Oct. 28, 1924. 1,513,103

G. H. GIBSON

COMBUSTION CONTROL

Filed Oct. 19, 1920 4 Sheets-Sheet 1

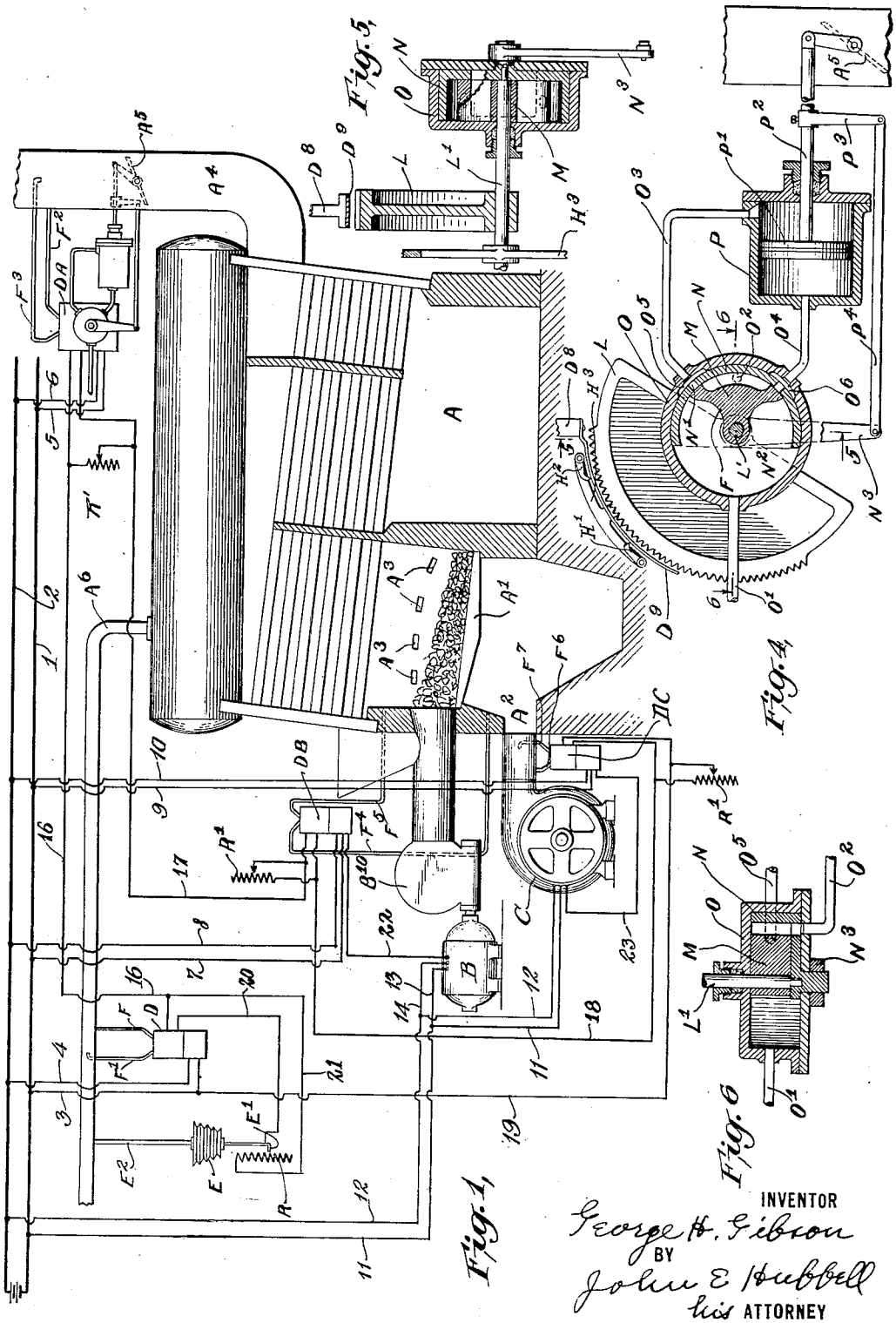


Fig. 1.

Fig. 4.

Fig. 5.

Fig. 6.

INVENTOR

George H. Gibson

BY

John E. Hubbell

his ATTORNEY

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G. H. GIBSON

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4 Sheets-Sheet 2

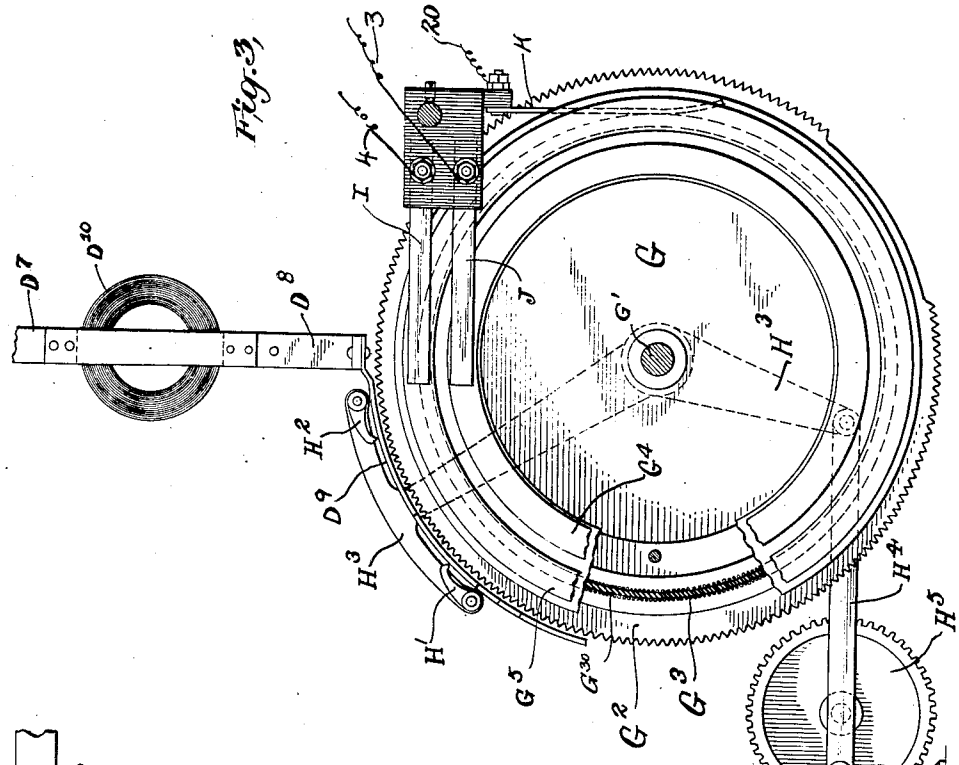


Fig. 3.

