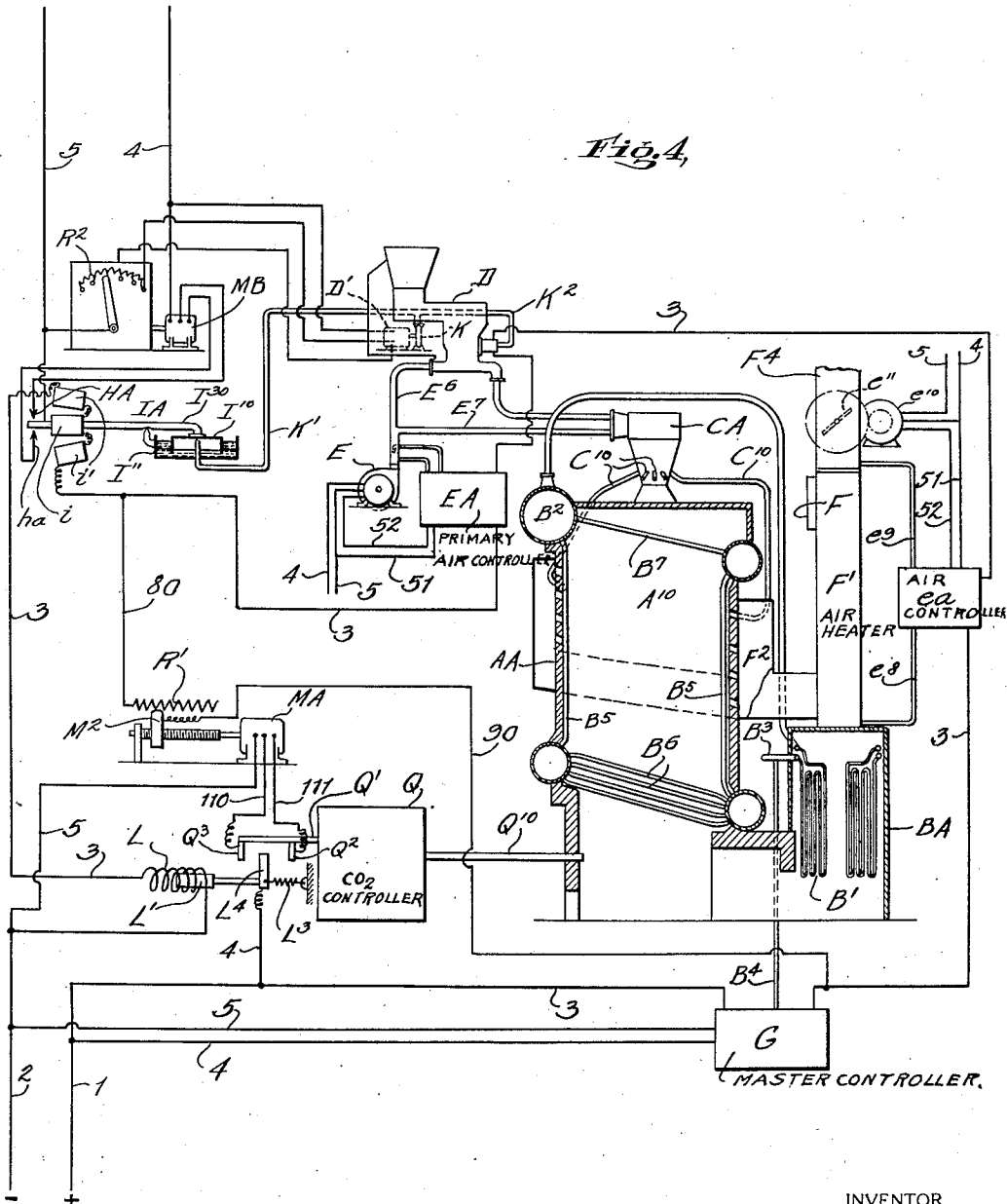
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COMBUSTION REGULATION

Filed Aug. 4, 1926

2 Sheets-Sheet 2



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COMBUSTION REGULATION

Application filed August 4, 1926. Serial No. 126,954.

The general object of my present invention is to provide for the automatic control of the ratio of fuel burned to air supplied for the combustion of the fuel in such manner as to effect advantageous variations in said ratio in response to certain variations in operating conditions. Since in practice air for combustion must always be supplied in excess of that theoretically required for the combustion of the fuel burned, the fuel-air ratio control with which the present invention is concerned, may be correctly designated as an excess air control.

