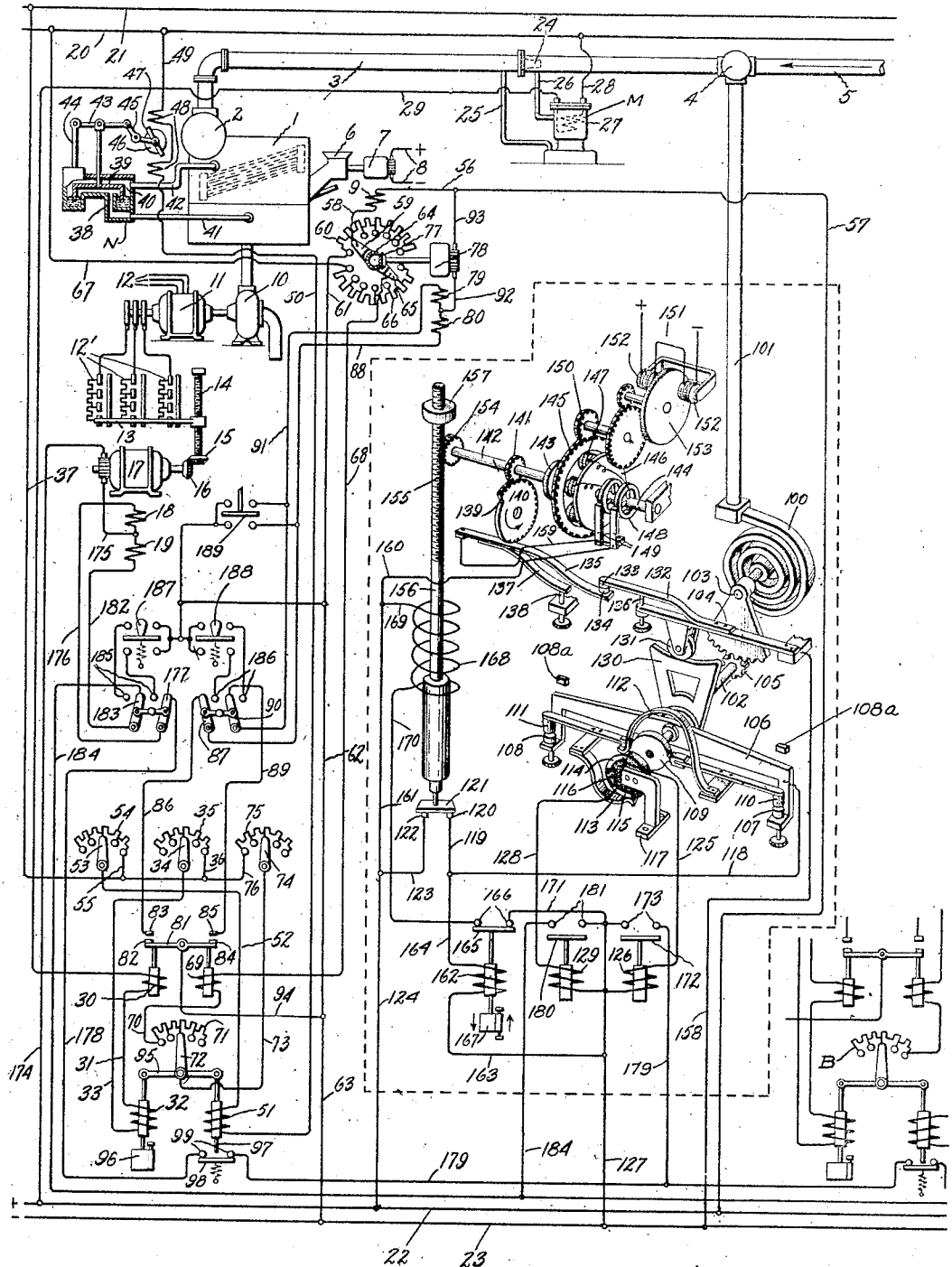
Oct. 1, 1929. F. S. BENNETT ET AL 1,729,701

COMBUSTION CONTROL

Filed Dec. 3, 1926



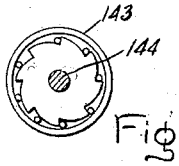


Fig. 2

Fig. 1.