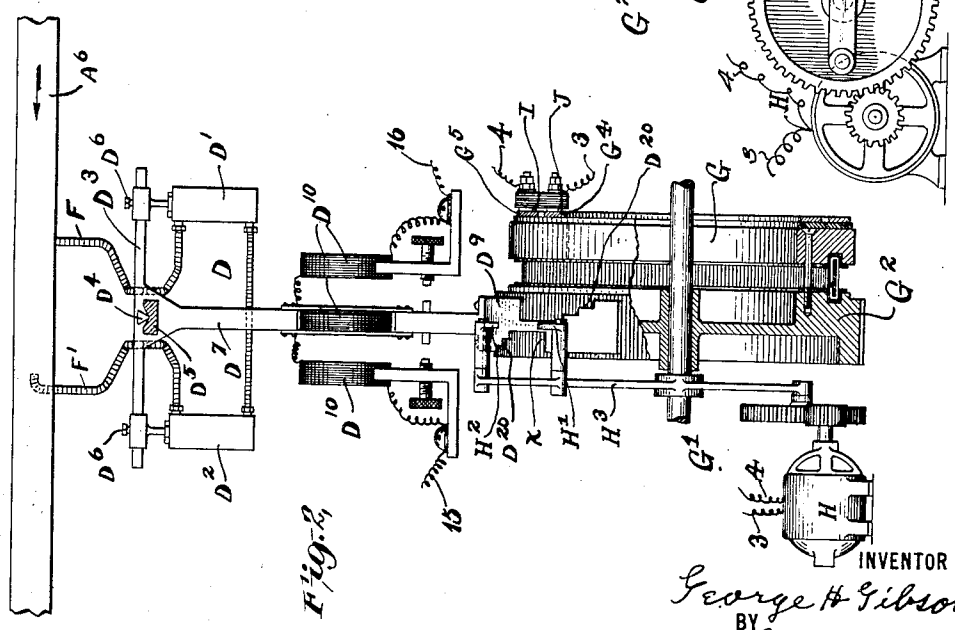


Fig. 2.