The invention is particularly useful in the operation of powered coal burning boiler furnaces. In such furnaces the amount of air supplied to the combustion chamber in excess of that theoretically required by the momentary rate of fuel combustion may advantageously be varied as the load and furnace temperature conditions vary. In burning powdered coal more excess air is ordinarily required to insure complete fuel combustion when the rate of combustion is relatively low, than when the rate of combustion is high. Generally speaking, the best thermal efficiency is obtainable when only so much excess air is supplied as is required to insure complete combustion of the fuel, but the extent to which the excess air can be reduced with advantage as the rate of combustion is increased, does not depend entirely on the thermal efficiency obtainable. On the contrary, with high rates of combustion it is usually desirable to supply more excess air than would give maximum thermal efficiency in order to limit the combustion chamber temperature and thereby avoid dangerous overheating of combustion chamber walls.

In a preferred practical mode of carrying out the invention I have provided means tending to automatically decrease the excess air ratio as the furnace load increases through a certain lower load range, and tending to increase the excess air ratio as the combustion chamber temperature increases.

The practical use of the general features of my invention in controlling combustion in powdered coal burning furnaces requires a proper control of the supply of fuel as well

as of the supply of air, and my invention, in its more limited aspects, comprises improved means for regulating the rate of supply of powdered fuel to a furnace.

While the invention is especially useful in controlling combustion in powdered coal burning furnaces, and some of the features of the invention are restricted to use with such furnaces, other and more general features of the invention are not dependent on the character of the fuel burned.

In lieu of, or in addition to an automatic control of the excess air ratio dependent on the combustion chamber temperature, in some cases I may make that ratio dependent on other factors such as the CO_2 content of the flue gases, or the smoke content of the flue gases. To this end I may employ a CO_2 measuring device of known type, or I may employ known means for determining the smoke content of flue gases from their light transmitting properties. The control of the excess air ratio in response to the smoke content of the gases is especially useful in the case of oil burning furnaces wherein, in ordinary practice, the smoke content of the flue gases may be the factor limiting the extent to which the excess air ratio may be advantageously diminished.

The air-fuel ratio control which forms the primary subject matter of the present invention, will ordinarily be incorporated in, or added to a combustion regulating system, which is adapted to vary the general rate of combustion in accordance with changes in furnace load, or which is employed to automatically control other combustion control factors.

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, its advantages and specific objects attained with its use, reference should be had to the accompanying drawings and descriptive matter in which I have illustrated and described preferred embodiments of my invention.

Of the drawings:

Fig. 1 is a diagrammatic representation of a powdered coal burning boiler furnace and combustion regulating provisions therefor;

Fig. 2 is a sectional elevation of the fuel feeding mechanism employed in Fig. 1;

Fig. 3 is a section on the line 3—3 of Fig. 2; and Fig. 4 is a diagrammatic representation of a modified form of powdered fuel burning furnace and combustion regulating provisions therefor.

In the drawings, and referring first to the construction shown in Figs. 1, 2 and 3, A represents a boiler furnace in which powdered coal is burned, and from which the products of combustion sweep over the water tubes B and superheater tubes B' of a superheater boiler comprising a steam drum B² from which steam passes to the superheater tubes. B³ represents the superheated steam outlet piping. The fuel burned in the combustion chamber A' is supplied by one or more, usually a plurality of, nozzles C through which a blast of powdered coal carrying air is passed into the combustion chamber. Powdered coal is supplied to the nozzles C by a fuel feeder D, and the carrying stream of air into which the coal supplied by the feeder D is introduced, is supplied by a blower E connected to the nozzle, or nozzles C, by piping E'. The main body of air for combustion supplied to the combustion chamber A', is furnished by a fan or blower F discharging into the inlet of an air preheater F' from which the heated air is passed through a distributing conduit or conduits F² to channels A² formed in the walls of the combustion chamber A' and opening to the latter through suitably distributed ports A³. The passage of the air through the channels A² serves to further heat the air, while at the same time desirably cooling the combustion chamber walls. The hot products of combustion escaping from the boiler furnace through the outlet A⁴ pass into the air preheater F' through a conduit F³ and pass away from the air heater through the stack connection F⁴. Insofar as the boiler furnace and accessories already described are concerned, the construction shown in Fig. 1 embodies nothing novel with me, but on the contrary is a typical example of the kind of boiler furnace installation with which the present invention may be used with advantage.