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UNITED STATES PATENT OFFICE

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COMBUSTION CONTROL

Application filed December 3, 1926. Serial No. 152,506.

The present invention relates to combustion control and especially to the control of combustion for a series of boilers supplying vapor to a common header. An application of the invention is in connection with stoker-fired steam boilers and our invention is hereinafter particularly illustrated and described as embodied in a system of control for such boilers. It is to be understood, however, that this is only by way of example and that the invention is not limited necessarily to this particular application.

The object of the invention is to provide an improved system of control which gives good regulation and which automatically takes care of various operating conditions met with, and for a consideration of what we believe to be novel and our invention, attention is directed to the accompanying description and the claims appended thereto.

In the drawing, Fig. 1 is a diagrammatic view of a combustion control system embodying the invention, and Fig. 2 is a detail view of a ratchet mechanism.

Referring to the drawing, 1 indicates a boiler, for example a steam boiler, having a vapor drum 2 from which vapor is conveyed by a conduit 3 to a header 4. Header 4 may be a header common to the several boilers of the plant, 5 indicating a conduit conveying vapor from the vapor drum of another boiler to header 4. 6 indicates a fuel feeding means such as a stoker mechanism for supplying fuel to the furnace of boiler 1, and 7 indicates an electric motor for driving the fuel feeding means. The armature of motor 7 is connected to a suitable source of electrical energy by leads 8 and its field winding 9 is connected into a control circuit as will be explained hereinafter. The fuel supplied to the furnace by the fuel feeding means 6 is proportional to the speed of the motor 7. 10 indicates a blower for supplying air to the furnace. It may be of any suitable type and is driven by an electric motor 11. 12 indicates the leads for the field of motor 11. They may be connected to any suitable source of electrical energy. Connected with the armature of motor 11 is a resistance 12′ adapted to be cut into and out of circuit by an arm 13 which travels up and down a threaded rod 14, the arm cutting the resistance into and out of circuit a notch at a time. On the lower end of rod 14 is a bevel gear wheel 15 which meshes with a similar gear wheel 16 on the end of the shaft of a motor 17. Motor 17 has two field windings 18 and 19. When current flows through one of these field windings, the winding 18 in the present instance, motor 17 is operated in a direction to cut resistance out of the armature circuit of motor 11 thus effecting an increase in the speed of motor 11 while when it flows through the other field winding, i. e., winding 19, motor 17 is operated in a direction to cut resistance into the armature circuit of motor 11 thus effecting a decrease in the speed of motor 11. The volume of air supplied to the furnace by blower 10 is proportional to the speed at which the blower is driven and thus motor 17 forms a regulating means whereby the amount of air supplied to the furnace may be increased and decreased.

20 and 21 indicate lead lines of a suitable source of electrical energy, in the present instance alternating current, and 22 and 23 indicate lead lines of a source of electrical energy which in the present instance is a source of direct current.

Connected to conduit 3 is a flow meter M which effects the production of electric current which bears a definite relation to the rate of flow of vapors in the conduit. In the present instance, it is shown as being a flow meter of the type disclosed in the patent to Thompson and McNairy, No. 1,560,961 patented November 10, 1925, this being a now known type of flow meter. 24 indicates a pressure difference creating device for the flow meter, 25 and 26 the leading and trailing pressure connections, and 27 a winding which in the type of flow meter illustrated, forms the primary winding of a transformer, the secondary winding of which is formed by a mercury ring in the flow meter casing. One terminal of winding 27 is connected by a conductor 28 to line wire 20; the other terminal is connected to line wire 21 by way of conductor 29, solenoid winding 30, conductor 31, solenoid winding 32, conductor 33, rheostat lever 34, resistance 35, conductor 36 and conductor 37.