INVENTOR

George H. Gibson

BY John E. Hubbell

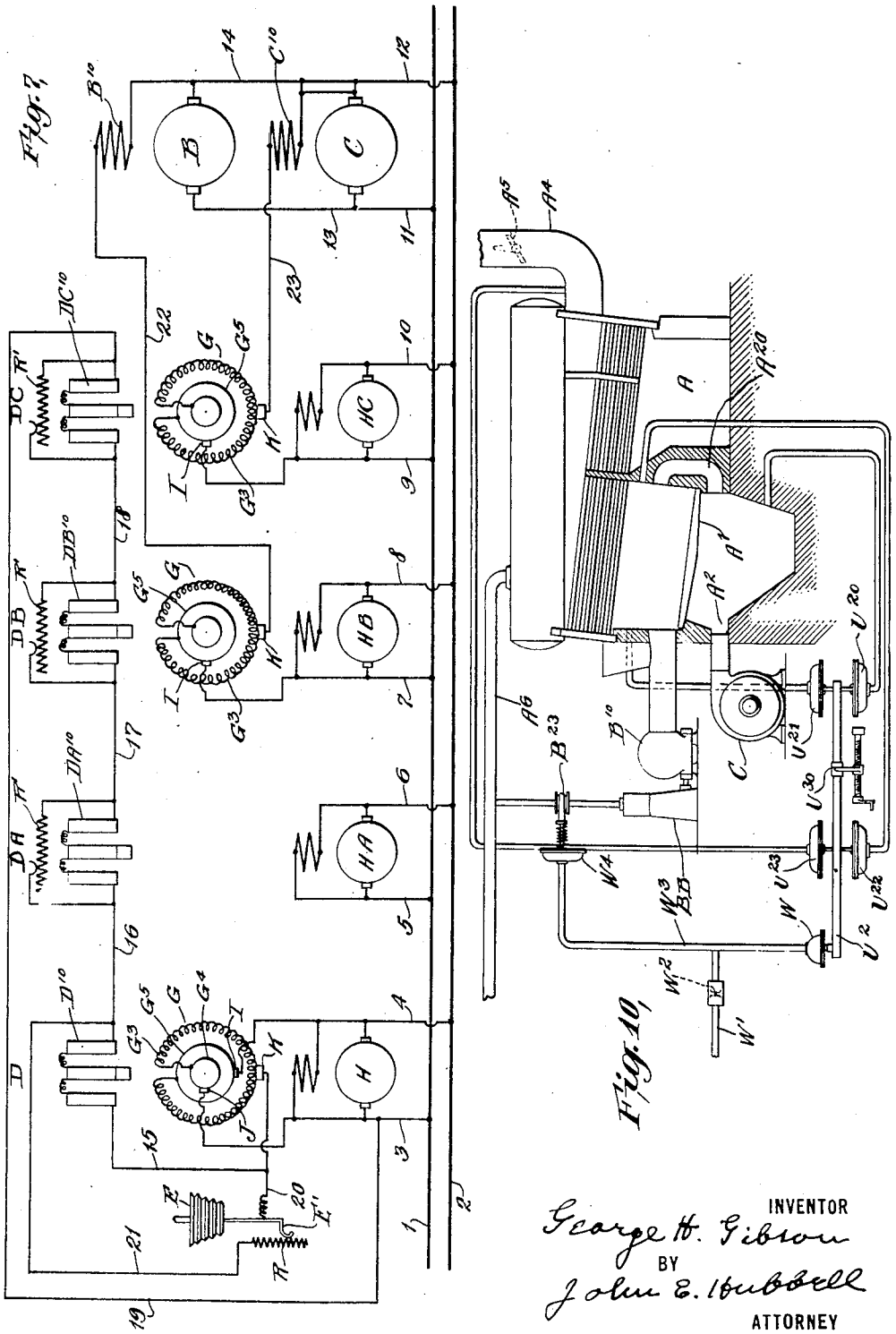
His ATTORNEY

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G. H. GIBSON

COMBUSTION CONTROL

Filed Oct. 19, 1920 4 Sheets-Sheet 3



INVENTOR
George H. Gibson
BY
John E. Hubbell
ATTORNEY

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G. H. GIBSON

COMBUSTION CONTROL

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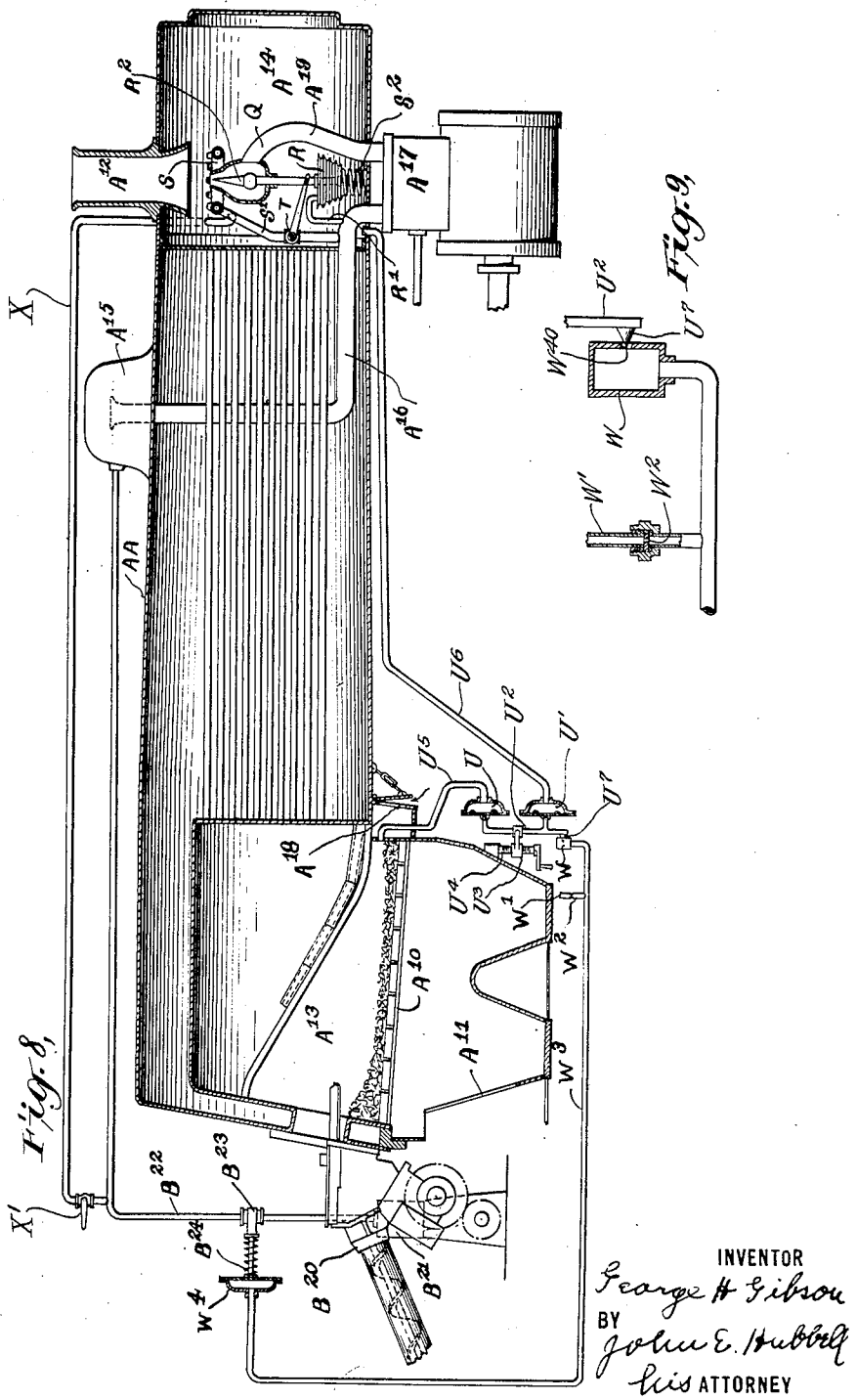


Fig. 8.

Fig. 9.

INVENTOR
George H. Gibson
BY
John E. Hubbell
his ATTORNEY

Patented Oct. 28, 1924. 1,513,103

UNITED STATES PATENT OFFICE.

GEORGE H. GIBSON, OF MONTCLAIR, NEW JERSEY.

COMBUSTION CONTROL.

Application filed October 19, 1920. Serial No. 418,087.

To all whom it may concern:

Be it known that I, GEORGE H. GIBSON, citizen of the United States, and resident of Montclair, in the county of Essex and State of New Jersey, have invented certain new and useful Improvements in Combustion Controls, of which the following is a specification.

The general object of the present invention is to provide an improved method of, and apparatus for regulating combustion in furnaces heated by the combustion of solid fuel.

One specific object of the invention is to provide an effective method of and apparatus for automatically regulating the supply of fuel to the fuel bed as required to maintain the fuel bed resistance to gas flow therethrough approximately constant.

The invention is especially devised and adapted for use in connection with steam generating boiler furnaces and another specific object of the invention is to provide an improved method of, and apparatus for automatically regulating the rate of combustion in response to the demand on the boiler; and in the practical accomplishment of this object, the supply of the air required for the combustion of fuel is made automatically responsive to the rate at which steam is withdrawn from the boiler with provisions, when desired, for modifying the direct ratio between the rate of steam flow and the combustion and fuel supply rates in response to changes in the boiler steam pressure.

A preferred form of my invention, as used to regulate combustion in a steam generating boiler furnace comprises cooperating provisions for simultaneously attaining both of the above mentioned specific objects of my invention, but they may be separately attained when conditions make this desirable.