The combustion regulating system shown in Fig. 1 comprises means for maintaining a control force in the form of an electric current which flows along a conductor 3, and varies with the boiler load. The control current is supplied by current supply mains 1 and 2, and its strength determines the rates of air delivery and is the primary factor determining the rate of fuel delivery by the fuel feeder D. As shown, the strength of the control current flowing along the con-

ductor 3 is dependent upon the amount of a variable resistance R in circuit the latter being adjusted by a master controller, in the form of a pressure device G, in automatic response to changes in the static steam pressure in the superheated steam outlet piping B³. Insofar as the general control of the air and fuel feeds referred to are concerned, the control force may be maintained and may control the air and fuel feeds in accordance with principles previously patented by me, but the control system shown in Fig. 1 differs from control systems heretofore known in the manner in which the controlling effect of the main control force is applied and modified to thereby desirably vary the excess air ratio as the conditions of operation vary.

The device G, as shown, comprises a pressure chamber G' to which the pressure in the superheated steam outlet piping B³ of the boiler, or battery, of boilers controlled, is transmitted by a conduit B⁴. A lever G³ bearing at one end against a fulcrum G⁴, opposes the outward thrust of the pressure in the chamber G' against a flexible wall G² of the latter with a force which depends on two opposing forces, one of which is due to an adjustable weight G¹⁰ carried by the arm G³, and the other of which is due to the electromagnetic interaction between a coil g carried at the free end of the lever G, and a pair of co-operating stationary coils g', the coils g and g' being connected in series with one another in the circuit 3. The weight G¹⁰ is so proportioned and disposed as to balance the steam pressure in the chamber G' when that pressure corresponds to the normal boiler steam pressure. Normally the pressure in the chamber G' is lower than the actual boiler steam pressure as a result of the drop in pressure or loss in head which results from, and is a measure of the rate of steam flow through the header B³. The current flow through the coils g and g' is adjusted by the balance in a manner now to be described, so that it normally acts on the lever G³ through the coils g and g' as required to hold the lever G³ in an intermediate position between a normally open pair of contacts H and a normally open pair of contacts h.

When the upward thrust of the pressure acting against the underside of the wall G² increases relatively to the magnetic interaction between the coils g and the coils g' and the lever G³ tilts in the counter-clockwise direction about the fulcrum G⁴, the contacts H are energized and the motor M is started into rotation in the direction to diminish the amount of resistance R in circuit, and the motor M thus continues to rotate until as a result of the decrease in the amount of resistance R in circuit the current flowing along the conductor 3 increases sufficiently to restore the lever G³

to its normal neutral position. Conversely, when the magnetic interaction between the coils g and g' overbalances the action of the pressure against the underside of the wall G^2 on the lever G^3 and the latter tilts in the clockwise direction the contacts h are closed. The closure of the contacts h starts the motor M into rotation in the direction to increase the amount of resistance R in circuit and thereby diminish the current flowing along the conductor 3 until the lever G^3 is again restored to its normal neutral position in which the contacts H and h are open.

The electromagnetic force exerted on the lever G^3 through the coils g and g' is proportional to the square of the current flowing through the circuit 3. The pressure in the chamber G' varies as the square of the steam flow through the piping B^3 , and also varies directly as the boiler steam pressure. In consequence the current flowing through the circuit 3 varies directly with the steam flow through the piping B^3 when the boiler steam pressure is at the normal value. On changes in the boiler steam pressure, the current varies to compensate for such changes. This mode of regulating the current flowing through the circuit 3 is an advantageous one, but as already indicated, the present invention in its more general aspects is not dependent on the precise character or mode of operation of the master controller G . r represents an adjustable resistance shown about the coils g and g' by which the constant, so to speak, of the controller G may be adjusted to vary the ratio between the boiler load and rate of combustion, or to adjust the apparatus to the flow resistance of the piping B^3 .

The blowers E and F are driven by electric motors E^5 and F^5 at the speeds required to make the rate of air delivery of each blower vary in proportion with changes in the control current flowing through the circuit 3. For this purpose the motor E^5 is provided with an electromagnetic flow balance controller EA comprising means for opposing the differential fluid pressure in the pipes e and e' which is a measure of the rate of flow of air delivered by the blower E against an electromagnetic force which is proportional to the square of the strength of the electric current flowing in the circuit 3. On a change of one of these forces relative to the other the controller EA varies the shunt field current of the motor E^5 as required to restore the balance. Branch conductors 4 and 5 from the supply conductors 1 and 2 furnish the armature currents required for energizing the motor E^5 and the field current is furnished by the conductors 4, and the branches 51 and 52 from the conductor 5, said branches being connected through the adjustable resistance (not shown) of the con-

troller EA . The said resistance may be associated with the motor E^5 and controlled by the controller EA in exactly the same manner in which the resistance R^2 is associated with the motor D' and is controlled by the controller I as hereinafter described.