There is thus in this circuit including solenoid windings 30 and 32 a flow of electric current which is a measure of the flow of vapor through conduit 3. This circuit may be termed the vapor flow or steam flow circuit. Connected to boiler 1 is an electric flow meter N for measuring the amount of air flowing through the furnace. It may be of any suitable type. In the present instance, there is indicated an electric flow meter of the type disclosed in the application of L. W. Thompson, Sr. No. 742,220, filed Oct. 7, 1924. It comprises a casing 38 which contains a movable element which may be in the form of an inverted bell 39, the lower edge of the bell being sealed in a liquid contained in an annular chamber 40. The opposite sides of bell 39 are connected by leading and trailing pressure pipes 41 and 42 to suitable points in the furnace of such character that there will be a drop in pressure between the connections which will bear a definite relation to the rate of flow of gases through the furnace. Bell 39 is pivotally connected to a lever 43 which at one end is pivoted on a fixed post 44. The other end of lever 43 is connected by link 45 to an armature 46 on which is a closed winding 47. In operative relation to armature 46 is a field structure comprising a winding 48. The flow meter mechanism illustrated serves to effect oscillating movement of armature 46 in response to changes in the rate of flow of gas through the boiler and such oscillating movement varies the current in the circuit of field winding 48 an amount proportional to the movement, providing therefore a current which is a measure of the air passing through the furnace. The electric flow meter here illustrated is shown only diagrammatically and by way of example. It is to be taken as typical of any suitable electric flow meter. Furthermore, its mode of operation is not explained in detail because it is now a known type of flow meter which may be purchased on the market. As already stated, the essential thing is that it be an instrument capable of producing a flow of electric current which is a measure of the air flow through the furnace.

One terminal of field winding 48 is connected by a conductor 49 to line wire 20 the other terminal being connected to line wire 21 by conductor 50, solenoid winding 51, conductor 52, rheostat arm 53, resistance 54, conductor 55 and conductor 37. There thus flows in this circuit and in the solenoid winding 51 an electric current which is a measure of the air supplied to the furnace. This circuit may be termed the air circuit.

One terminal of field winding 9 of fuel supply motor 7 is connected by conductors 56 and 57 to line wire 22. The other terminal is connected to line wire 23, by conductor 58, rheostat arm 59, resistance 60, conductor 61, conductor 62, and conductor 63. Rheostat arm 59 is carried by a shaft on which is a bevel gear wheel 64, the arm being suitably insulated fom the shaft. Also carried by this same shaft is an insulated rheostat arm 65 which cooperates with the electrical resistance 66. One terminal of electrical resistance 66 is connected by a conductor 67 to line wire 20, the other terminal being connected to line wire 21 by rheostat arm 65, conductor 68, solenoid winding 69, conductor 70, resistance 71, rheostat arm 72, conductor 73, rheostat arm 74, resistance 75, conductor 76 and conductor 37. Connected to bevel gear wheel 64 is a bevel gear wheel 77 carried by the shaft of an electric motor 78. Motor 78 has two field windings 79 and 80. When a circuit is closed on one of these windings, it operates motor 78 in a direction to move simultaneously rheostat arms 59 and 65 in a direction to increase the amount of the resistance 60 in circuit with motor field 9 and decrease the amount of the resistance 66 in the circuit just traced through solenoid winding 69. On the other hand, when a circuit is closed through the other of these field windings, motor 78 is operated in a direction to decrease the amount of the resistance 60 in circuit with field winding 9 and increase the amount of the resistance 66 in the circuit including solenoid winding 69. Resistance 60 serves to regulate the speed of stoker motor 7. When the amount of resistance 60 in circuit with field winding 9 is increased the field is weakened whereby the speed of the motor is increased to increase the amount of fuel supplied to the furnace. On the other hand, when the amount of resistance 60 in circuit with the field winding 9 is decreased, the field is strengthened thereby decreasing the speed of the fuel feed motor 7. As will be noted, the arrangement of resistance 66 is such that when motor 78 operates in a direction to increase the speed of the fuel feed motor, rheostat arm 65 is moved in a direction to decrease the amount of resistance 66 in circuit and thus increase the current flowing in the circuit of solenoid 69, and when motor 78 moves rheostat arm 59 in a direction to decrease the speed of fuel feed motor 7, then rheostat arm 65 is moved in a direction to increase the amount of resistance 66 in circuit, thereby decreasing the amount of current flowing through solenoid 69. The arrangement is such that the current flow in the circuit including resistance 66 and solenoid 69 bears always a definite relation to the speed of the fuel feed motor 7. The current flowing through solenoid 69 therefore varies with and forms a measure of the fuel being supplied to the furnace. This circuit may be termed the fuel circuit.