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, advantages possessed by it, and various specific objects attained with it, reference should be had to the accompanying drawings and descriptive matter in which I have illustrated and described preferred forms of embodiment of the invention.

Of the drawings:

Fig. 1 is a diagrammatic representation of a stationary boiler furnace plant;

Fig. 2 is an elevation with parts broken and in sections of a portion of the apparatus employed in Fig. 1;

Fig. 3 is an elevation of a portion of the apparatus shown in Fig. 2 taken at right angles to the last mentioned figure;

Fig. 4 is a sectional elevation of another portion of the apparatus shown in Fig. 1;

Fig. 5 is a section on a line 5—5 of Fig. 4;

Fig. 6 is a section taken on a line 6—6 of Fig. 4;

Fig. 7 is a diagram illustrating the electrical circuits employed in the apparatus of Fig. 1;

Fig. 8 is a sectional elevation of a modified form of my invention embodied in a locomotive;

Fig. 9 is a sectional elevation of a detail of construction employed in Fig. 8; and

Fig. 10 is a diagrammatic representation of another modification of my invention.

In Fig. 1, I have illustrated the use of my invention in connection with a stationary boiler furnace A of conventional type. As shown, the boiler furnace A comprises a fuel bed supporting grate A′, with a primary air inlet A^2 to the furnace chamber below the grate and with secondary air inlets A^3 to the furnace chamber above the grate, and with a products of combustion outlet A^4 leading to a stack or other draft creating device, the latter being controlled by a stack damper A^5. The steam generated in the boiler is withdrawn through a pipe A^6. Fuel is supplied to the grate A′ by an automatic stoker mechanism B^{10} including a driving motor B, the speed of which is automatically adjusted as hereinafter explained so as to maintain a fuel bed of determined resistance to gas flow therethrough. Primary air is supplied to furnace inlet A^2 by a blower or other air moving device driven by a motor C at a speed dependent upon the boiler steam output, and the damper A^5 is automatically adjusted as required to maintain a pressure in the boiler

chamber above the furnace grate which will insure the proper inflow of secondary air from the external atmosphere through the inlets A^3.

The apparatus shown in Fig. 1 for automatically regulating the speed of the stoker motor B and of the blower motor C and for adjusting the damper A^5 comprises a master controller D, which includes an electromagnetic flow balance D and a current regulator G for maintaining an electrical current flow through a control circuit the strength of which is dependent on the steam output of the boiler. This current strength in the control circuit may vary directly with the rate of steam outflow but preferably as shown in Fig. 1, provisions are made for modifying the ratio between the rate of steam outflow and the current flow through the control circuit in response to variations in the steam pressure, so that the current flow tends to increase both upon an increase in the rate of steam outflow and upon a decrease in the steam pressure, and tends to decrease upon a decrease in the rate at which steam is withdrawn from the boiler and on an increase in the steam pressure.

The stack damper A^5 is adjusted by a controller DA comprising an electromagnetic flow balance connected in the control circuit and operating to adjust the damper A^5 as required to maintain a predetermined ratio between the rate of flow of products of combustion through the stack connection A^4 and the current in the control circuit. The speed of the stroker motor B is directly regulated by a controller DB including an electromagnetic flow balance connected in the control circuit and adjusting the speed of the motor B in a manner tending to maintain a predetermined ratio between the differential of the furnace chamber pressures above and below the furnace grate and the square of the current strength in the control circuit. The speed of the blower motor C is regulated by a controller DC including an electromagnetic flow balance connected in the control circuit and adjusting the speed of the motor C as required to maintain a predetermined ratio between the current in the control circuit and the amount of primary air delivered by the blower to the furnace chamber.

The electromagnetic flow balance of the master controller D, see Figs. 2 and 3, comprises a tilting differential pressure gauge of the U tube type, the vertical legs D′ and D^2 of which are carried by a frame D^3 having a knife-edge pivot D^4 mounted on a bearing D^5. Advantageously the legs D′ may be separately adjusted on arms of the frame member D^3 toward and away from the pivot D^4 and clamped in any desired adjustment as by means of the set screws D^6. The static pressure in the steam conduit A^6 is transmitted to the upper end of gauge chamber D′ by a flexible pipe F, and the total pressure in the conduit A^6 is transmitted to the upper end of the gauge chamber D^2 by a flexible conduit F′. The frame D^3 comprises a depending arm D^7 which carries the floating coil or winding D^{10} of an electrodynamometer of the Kelvin balance type. The floating coil D^{10} is located between and connected in series with a pair of stationary coils or windings D^{10}.

Associated with and regulated by the electromagnetic flow balance of the master controller D is an electrical current adjusting device or current controller G comprising, in the form shown, a supporting shaft G′ on which is loosely journaled a member G^2 having ratchet teeth at its periphery. Also journaled on the shaft G′ is a reciprocating power actuator for current controller G. This actuator comprises a ratchet actuating lever H^3. The latter is oscillated by a constantly running electric motor H through connections including a gear wheel H^5 in mesh with the motor shaft and carrying a crank pin connected by the link H^4 to the lever H^3. The latter is provided with two pawls H′ and H^2. The pawl H′ tends to engage the ratchet teeth on the periphery of the member G^2 and turn the latter with the lever H^3 when the latter swings into the clockwise direction as seen in Fig. 3, while on the return stroke of lever H^3, the pawl H^2 tends to move the member G^2 in the counter clockwise direction. A pawl controller D^9 carried by an extension D^8 of the flow balance frame prevents the simultaneous engagement of both pawls H′ and H^2 with the ratchet teeth of the member G^2, and regulates the amount and direction of movement imparted to the member G^2 by the movements of the pawls. As shown the pawl controller is in the form of an arc shaped strip of sheet metal fitting over a portion of the periphery of the member G^2 and serving, when the tilting pressure gauge is in its neutral position as shown in Fig. 2, to hold both pawls H′ and H^2 out of engagement with the ratchet teeth G^2 in all positions of the lever H^3. When the tilting pressure gauge is swung from its neutral position in a clockwise direction as it will be when the steam flow through the conduit A^6 increases relative to the current flow through the coils D^{10}, the shield D^9 will hold the pawl H^2 out of engagement with the ratchet teeth G^2 throughout the complete stroke of the lever H^3, but the pawl H′ will then be permitted to engage the ratchet teeth during a portion of the movement of the lever H^3 and correspondingly adjust the member G^2 in a clockwise direction as seen in Fig. 3. The portion of the movement of the lever H^3 in which the pawl H′ operatively engages and adjusts the member G^2

will vary with the extent of displacement of the shield D^9 from its neutral position owing to the shaped side edges D^{20} of the shield member. Similarly when the shield member is displaced to the right from its neutral position as shown in Fig. 2, the pawl H′ will be held out of engagement with the teeth of the member G^2 and the pawl H^2 will effect adjustments of member G^2 in the counter clockwise direction as seen in Fig. 3 in steps the magnitude of which depends upon the extend to which the shield D^9 is displaced from its neutral position.