The controller FA may be similar in construction and operation to the controller EA and serves to vary the current supplied to the motor F^5 from the corresponding branch supply conductors 4 and 5 as required to maintain the predetermined relation between the strength of current flow through the circuit 3 and the rate of air delivery by the blower F . The controllers EA and FA each may be similar to the balance G and its motor M , except that the single chamber G' of the balance is replaced by two chambers connected to the pipes e and e' in the controllers EA and FA . The latter need not be further illustrated or described herein, however, as various types of controllers suitable for the purpose are known, one suitable type being shown, for example, in Fig. 7 of my Patent No. 1,167,343, granted January 4, 1916.

In the apparatus shown in Fig. 1, the rate at which fuel is passed into the combustion chamber A' through the nozzle or nozzles C depends primarily on the speed of the motor D' which, as shown in Fig. 2, rotates the feed screw D^2 employed to feed coal from a supply hopper traversed at the bottom by the feed screw D^2 into the feeder outlet chamber D^3 through which the coal is discharged into the pipe E^6 . The speed of the fuel feeder motor D' is made primarily dependent on the strength of the current flowing through the circuit 3 by a controller I , but the speed of the motor D' is varied to vary the excess air ratio, by passing more or less of the control current through a by-pass about the fuel control mechanism. As shown, said by-pass includes conductors 8 and 9, contacts L^4 and M^2 , and the portion of the resistance R' between the contacts L^4 and M^2 . In Fig. 1 means are provided which tend to increase and decrease the amount of the resistance R' in the by-pass as the control current increases and decreases, and tend to decrease or increase the amount of the resistance R' in the by-pass accordingly as the combustion chamber temperature measured by a thermocouple P rises or falls.

The means shown for increasing the resistance R' in the by-pass as the control current increases comprises a solenoid L in series with the circuit 3, and a magnetic core L' drawn into the solenoid by the current flow through the latter, to the position at which the pull of the solenoid L on the core L' is balanced by a tension spring L^2 connected to the core and opposing the movement of the latter into the solenoid. The contact L^4 is connected to the core L' and slides along in contact with the resistance R'

as the current in the circuit 3 increases and diminishes. As already indicated, I regard it as generally undesirable to decrease the excess air ratio as the load increases, except through a lower portion of the load range. On this account, I provide a stop L^5 limiting the movement of the core L' into the solenoid L beyond the position to which it is moved when the load increases to a certain value well below the maximum load which may be carried.

The means illustrated for adjusting the contact M^2 as the combustion chamber temperature varies comprises a motor MA having a threaded spindle passing through a nut-like portion of the contact M^2 .

The motor MA is controlled by a pyrometer controller O which operates to move a contact O' into engagement with a terminal 10 of the motor M when the combustion chamber temperature to which the thermo-couple P responds rises above a predetermined value. This energizes the motor MA through a branch conductor 4 connecting the contact O' to the supply conductor 1, and a corresponding branch 5 from the supply conductor 2 permanently connected to one terminal of the motor MA . When so energized the motor rotates in the direction to decrease the amount of resistance R' in the by-pass, and thereby increase the excess air ratio. When the combustion chamber temperature to which the thermocouple P responds falls below a predetermined value, the pyrometer controller O moves the contact O' into engagement with the terminal 11 of the motor MA , and thereby energizes said motor through said terminal 11 and the terminal of the motor MA connected by the conductor 5 to supply conductor 2. When thus energized, the motor MA rotates in the direction to increase the resistance R' in the by-pass and thereby decrease the excess air ratio. The pyrometer controller O need not be further illustrated or described herein, as such controllers are well known and in common use, one form of pyrometer controller suitable for the purpose being shown in the patent of Leeds No. 1,332,182, granted February 24, 1920.

The controller I which directly controls the fuel feed motor D' , tends to maintain the latter in operation at a speed proportional to the fraction of the control current not bypassed about the controller I . In the form shown in Fig. 1, the controller I comprises parts $I^1, I^2, I^3, I^4, i, i', H$ and h identical respectively with the parts $G^1, G^2, G^3, G^4, g, g', H$ and h of the controller G . The controller I differs from the controller G , however, in that the controller I includes nothing analogous to the weight G^{10} and the magnetic interaction of the coils i and i' opposes, and normally balances the action of the flexible wall I^2 on the lever I^3 .

The pressure acting against the flexible wall I^2 of the controller I is proportional to the square of speed of the motor D' . For this purpose a small blower K is driven by the motor D , at a speed proportional to the speed of the motor D , the blower K having such characteristics that the pressure at its outlet will vary with the square of the speed of the motor D' . The outlet of the blower K is connected by a pipe K' to the chamber I' of the controller I .