The plungers of solenoid windings 30 and 69 are connected to opposite ends of lever 81 suitably pivoted at its central point. On one end of lever 81 is a contact 82 adapted to engage a contact 83 and on the other end of lever 81 is a contact 84 adapted to engage a

contact 85. Contact 83 is connected to one terminal of field winding 80 by conductor 86, switch arm 87 and conductor 88 and contact 85 is connected to one terminal of field winding 79 by conductor 89, switch arm 90, conductor 91. The other terminals of field windings 79 and 80 are connected to line wire 22 by conductor 92, armature of motor 78, conductor 93, and conductor 57. Contacts 82 and 84 are connected to line wire 23 by conductor 94 and conductor 63. The plungers of solenoid windings 32 and 51 are connected to a lever 95 pivoted at its central point and carrying the rheostat arm 72, already referred to. The plunger of solenoid winding 32 is provided with a dash pot 96 to dampen the movement of it. The lower end of the plunger for solenoid winding 51 is provided with a pin 97 adapted upon a certain movement to move a connector 98 away from a pair of contacts 99.

100 indicates a pressure responsive device connected to header 4 by a pipe 101. Its purpose is to effect oscillating movement of a shaft 102 in response to changes in pressure in header 4. Any suitable arrangement for effecting oscillation of shaft 102 in response to and by amounts proportional to changes in pressure in header 4 may be utilized. In the present instance, the pressure responsive device is shown as being in the form of a coiled tubular member having one end fixed to a shaft 103 on which is a gear segment 104 which meshes with a pinion 105 on shaft 102. Upon an increase in pressure in header 4 the coiled tubular member tends to unwind which serves to effect movement of shaft 102 in a clockwise direction as viewed from the left hand end while upon a decrease in pressure in header 4 the result is to effect a movement of shaft 102 in an anti-clockwise direction. Fixed on shaft 102 is a contact bridge 106 having at its ends adjustable contacts 107 and 108. Stops 108A are provided for limiting the movement of bridge 106. Loosely mounted on shaft 102 is a contact bridge 109 having contacts 110 and 111 at its two ends. The central portion of bridge 109 may be formed by insulating material so that the two ends of the bridge are insulated from each other. Carried by the two ends of bridge 109 are spring contact members 112 and 113 which cooperate with metal insets 114 and 115 in an insulating disk 116 carried by a fixed arm 117. When shaft 102 turns in a clockwise direction it moves contact 108 into engagement with contact 111 after which further movement of shaft 102 serves to move bridge 109 along with bridge 106. When this takes place spring contact 113 remains in engagement with metal inset 115 while spring contact 112 is moved away from metal inset 114. When shaft 102 moves in an anti-clockwise direction contact 107 engages contact 110 after which bridge 109 moves along with bridge 106 bringing spring contact 112 into further engagement with inset 114 and moving spring contact 113 off inset 115. The frictional engagement of spring contacts 112 and 113 with the edge of disk 116 is such that bridge 109 remains in any position to which it is moved. Bridge member 106 is connected to line wire 22 by conductor 118, conductor 119, contact 120, connector 121, contact 122, conductor 123 and conductor 124. Contact 110 is connected to line wire 23 by spring contact 112, metal inset 114, conductor 125, solenoid winding 126 and conductor 127; and contact 111 is connected to line wire 23 by spring contact arm 113, metal inset 115, conductor 128, solenoid winding 129 and conductor 127. Thus it will be seen that when the pressure in header 4 increases, effecting a turning movement of shaft 102 in a clockwise direction, a circuit is closed through solenoid 129 and that when the pressure in header 4 decreases effecting a turning movement of shaft 102 in an anti-clockwise direction, a circuit is closed through solenoid winding 126.