The member G includes a resistance G^3 wound in a flattened helix about a cylindrical support G^{30}. The terminals of the conductor G^3 are connected, respectively, to inner and outer concentrically disposed contact rings G^4 and G^5. I and J represent stationary brushes engaging the slip rings G^5 and G^4 respectively and K is a stationary brush engaging the resistance conductor G^3. The brushes I and J (see Fig. 7) are connected by branch conductors 4 and 3, to the main current supply conductors 1 and 2, respectively, between which any suitable potential difference may be maintained.

The coils D^{10} of the master controller D are connected in a control circuit (see Figs. 1 and 7) including the conductor 4, brush I, slip ring G^5, the portion of the resistance G^3 between the end of the latter connected to the slip ring G^5 and the point at which the resistance G^3 is engaged by the brush K, the latter, a conductor 15, conductor 16, coils DA^{10}, conductor 17, coils DB^{10}, conductor 18, coils DC^{10}, conductor 19, and a portion of the conductor 3. The control circuit also includes adjustable resistance shunts R and R′ hereinafter referred to. The potential impressed upon this circuit is a fraction of the potential between the supply conductor 1 and 2 which depends upon the position of the member G^2 relative to the brush K.

In the apparatus shown in Fig. 1, a shunt comprising conductors 20 and 21, contact E′, and a portion of the resistance R is placed about the windings of the balance coils D^{10}. The contact E′ is carried by the movable end of a bellows pressure chamber E to the interior of which the static pressure in the steam conduit A^6 is transmitted by a pipe E^3. With the apparatus shown in Fig. 1, the flow balance of the master controller D adjusts the current regulator G as required to maintain an electric current flow through the windings D^{10} which varies in strength with the rate of steam flow through the conduit A^6. The total current flowing through the control circuit is equal to the sum of the current flowing through the coils D^{10} and the current flowing through the shunt including the conductors 20 and 21. So long as the steam pressure remains constant, the current flowing through the coils D^{10} and the current flowing through the shunt are in the same ratio, and in consequence the total current flowing through the control circuit varies directly with the current flowing through the coils D^{10}. The tendency of an increase or decrease in the steam pressure in the pipe A^6 is to increase or decrease, respectively, the portion of the resistance R in the shunt about the coils D^{10} and consequently to decrease or increase respectively, the total current flow through the control circuit and to correspondingly decrease or increase the rate of combustion. In the construction illustrated, the controllers DA, DB and DC each include an electromagnetic flow balance which may be identical with the flow balance of the master controller D. In Fig. 7 DA^{10}, DB^{10} and DC^{10} indicate the flow balance coils of the controllers DA, DB and DC respectively, corresponding to the coils D^{10} of the balance D. The controllers DA, DB and DC each comprises a motor HA, HB and HC, respectively, corresponding to the motor H of the master controller. The motors HA, HB and HC are connected across the supply lines 1 and 2 by conductors 5, 6; 7, 8; and 9, 10, respectively.

The flow balance of the controller DA controlling the stack damper A^5 is made responsive to the flow through the stack outlet A^4 by the static and total pressure transmitting connections F^2 and F^3, respectively. The controller DA includes a ratchet lever H^3 continuously oscillated by the motor HA and serving through its pawls H′ and H^2 to adjust a gear segment L in response to the position of the shield D^9 of the controller DA in the same manner in which the position of the member G^2 is controlled as above described. The gear segment L is secured to a shaft L′ on which the ratchet lever H^3 is journaled and to which is secured a valve member M of the rotary D type valve, the valve M working in the valve chest O. Interposed between the inner wall of the valve chest and the valve member M is a cylindrical valve member N. The valve chest O is provided with an inlet O′ for a suitable motive fluid such as water under pressure, with an exhaust outlet O^2 and with spaced apart ports connected by pipes O^3 and O^4 to the opposite ends of the damper actuating cylinder P. The piston P′ working in the cylinder P has its stem P^2 connected to the operating arm of the damper A^5. The piston stem P^2 also is connected by an arm P^3, link P^4 and arm N^3 to the valve member N. The valve member N is formed with spaced apart ports N′ and N^2 the inner ends of which are normally closed by corresponding portions of the valve member M. The

ports in valve member N open at their outer ends to recesses or pockets O^5 and O^6 formed in the inner wall of the valve chamber and into which the pipes O^3 and O^4, respectively, open.

The intended operation of the controller DA is to adjust the damper A^5 as required to maintain a constant ratio between the current flowing through the coils DA^{10} and the flow of products of combustion through the stack connection A^4. When the current flowing through the coils DA^{10} rises relative to the fluid flow through the conduit A^4, the shield D^9 is shifted to the left as seen in Fig. 5 and the member L is thereby adjusted by the action of the pawl H' in the clockwise direction to thereby permit pressure fluid to flow from the valve chest O through the pipe O^3 into the right hand end of the cylinder P, while at the same time permitting the left hand end of the cylinder to exhaust through the pipe O^4 and exhaust outlet O^2. This shifts the piston P' to the left and opens the damper A^5 thereby increasing the flow through the conduit A^4. An adjustment of the member L in the counter clockwise direction correspondingly adjusts the damper A^5 in the closing direction. With either adjustment of the damper, the corresponding movement of the valve member N produeed through the arms P^3 and M^3 and link P^4 tends to prevent over travel and hunting of the piston and damper.