The controller I controls the speed of the motor D' through a relay actuated motor control mechanism comprising a reversible motor MB which may be identical with the motor MA , and which is caused to run in one direction or the other accordingly as the lever I^3 closes the associated contacts H or h . When the pressure in the chamber I' rises relative to the strength of current flow through the coils i and i' , the contacts H are closed and the motor MB then rotates in the direction to move the contact nut M' on the threaded motor spindle so as to decrease the amount of resistance R^2 in the shunt field circuit including the conductors 51 and 52 from the conductor 5 which with the conductor 4 supplies both armature and field current, thereby decreasing the speed of the motor D' . Conversely, on a relative decrease in the pressure in the chamber I' which causes the lever I^3 to close the associated contacts h , the motor MB turns in the direction to increase the amount of resistance R^2 in circuit, and thereby speed up the motor D' .

The rate at which powdered coal is delivered by a feeder like the feeder D , is not strictly proportioned to the speed of the feed screw of the feeder. On the contrary, changes in the extent to which the coal is aerated, variations in the moisture content of the coal, and even changes in atmospheric humidity may make significant differences in the amount of coal delivered with a given speed of rotation of the feed screw D^2 . Furthermore, the rate at which coal is delivered by the feed screw is interfered with, of course, by any packing of the coal in the hopper from which the coal is discharged by the feed screw.

In accordance with the present invention I provide means for making the actual rate of fuel feed, rather than the speed of the feed screw D^2 , proportional to the part of the control current passing through the coils i and i' of the controller I . This I accomplish by the use of a mechanism measuring the actual rate of coal delivery by the feed screw D^2 . The particular mechanism shown for this purpose comprises an impact plate D^4 against which the coal dropping away from the feed screw D^2 impinges.

As shown, guides D^{10} are provided to drive all of the coal falling away from the feed screw into impingement with the plate D^4 .

along a rather narrow horizontally elongated central portion of the surface of the plate. The impact plate D^4 is inclined to the horizontal at a sufficient angle to prevent the coal impinging against it from adhering to the plate. The plate is carried at one end of a horizontal lever D^5 which is pivotally supported at D^6 .

The impingement of the falling coal against the plate D^4 subjects the lever D^5 to a clockwise torque normally balanced by an electromagnetic force proportional to the control current, or rather to the portion of that current flowing through the coils i and i' . As shown, this magnetic force action is due to a vertically disposed polarized magnet or core D^7 , the ends of which extend into stationary solenoid coils D^8 which are connected in series with the coils i and i' of the controller I , and, like the latter, are included in the branch of the circuit 3 in multiple with the by-pass conductors 8 and 9 and the variable resistance R' . The two coils D^8 are so wound that the current flow through each acts on the core D^7 in a direction tending to turn the lever D^5 in the counter clockwise direction. This tendency of the coils D^8 and core D^7 to turn the lever D^5 opposes, and normally balances, the tendency of the falling coal impinging against the plate D^4 to turn the levers in the clockwise direction. With a polarized or fully saturated core D^7 , the torque to which the lever D^5 is subjected by the current flow through the coils D^8 , is proportional to the strength of the electric current flowing through those coils. In consequence, if the rate at which coal impinges against the plate D^4 is just sufficient to balance the torque due to the interaction of the coils D^8 and core D^7 , the lever D^5 will remain in a neutral position. The clockwise torque impressed on the plate D^4 varies, of course, with the amount of coal falling, and it is to be noted that any slowing down of the falling coal particles by the air, through which they fall does not affect the situation since the force then transmitted by the coal to the air, is transmitted by the air to the plate D^4 .

The control provisions for the motor D' previously described tend to make the speed of the motor D' proportional to the portion of the control current passing through the coils i and i' of the controller I . If, for such reasons as have already been mentioned, the rate at which fuel is delivered is not maintained proportional to the speed of the motor D' the lever D^5 tilts in one direction or the other and thereby adjusts a valve D^9 carried by the lever D^5 . The valve D^9 regulates the air flow through a bleeder outlet pipe K^2 connected to the delivery outlet of the fan K . If, as a result of an increase in the rate of fuel feed relative to the current flowing through the coils D^8 , the lever D^5 tilts in the

clockwise direction, the valve D^9 throttles the bleeder outlet. This increases the pressure transmitted by the pipe K' from the blower K to the pressure chamber I' of the controller I , and the controller I then operates to decrease the speed of the motor D' . Conversely, when the rate of fuel feed is relatively low, the lever D^5 tilts in the counter-clockwise direction and moves the valve D^9 to increase the effective area of the bleeder outlet. In consequence the pressure then transmitted to the pressure chamber I' is diminished, and the speed of the motor D' is correspondingly increased. In order to dampen any tendency of the arm D^5 to oscillate it is connected to a plunger D^{12} which moves in an air dash pot D^{13} . A variable resistance shunt R^{10} permits of an adjustment of the constant, so to speak, of the lever D^5 , which is useful for various purposes as to compensate for changes in the B. t. u. value of the coal.