Fixed on shaft 102 is a segment 130 having a cam surface on which rests a roller 131. The central portion of the cam surface is flat and the two ends project upwardly. Roller 131 is carried on the underside of an adjustable spring arm 132 having a contact 133 at its free end which engages a contact 134 on the free end of a spring arm 135. Movement of shaft 102 in either direction serves to turn segment 130 beneath roller 131. If shaft 102 is turned to an extent sufficient to bring a cam surface on segment 130 beneath the roller, it serves to lift spring arm 132 upward, thereby tending to move contact 133 away from contact 134. Spring arms 132 and 135 are fixed at their outer ends. 136 is a threaded pin adapted to adjust the position of contact 133. On the underside of spring arm 135 is a leaf spring 137 which engages the end of a threaded pin 138. By adjusting pin 138 in its fixed support the upward spring pressure on spring arm 135 may be adjusted. Spring arm 135 is engaged by a cam surface 139 on a gear segment 140. Meshing with the teeth on gear segment 140 is a pinion 141 carried by a shaft 142. Shaft 142 is connected by a ball and ratchet coupling 143 to a second shaft 144. Coupling 143 may be of usual construction as is illustrated in Fig. 2. Loosely mounted on shaft 144 is a gear wheel 145 and fixed on such shaft is a disk 146 which forms a part of a magnetic clutch comprising windings 147 connected by suitable conductors to slip rings 148 on shaft 144. Bearing on slip ring 148 are contact fingers 149 through which an electric circuit is connected to winding 147.

Meshing with gear wheel 145 is a gear wheel 150 which forms a part of the gear train of a magnetic retarding device indicated generally by reference numerals 151.

The magnetic retarding device may be of any suitable construction, in the present instance being shown as comprising two electric magnets 152 connected to a suitable source of electric current and operating on a disk 153 which rotates between them. On the outer end of shaft 142 is a pinion 154 which meshes with a rack 155 on the upper end of a solenoid plunger 156, the lower end of which carries connector 121. The ball and ratchet connection 143 is arranged so that solenoid plunger 156 may be moved upward freely without turning shaft 144. It can thus move upward independently of the magnetic retarding mechanism 151. On its downward movement however, the ball and ratchet connection becomes operative to connect shaft 142 to shaft 144 thereby connecting retarding mechanism 151 to the solenoid plunger, providing the circuit through the magnetic clutch is closed, so that the magnetic retarding device is connected to shaft 144. On the upper end of rack 155 is a weight 157 which tends to move the rack downward.

The windings 147 of the magnetic clutch are connected into a circuit including contacts 133 and 134 which may be traced as follows:—Line wire 23, conductor 158, spring arm 132, contacts 133 and 134, spring arm 135, conductor 159, contact fingers 149 and windings 147, conductor 160, conductor 161, and conductor 124. As long as contacts 133 and 134 are in engagement this circuit through windings 147 of the magnetic clutch is closed, this being a normal condition of this circuit.