The controller DB for the stoker feed may be identical in construction with the master controller D except that the resistance conductor G^3 of controller DB, as shown clearly in Fig. 7, is not connected to the balance coils DB^{10} but serves as a means for regulating the speed of the stoker motor B, the shunt field winding B^{10} of which has one terminal connected by the conductor 22 to the brush K of the controller DB. In the controller DB, the brush J and indeed the contact ring G^4 are idle elements and may be omitted. As shown the motor B has its terminals connected by conductors 13 and 14, and 11 and 12 to the supply conductors 1 and 2. The second terminal of the shunt field winding B^{10} of the motor B is connected to the conductor 14. The differential pressure gauge of the balance DB has its legs connected to the furnace chamber above and below the furnace grate by the pressure transmitting pipes F^5 and F^4 respectively. With the described arrangement when the current flow through the coils DB^{10} of the controller DB, rises relatively to the differential of the pressures at the opposite sides of the grate A' and fuel bed thereby supported, the current controller G of the balance DB is adjusted in the clockwise direction. This increases the portion of the resistance conductor G^3 in series with the shunt field winding D^{10} and thereby reduces the field strength of the motor B and increases its speed, and thus tends to increase the thickness of the fuel bed and the pressure differential between the opposite sides of the fuel bed. Conversely when the current through the coils DB^{10} falls relatively to the pressure drop through the fuel bed, the rheostat element G of the controller DB is adjusted in the counter clockwise direction and thereby increases the field strength of the motor B and reduces the speed of the latter, and thus tends to produce a reduction in the fuel bed thickness.

The controller DC may be identical in construction and arrangement with the controller DB. 23 represents the conductor connecting the brush K of the controller DB to one terminal of the shunt field winding C^{10} of the motor C. The terminals of the motor C are connected by conductors 11 and 12 respectively to the supply conductors 1 and 2. The second terminal of the field winding C^{10} is connected to the conductor 12. The static pressure in the outlet pipe running from the blower C to the furnace inlet A^2 is transmitted to one leg of the differential pressure gauge element of the controller DC by a conduit F^6 and the total pressure in the blower outlet is transmitted to the other leg of the gauge by a pipe F^7. When the control current flowing through the coils DC^{10} rises relative to the rate of air flow into the furnace outlet A^2 the current controller G of the controller DC is adjusted in a clockwise direction to thus increase the resistance in series with the field winding C^{10} and correspondingly increases the speed of the motor C and thereby increase the amount of air supplied to the furnace inlet A^2. A decrease in the strength of current flow through the coils DC^{10} relative to the rate of air flow into the furnace inlet A^2 causes the rheostat element of the controller DC to be adjusted in the counter clockwise direction thereby decreasing the speed of the motor C and the rate at which air is passed to the inlet A^2.

The master controller D tends to maintain a current flow through the control circuit which is proportional to the steam flow through the boiler steam pipe A^6. The pressure chamber E acting on the resistance R tends to vary the current flow through the control circuit in inverse proportion to the changes in steam pressure. The master controller and the pressure chamber E cooperate to maintain a total current flow through the control circuit which is responsive to the heat requirements of the boiler furnace. The controllers DA, DB and DC cooperate to maintain a rate of combustion and a rate of fuel supply proportional to

the total current flow through the control circuit and hence to the heat requirements of the boiler furnace. The operation of each of the controllers DA, DB and DC can be independently regulated by manually adjusting the corresponding resistance R′ to divert more or less of the total current flow in the control circuit through the shunt about the dynamometer coils of the controller. The rate of combustion is directly regulated by the controllers DA and DC which respectively control the inflow of primary air to the boiler furnace, and the outflow therefrom of products of combustion. These two controlling devices act conjointly to maintain a pressure in the furnace chamber above the fuel bed which varies inversely with the rate of combustion and hence insures the proper influx of secondary air through the inlet A^8. The controllers DA and DC can maintain the proper rate of combustion, of course, only in case fuel is kept on the grate A′. The controller DB not only insures the continuous maintenance of fuel on the grate A′ but insures a rate of fuel supply which tends to maintain a fuel bed of approximately constant resistance and thickness as is desirable for efficient combustion and ease in regulating the rate of combustion.

Variations in the rate of combustion and consequently in the volume of gas flow through the fuel bed do not disturb the tendency of the controller DB to maintain a fuel bed of constant resistance to gas flow through it, since the two opposing forces, acting on the flow balance, namely, the differential of the pressures transmitted to the gauge element by the pipes F^4 and F^5, and the electromagnetic action between the stationary and floating coils DB^{10}, both vary in the same proportion and in the same direction with a given change in the volume of draft. The differential between the pressures at the opposite sides of the fuel bed is proportional to the product of the fuel bed resistance multiplied by the square of the volume of flow through the fuel bed. The electro-magnetic force which the stationary coils DB^{10} exert on the floating coil DB^{10} is proportional to the square of the current flow through the coils, and this current flow is itself proportional to the total volume of draft, and hence to the volume of gas flow through the fuel bed. The controller DB responds, therefore, to variations in fuel bed resistance and is unaffected by changes in the volume of draft.

While I have said that the controller DB tends to maintain a fuel bed of constant thickness, this is not strictly correct since when the rate of combustion is relatively rapid, the strong draft necessarily then existing tends to make the fuel bed more open or porous than it is with slower rates of combustion. This increase in porosity or openness of the fuel bed reduces the resistance to gas flow therethrough and in consequence the fuel bed becomes slightly thicker when a rapid rate of combustion is maintained than when the rate of combustion is slower. This thickening of the fuel bed when the rate of combustion is rapid is a desirable feature as those skilled in the art will readily understand.

The general mode of operation obtained with the apparatus disclosed by way of illustration in Figs. 1 to 7, can be secured with apparatus varying greatly in form therefrom. For example, the very different apparatus shown in Fig. 8, may be employed to maintain a rate of combustion proportional to the normal heat requirements of the locomotive furnace shown, and to maintain a fuel bed of constant resistance.