The piping E^a connecting the outlet of the blower E to the nozzle or nozzles C is open at its upper side to the chamber D^3 for a corresponding portion of the length of the piping. To prevent disturbances in the air pressure in the chamber D^3 by the air flow through the pipe E^a , I provide a rotating gate D^{11} geared to, and driven by the motor D' for transferring the coal reaching the bottom of the chamber D^3 to the piping E^a , while at the same time substantially preventing air flow between the chamber D^3 and the piping E^a .

From the foregoing it will be apparent that the apparatus shown in Figs. 1, 2 and 3 normally operates to maintain a control current in the circuit 3 which varies in response to changes in the boiler load in the manner in which the general rate of combustion should vary in response to load changes. The controllers EA and FA operate to make the supplies of primary and secondary air furnished by the blowers E and F , respectively, proportional at all times to the strength of the control current. With suitable combustion chamber temperature conditions the rate of fuel feed will vary with the boiler load, and the excess air ratio will consequently remain constant, throughout an upper load range above the load value at which the contact L^4 is moved against the stop L^5 . In this upper load range, however, the excess air ratio will ordinarily be increased as the load increases because with load increases the combustion chamber temperature tends to rise, and the thermocouple P and controller O operate as previously described to decrease and increase the rate of fuel feed and thereby increase and decrease, respectively, the excess air ratio as required to maintain an approximately constant combustion chamber temperature. During a lower load range in which contact L^4 is not in engagement with the stop L^5 , the solenoid L

and associated parts tend to decrease the excess air ratio as the load increases. In this lower portion of the load range, control of the excess air ratio is not ordinarily required to prevent overheating of the combustion chamber walls but is required to insure complete combustion on the one hand, and the avoidance on the other hand of excess air in amount to objectionably decrease the thermal efficiency of the unit. Generally speaking, in the operation of a furnace, and particularly in the operation of a furnace burning fuel in suspension in air, whether that fuel be powdered coal, gas or oil, combustion conditions improve and less excess air is required for complete combustion as the rate of combustion increases. This is due to the fact that as the rate of combustion increases better mixing of the fuel and air is ordinarily obtained, and also because an increase in combustion chamber temperature accelerates the combustion of the fuel.

With the apparatus shown in Figs. 1, 2; and 3, the desired excess air control is secured by modifying the rate of fuel supply. The same general character of excess air control can also be secured by modifying the rate of air supply rather than the rate of fuel supply, and superficially considered, the last mentioned mode of excess air control may seem to be the only logical one. In practice, however, with the general type of control apparatus shown in Figs. 1, 2, and 3, and with the range in excess air required in the control of a boiler furnace of the type illustrated in Fig. 1, it is, generally speaking, immaterial whether the excess air control is secured by modifying the rate of fuel supply or by modifying the rate of air supply. In the apparatus shown in Fig. 4 now to be described, the excess air control is obtained by modifying the rate of air supply by apparatus which, in this respect, differs from that shown in Figs. 1, 2 and 3 substantially only in that in Fig. 4, the by-pass including the resistance R' extends about the portion of the circuit 3 including the instrumentalities regulating the volume of draft, instead of about the instrumentalities regulating the fuel feed.

In Fig. 4 I have illustrated the use of the present invention in controlling combustion in a boiler furnace AA in which the combustion chamber A^{10} has all or a large portion of its walls lined by suitably disposed tubes B^5 , B^6 , and B^7 forming a part of the water circulating system of the boiler and exerting such a combustion chamber wall cooling effect that the combustion chamber temperature may safely be materially higher than with the type of boiler furnace shown in Fig. 1. In the form shown in Fig. 4, the excess air ratio is primarily dependent on the CO_2 content of the flue gases, and means are provided for varying the excess air ratio as re-

quired to increase the CO_2 content of the flue gases as the load increases.