At 162 is a solenoid winding having one terminal connected to line wire 23 by conductor 163 and conductor 127 and the other terminal connected to line wire 22 by conductor 164, contact 120, connector 121, contact 122, conductor 123 and conductor 124. Thus it will be seen that a circuit is closed through solenoid winding 162 whenever connector 121 bridges contacts 120 and 122. The plunger of solenoid 162 carries a connector 165 which bridges a pair of contacts 166 whenever solenoid 162 is energized. 167 is a dashpot for retarding the movement of the plunger for solenoid winding 162 in both its up and down movements. When solenoid winding 162 is energized to bridge contacts 166 a circuit is closed on a solenoid winding 168 which cooperates with plunger 156 and which may be traced as follows:—Line wire 22, conductor 124, conductor 161, conductor 169, solenoid winding 168, conductor 170, contacts 166, conductor 171 and conductor 127 to line wire 23. This serves to energize solenoid winding 168 thereby lifting plunger 156 and moving the connector 121 away from contacts 120 and 122.

Solenoid winding 126 has a plunger to which is connected a bridge member 172 adapted to bridge contacts 173. When these contacts are bridged a circuit is closed through field winding 18 of motor 17 which may be traced as follows:—Line wire 22, conductor 174, armature of motor 17, conductor 175, field winding 18, conductor 176, switch arm 177, conductor 178, contacts 99 and connector 98, conductor 179, contacts 173, and conductor 127 to line wire 23. This serves to operate motor 17 in a direction to increase the speed of motor 11 and hence the amount of air being supplied to the furnace. Solenoid winding 129 has a plunger which carries a connector 180 adapted to bridge a pair of contacts 181. When contacts 181 are bridged by connector 180, a circuit is closed through field winding 19 of motor 17 which may be traced as follows:—Line wire 22, conductor 174, armature of motor 17, conductor 175, field winding 19, conductor 182, switch arm 183, conductor 184, contacts 181 and conductor 127 to line wire 23. When this circuit is closed it serves to operate motor 17 in a direction to decrease the speed of motor 11 and hence the amount of air being supplied to the furnace.

The switches comprising switch arms 177 and 183 and switch arms 87 and 90 are adapted to be moved into engagement with pairs of contacts 185 and 186 respectively. This serves to throw the control of air regulating motor 17 and fuel regulating motor 78, to two manual switches 187 and 188 whereby such control motors may be manually operated as is obvious from an inspection of the circuit connections. At 189 is a manually operated two-way switch connected directly with the field windings 79 and 80 of motor 78. This permits of adjustment of the fuel manually while the automatic control is operative. If desired, a similar switch may be provided for motor 17 also.

The mechanism shown in the dotted square is mechanism appurtenant to all the boilers of the battery of boilers and may be termed the air control mechanism. The mechanism at the left of the drawing is appurtenant to the individual boiler 1 only and operates the fuel and air supplies for it. For each of the other boilers of the battery a similar mechanism is provided and character B at the right hand side of the drawing indicates mechanism for a second boiler. When the air control mechanism operates it effects adjustment of the air supplying means for all the boilers in the same manner. The operation will be described now for the boiler shown, it being understood that the description applies also to the other boilers of the battery connected to the air control mechanism.

Assume that boiler 1 is supplying steam at a certain rate to conduit 3 and that the stoker motor 7 and blower motor 11 are supplying fuel and air in the quantities required to generate the steam flowing through conduit 3 and maintain the desired pressure in the boiler. Under these circumstances, the cur-

rent flow through solenoid winding 30, which current is proportional to the steam flow and the current flow through solenoid winding 69, which current is proportional to the fuel flow, balance each other so that contacts 82 and 84 are out of engagement with contacts 83 and 85 as shown in the drawing. Also, the current flowing through solenoid winding 32 which current is a measure of the steam flow and the current flow through solenoid winding 51 which current is a measure of the air flow, balance each other and hold the contact arm 72 in a certain position.