In Fig. 8, AA represents a locomotive of which A^{10} is the grate, A^{13} the firebox, A^{14} the smoke box, A^{11} the primary air inlet to the ash pit, A^{12} the smokestack, A^{15} the steam dome, A^{16} the steam pipe leading from the steam dome to the valve chest A^{17}, of the locomotive, and A^{18} the secondary air inlet. The exhaust pipe A^{19} leads from the valve chest to an exhaust nozzle Q discharging axially through the smoke stack A^{12} as is usual. A bellows pressure chamber R has its interior connected by a pipe R′ to steam pipe A^{16} and has its movable lower end connected to the stem of a needle valve R^2 which throttles the outlet of the exhaust nozzle Q more or less in inverse relation to the locomotive steam pressure. Fuel is fed on to the grate A^{10} by an automatic stoker mechanism B^{20} at a rate regulated by the valve B^{23} controlling the flow of steam through the pipe B^{22} from the steam dome of the locomotive to the steam motor B^{21} driving the stoker mechanism.

The extent to which the valve B^{23} is opened and consequently the rate at which fuel is fed on to the grade A^{10} is controlled by a pressure motor W^4 and the means provided for regulating the pressure therein. The pressure regulating means comprises a pair of pressure chambers U and U′ having flexible walls or diaphragms connected to the opposite ends of a lever U^2, the fulcrum U^3 of which can be adjusted lengthwise of the lever by rotating the adjusting screw U^4. The pressure chamber U is connected to the firebox by the pressure transmitting pipe U^5 and the chamber U′ is connected to the smoke box by the pressure transmitting pipe U^6. The lever U^2 carries a needle valve U^7 which regulates the leakage from a chamber W (see Fig. 9) through an outlet W^{40}. A pipe W^3 connects the chamber W to the pressure motor chamber W^4. A motive fluid such as compressed air is constantly supplied to the pipe W^3 through the supply connec-

tion W′ which includes a restricted orifice W².

With the arrangements described substantially all of the steam generated by the locomotive is discharged in normal operation through the exhaust nozzle Q, and the ejector or draft producing effect of the latter is therefore approximately proportional to the rate of steam output from the locomotive boiler. The effect of the exhaust nozzle is to create a pressure less than that of the atmosphere in the firebox of the locomotive and a still lower pressure in the smoke box. The drop in pressure between the firebox and the smoke box is a function on the one hand of the volume of flow through the boiler tubes and on the other hand of the resistance of the boiler tubes to the flow through them. Similarly the drop in pressure between the atmosphere and the firebox is a function of the amount of gas flow through the fuel bed and the resistance of the fuel bed to the gas flow through it. If the fuel bed resistance to flow is constant, the difference between the pressure of the atmosphere and the pressure in the smoke box will vary in proportion to the difference between the pressure of the atmosphere and the pressure in the smoke box. Therefore if the fulcrum U³ for the lever U² is nearer the center of chamber U′ than to the center of the chamber U when the flexible walls of the two chambers are of the same size, or if the fulcrum is midway between the centers of the two chambers and the diaphragm of the chamber U′ is smaller than the diaphragm of the chamber U, there will be a certain standard fuel bed resistance to flow which will maintain the lever U in equilibrium regardless of whether the rate of combustion is slow or rapid. The resistance of the fuel bed to gas flow through it, required to maintain the lever U in equilibrium can be adjusted, in the apparatus shown, by adjusting the fulcrum block U³ along the screw U⁴. The maintenance of a constant fuel bed resistance insures, and with the apparatus of Fig. 8 is necessary to secure the proper influx of secondary air through the inlet A¹⁸.

When the fuel bed resistance to flow becomes greater than the predetermined standard, the differential between the pressure of the atmosphere and that in the firebox increases relative to the differential between the pressure of the atmosphere and that in the smoke box, and this shifts the lever U² in the direction moving the needle valve U⁷ farther into the orifice W⁴⁰ and thereby causes the pressure in the pipe W³ and the chamber W⁴ to build up. This moves the valve B²³ in the closing direction, throttles the supply of steam to the stoker motor B²¹, reduces the rate of fuel supply to the grate and thereby brings about a reduction in fuel bed thickness and resistance. Conversely when the fuel bed resistance falls below the standard value, the lever U² is shifted to withdraw the needle valve U⁷ somewhat, whereby the pressure in the pipe W³ and chamber W⁴ is reduced, and the valve B²³ is correspondingly opened by the spring B²⁴, thus speeding up the stoker motor and restoring the normal fuel bed thickness. In the apparatus of Fig. 8, as in that of Figs. 1 to 7, the strong draft prevailing when the rate of combustion is high, tends to loosen up the fuel bed, and in consequence tends to the maintenance of a slightly thicker fuel bed when the rate of combustion is high than when the rate of combustion is low.

When the steam pressure falls below the normal, a valve T connected to the stem of the valve R² and located in the live steam supply connection S′ to the live steam auxiliary draft creating nozzle S is opened, thus increasing the draft and tending to bring the steam pressure up to normal. The automatic control of the draft effected by the discharge through the exhaust nozzle Q, and the pressure chamber R may be supplemented, if desired, by the auxiliary steam supply through the pipe X and manually controlled valve X′ to the live steam draft nozzle S.

It is to be noted that the maintenance of a constant relation between the drop in draft pressure between points immediately above and below the fuel bed and the drop in draft pressure through the subsequent portion of the furnace system in which the flow resistance is constant which is obtained directly with the apparatus of Fig. 8 is obtained indirectly with the apparatus of Fig. 1. With the apparatus of Fig. 1 this result is obtained indirectly since the volume of draft and the pressure drop through the fuel bed are both kept proportional to the same quantity. The same result is also directly obtained in the modified construction shown in Fig. 10 wherein the furnace system shown by way of illustration is identical with that of Fig. 1, except that the secondary air is supplied from the ash pit of the furnace through a by pass A²⁰ of regulated resistance, and the stoker motor BB is shown as steam driven, and is controlled by a valve B²³, pressure motor W⁴ and means for varying the pressure therein similar to that employed in Fig. 8, except as to the character of the differential devices acting on the lever U². In Fig. 8 the lever U² is acted upon by a force proportional to the pressure drop through the fuel bed, and by an opposing force proportional to the pressure drop through the portion of the furnace system between the fuel bed and the stack connection A⁴. For this purpose one

end of the lever U^2 is subjected to the opposing action of the flexible diaphragm walls of a pair of pressure chambers U^{20} and U^{21}, one connected to the furnace ash pit and the other to the furnace chamber immediately above the fuel bed; while the other end of the lever is subjected to the opposing action of the flexible walls of a pair of pressure chambers U^{22} and U^{23} connected one to the furnace chamber immediately above the fuel bed and the other to the smoke stack connection A^4.