In the form shown in Fig. 4, the primary air carrying the powdered coal supplied by the feeder D is discharged into a so-called cyclone air and fuel mixer CA which also receives air unmixed with coal from the blower E through a branch pipe E^7 . The fuel and air mixture passes from the mixer CA to the upper portion of the chamber A^{10} through distributed branch supply pipes C^{10} . The heating gases pass from the combustion chamber downward across the tubes E^6 into a chamber BA containing the superheater tubes B^7 , which chamber may also contain feed water preheating tubes. From the top of the chamber BA the heating gases pass into an air preheater F' . The latter, as shown, has its air inlet F open to the atmosphere, and has its air outlet connected by piping F^2 to the combustion chamber A^{10} . In Fig. 4 the volume of secondary air passing through the preheater F' is controlled by the adjustment of a stack damper e^{11} . The latter is adjusted by a reversible motor e^{10} controlled by a controller ea which is generally like the balance EA previously described, but the balance ea instead of controlling a variable speed motor energizes the normally inactive motor e^{10} to run in one direction or the other as the controller G energizes the motor M.

The control system shown in Fig. 4 is, generally speaking, of the same character as that shown in Fig. 1. It comprises a main control circuit 3, the current flow through which is regulated by a master controller G which may be identical with the controller G of Fig. 1, and like the latter is directly responsive to the pressure in the superheater outlet piping B^3 . The controller ea may be identical in construction and operation with the controller EA first described. The motor D' is controlled by a controller IA which might be identical with the controller I first described, but as diagrammatically illustrated differs in that the lever I^{30} of the controller IA, corresponding to the lever I^2 of the controller I, is pivotally supported between its ends, and instead of bearing against the flexible wall of a pressure chamber carries a bell I^{10} dipping into a sealing liquid held in a chamber I^{11} open at its top to the atmosphere. The pipe K' from the blower K opens into the space beneath the bell I^{10} . The tilting of the lever I^{30} out of its neutral position brings the lever IA into engagement with upper and lower contacts HA and ha , respectively, and thereby energizes a motor MB to increase or decrease the amount of resistance R^2 in the energizing circuit of the motor D' as required to make the speed of that motor such that the rate of fuel discharged by the feeder D will be maintained in a constant ratio with the strength of the control current flowing through the circuit 3.

The controllers EA, ea, and IA are all connected in series in the control circuit 3, but the portion of the circuit 3 containing the controllers EA and ea which collectively regulate the combustion air supplied to the combustion chamber A¹⁰, is in multiple with a by-pass. The latter includes conductors 80 and 90, a resistance R' and a contact M² adjusted by the rotation in one direction or the other of the motor MA. When the motor MA of Fig. 4, turns in the direction to decrease the amount of resistance R' in the by-pass circuit, the excess air ratio is diminished, and the latter is increased by the rotation of the motor MA in the direction to increase the amount of resistance R' in the by-pass circuit.

In Fig. 4, the motor MA is operated to increase and decrease the excess air ratio as required to maintain a CO₂ content in flue gases which varies with the load. This result is secured by the use of a CO₂ meter Q operating in conjunction with a solenoid L and associated parts including a contact L⁴ adjusted by the solenoid L as the strength of the current flowing through the circuit 3 varies just as the contact L⁴ of Fig. 1 is adjusted. The CO₂ meter comprises a stem Q' which carries a pair of spaced apart contacts Q² and Q³, and which is moved to the left or to the right, as the CO₂ content in a flue gas sample passing to the controller Q through a pipe Q¹⁰ increases or diminishes. As CO₂ meters of various forms suitable for use in the manner described are well known and in common use, further illustration or description of the controller Q is unnecessary.

In the operation of the apparatus shown in Fig. 4, the contact Q² is moved by the CO₂ meter Q into engagement with the contact L⁴ when the CO₂ content in the flue gases is higher than the predetermined amount for the corresponding furnace load. When the contact Q² engages the contact L⁴, the motor MA is set into operation in the direction to increase the resistance R' in circuit. This increases the excess air ratio, and thereby reduces the CO₂ content of the flue gases. Conversely, when the CO₂ content in the flue gases falls below the predetermined amount for the then load, the meter Q moves the contact Q³ into engagement with the contact L⁴ and thereby energizes the motor MA in the direction to reduce the amount of resistance R' in the by-pass circuit, thereby decreasing the excess air ratio and increasing the CO₂ content in the furnace gases.

In lieu of the CO₂ meter employed in Fig. 4, I may employ an oxygen meter or a combustible gas constituent meter, each of which may be of known type. An oxygen meter should be arranged to decrease and increase the excess air ratio as the oxygen in the flue gases increases and decreases, while the combustible gas meter should increase and decrease the excess air ratio as the combustible

gas in the flue gases increases and decreases.

While in accordance with the provisions of the statutes, I have illustrated and described the best forms 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. In a boiler furnace combustion control system, the combination with means for creating a control force varying in a predetermined manner with changes in the boiler load, of a fuel feeder, means actuated by and responsive to the rate of fuel delivery by said feeder, and control means for the fuel feeder jointly responsive to the action of said second mentioned means and to said control force for making the rate at which fuel is delivered proportional to said control force.

2. In a powdered coal burning furnace, the combination with a fuel feeder, of control mechanism therefor comprising means for maintaining a control force independent of the operation of said feeder, and means actuated by and responsive to the rate at which fuel is discharged by the feeder and to said control force for maintaining said rate proportional to said force.

3. In a boiler furnace combustion control system, the combination with a fuel feeder, of means controlling the operation of said feeder tending to operate it at a speed varying in a predetermined manner with changes in the boiler load, and means actuated by and responsive to the rate at which fuel is delivered by said feeder for adjusting said control means.

4. In a boiler furnace combustion control system, the combination of fuel feeding means, draft regulating means, means responsive to the volume of draft, means responsive to the rate of fuel feed, and controlling means responsive to a condition of boiler load and to the action of the third and fourth mentioned means and tending normally to maintain a predetermined proportion between the rate of fuel feed and the volume of draft and thereby maintain a constant excess air ratio, and cooperating means responsive to the combustion chamber temperature for increasing the ratio of draft relative to the rate of fuel feed as the furnace chamber temperature increases.

5. In a boiler combustion control system, means for creating a control force comprising a balance means for subjecting the balance to a pressure which is less than the boiler steam pressure by an amount which

is a function of the steam outflow from the boiler, means for subjecting said balance to a constant opposing force sufficient to neutralize the action on the balance of the first mentioned force when the latter is equal to the normal boiler steam pressure, means for subjecting said balance to a force created by said control force and acting on said balance in the same direction as the first mentioned pressure, and a regulator actuated by said balance to increase and decrease said control force accordingly as said constant force overbalances or under-balances the action on the balance of the first mentioned pressure and said constant force.

6. In a boiler combustion control system, means for creating an electric control current comprising a balance, means for subjecting the balance to a pressure which is less than the boiler steam pressure by an amount which is a function of the steam outflow from the boiler, means for subjecting said balance to a constant opposing force sufficient to neutralize the action on the balance of the first mentioned force when the latter is equal to the normal boiler steam pressure, means for subjecting said balance to an electro-magnetic force created by said control current and acting on said balance in the same direction as the first mentioned force, and a current regulator actuated by said balance to increase and decrease said control current accordingly as said constant force overbalances or underbalances the joint action on the balance of the other two forces.

7. In a boiler furnace control system, the combination with a boiler and a pipe to which steam generated in the boiler is delivered, of a balance including a pressure chamber having a flexible wall, means connecting said chamber to said pipe at a point at which the pressure is appreciably less than that in the boiler when steam is flowing through said pipe, a member opposing the outward movement of said flexible wall with a constant force balancing the action of the pressure in said chamber when that pressure is equal to the normal boiler steam pressure desired, means for subjecting said member to a control force acting on the member in the same direction as the pressure in said chamber, and a regulator actuated by the movements of said member away from a neutral position for increasing and decreasing said control force as required to return said member to said neutral position, and combustion regulating means controlled by the strength of said control force.

8. In a boiler furnace control system, the combination with a boiler and a pipe to which steam generated in the boiler is delivered, of a balance including a pressure chamber having a flexible wall, means connecting said chamber to said pipe at a point which is at a distance from the boiler, a member oppos-

ing the outward movement of said flexible wall with a constant force sufficient to balance the action of the pressure in said chamber when that pressure is equal to the normal boiler steam pressure desired, a coil carried by said member, a cooperating stationary coil, means for passing a current through said coils and thereby subjecting said member to an electro-magnetic force acting on the member in the same direction as the pressure in said chamber, and a current regulator actuated by movements of said member out of a normal position for increasing and decreasing said current as required to return said member to said normal position, and combustion regulating means controlled by the strength of said current.

9. In a boiler furnace combustion regulating system, the combination with means responsive to the boiler load for normally supplying fuel and air for combustion at predetermined rates dependent on the boiler load, of means responsive to the combustion chamber temperature for varying one of said rates and thereby varying the excess air ratio in a manner minimizing variations in said temperature.

10. In a boiler furnace combustion control system, the combination with means for creating a control force varying in a predetermined manner with changes in the boiler load, of a fuel feeder, control means for the latter jointly responsive to the rate at which fuel is delivered by said feeder and to said control force for making the rate at which fuel is delivered proportional to said control force, and means responsive to the furnace combustion chamber temperature for modifying the rate at which fuel is fed in predetermined accordance with changes in said temperature.

Signed at Philadelphia, in the county of Philadelphia and State of Pennsylvania, this second day of August, A. D. 1926.

GEORGE H. GIBSON.