It will be apparent to those skilled in the art without further explanation that the same sort of control of the supply of fuel bed is had with the apparatus of Fig. 10 as with the apparatus of Fig. 8. The pressure chambers U^{21} and U^{23} in Fig. 10 are necessary to compensate for variations in stack suction. If the pressure in the stack connection A^4 were always atmospheric, the two chambers U^{21} and U^{23} of Fig. 10 would be unnecessary and might be dispensed with in which case the fulcrum U^{30} for the lever U^2 should be adjusted toward the chamber U^{20}.

The regulation of the supply of fuel to the fuel bed so as to maintain a constant fuel bed resistance to gas flow therethrough is desirable, regardless of how the volume of draft and combustion rate are controlled. It could be had advantageously for example with the apparatus shown in Fig. 10 if the control of the stack damper A^5 and the blower motor C thereof were purely manual, or if the blower C and stack damper A^5 were controlled in automatic response to the steam output from a battery of boilers of which the boiler shown in Fig. 10 is one unit, or were controlled as in other known systems of combustion regulation. Novel features of the fuel feed control employed in the construction shown in Fig. 8 hereof but not claimed herein are claimed in my copending application, Serial No. 583,491 filed August 22, 1922.

While in accordance with the provisions of the statutes I have illustrated and described the best forms of my invention now known to me, it will be apparent to those skilled in the art that many changes may be made in the forms of the apparatus and modes of operation described without departing from the spirit of my invention as set forth in the appended claims.

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

1. The combination with a furnace having a furnace chamber and a fuel bed supporting grate in the furnace chamber and normally open primary and secondary air inlets opening to the furnace chamber at opposite sides of the grate, of means regulating the total volume of draft through the furnace chamber, and means cooperating therewith and responsive to the drop in pressure between points above and below the grate regulating the supply of fuel to the grate as required to maintain an approximately constant fuel bed resistance to gas flow therethrough.

2. The combination in a furnace having a furnace chamber a burning fuel bed therein, and an inlet thereto for primary air, and an inlet thereto for secondary air, of means jointly responsive to the volume of draft and to the resistance of the fuel bed to flow therethrough for maintaining a predetermined ratio between the resistance to flow through the fuel bed and the resistance to flow through said secondary air inlet.

3. Control apparatus comprising in combination a tilting differential pressure gauge element, a winding carried by the tilting gauge element, a cooperative stationary winding and means for creating an electric current flow through said windings exerting an electromagnetic action on the first mentioned winding tending to hold the gauge element in a neutral position, comprising an adjustable current controller, a reciprocating actuator for said current controller, and means moved by the gauge element controlling a mechanical connection between said actuator and current controller whereby the actuator is prevented from operating said controller or is made effective to operate the latter in one direction or the other accordingly as said gauge is in a neutral position or is displaced therefrom in one direction or the other.

4. In control apparatus the combination with an instrument element displaceable in opposite directions from a neutral position, of a relay mechanism comprising a member mounted for reciprocatory movement, a reciprocating actuator, a clutch mechanism carried by said actuator and adapted to connect said actuator and member for movement together, means moved by said instrument element and moved by the latter in a direction transverse to the plane of movement of said member adapted to render said clutch mechanism inoperative to connect said actuator and member for movement in either direction in the neutral position of said instrument element, and adapted to render said clutch mechanism inoperative to connect the actuator and member for movement in one direction or the other when said element is displaced from the neutral position according to the direction of the displacement.

5. In control apparatus the combination with an instrument element displaceable in opposite direction from a neutral position, of a relay mechanism comprising a pivotally mounted member provided with ratchet teeth, a pivotally mounted actuator, means

for oscillating said actuation, a pair of pawls carried by said actuator, one adapted to couple the actuator and member for movement together in one direction and the other adapted to connect the actuator and member for movement in the opposite direction, and a pawl controller moved by the instrument element in a direction transverse to the plane of rotation of said member and adapted to render both or one or the other of said pawls inoperative accordingly as the instrument element is in a neutral position or is displaced therefrom in one direction or the other.

6. In control apparatus the combination with an instrument element displaceable in opposite directions from a neutral position, of a relay mechanism comprising a pivotally mounted member provided with ratchet teeth, a pivotally mounted actuator, means for oscillating it, a pair of pawls carried by said actuator, one adapted to couple the actuator and member for movement together in one direction and the other adapted to couple the actuator and member for movement in the opposite direction, and a pawl controller moved by the gauge element in a direction transverse to the plane of rotation of said member and adapted to make both, or one, or the other of said pawls totally inoperative accordingly as the instrument element is in a neutral position or is displaced therefrom in one direction or the other, and when displaced regulating the operativeness of the pawl not totally inoperative in accordance with the degree of displacement.

7. In a flow balance, the combination with a tilting differential pressure gauge and electromagnetic means adapted to hold said gauge in a neutral position when energized by an electric current of proper strength, of means for adjusting the strength of said energizing current comprising a current controller, a power actuator, and means moved by said gauge when displaced in either direction from a neutral position for mechanically coupling said actuator to said current controller to actuate the latter in the direction tending to vary the energizing current as required to restore said balance to its neutral position.

8. In a boiler furnace system in which solid fuel is burned in a bed on a grate, with primary and secondary air supplies, including provisions for supplying air under pressure at the under side of the grate, the combination of automatic means controlling the supply of air to the under side of the grate and the flow of gases from the furnace in response to the boiler load, a mechanical stoker, and automatic controlling means therefor jointly responsive to the draft loss through the fuel bed and to the boiler load.

Signed at New York in the county of New York and State of New York this fourteenth day of October A. D. 1920.

GEORGE H. GIBSON.