Referring to the air control mechanism, contacts 133 and 134 are in engagement with each other, which means that the circuit through the magnetic clutch windings 147 is closed and that the magnetic retarding device 151 is connected to shaft 144 and is functioning to retard downward movement of plunger 156. Connector 121 is shown as having just bridged contacts 120 and 122. This has closed the circuit through solenoid winding 162 and operated its plunger so as to bring the connector 165 into engagement with contacts 166. This in turn has closed a circuit through solenoid winding 168 by way of line wire 22, conductor 124, conductor 161, conductor 169, solenoid winding 168, conductor 170, contacts 166 and conductors 171 and 127 to line wire 23. Solenoid 168 is thereupon energized to lift its plunger 156 thus moving connector 121 away from contacts 120 and 122. The upward movement of plunger 156 takes place quickly because of the fact that ratchet 143 permits shafts 132 to turn independently of the magnetic retarding device 151 which is connected to shaft 144. During this movement pinion 141 turns gear wheel 140 so as to move cam 139 in the direction indicated by the arrow. This serves to move the cam away from contact with spring arm 135. However, spring arm 135 is prevented from moving upward by spring arm 132 which lies above it. As soon as connector 121 moves away from contacts 120 and 122, the circuit through solenoid 162 is opened but solenoid 162 is retarded by dashpot 167 so as to maintain the circuit through solenoid 168 closed until plunger 156 reaches the top of its movement. After a predetermined interval of time, connector 165 moves away from contacts 166 thereby opening the circuit on solenoid 168. Plunger 156 starts then to move downward slowly against the action of magnetc brake 151, the arrangemet being such that the bottom of its movement is reached after a predetermined interval of time. When it reaches the lowermost position, connector 121 again bridges contacts 120 and 122 whereupon the cycle of operation just described is repeated again. This operation goes on continuously but if the pressure in conduit 3 remains at the desired value, no regulating action takes place.

Assume now that the demand for steam decreases so that there is a decrease in the rate of steam flow from boiler 2. This decrease in steam flow is recorded immediately on steam flow meter M, the current through the steam flow meter circuit which includes solenoid windings 30 and 32 being reduced to a value corresponding to the decreased rate of steam flow. The pull of solenoid winding 30 on its plunger is thus decreased whereupon solenoid winding 69 moves contact 82 into engagement with contact 83. This closes a circuit on field winding 80 of motor 78 which circuit may be traced as follows:—Line wire 23, conductor 63, conductor 94, lever arm 81, contacts 82 and 83, conductor 86, switch arm 87, conductor 88, field winding 80, conductor 92, armature of motor 78, conductor 93, conductor 57 to line wire 22. Motor 78 is thereupon operated in a direction to move contact arms 59 and 65 in a counter-clockwise direction, thereby decreasing the amount of resistance in the circuit of field winding 9 for motor 7 and increasing the amount of resistance 66 in the fuel circuit which includes the solenoid winding 69 and resistance 71. Decreasing the amount of resistance 60 in the field circuit of motor 7 serves to strengthen the field and thereby decrease the speed of motor 7 and hence the amount of fuel supplied to the furnace. At the same time increasing the amount of resistance 66, in the circuit of solenoid winding 69 serves to decrease the amount of current flowing in this circuit whereupon contact 82 is moved from engagement with contact 83 thus opening the circuit on field winding 80. As a result the rate at which fuel is supplied to the furnace is brought down to a value corresponding to the amount of steam being generated.

The change in current value through solenoid winding 32 unbalances also the pull on lever 95. However, because of the retarding effect of dashpot 96, lever 95 is not moved immediately.

The decrease in steam flow which has been assumed to have taken place will be accompanied by an increase in the steam pressure in header 4. This acts on pressure responsive device 100 tending to uncoil it, thereby moving gear segment 104 toward the right as viewed in the drawing. This turns shaft 102 in a clockwise direction, thereby bringing contact 108 into engagement with contact 111. At the same time, cam 130 moves under roller 131, but if the change in pressure is of small value roller 131 will not be lifted because of the flat central position of the cam. When solenoid plunger 156 now reaches its lowermost position, bringing connector 121 into engagement with contacts 122 and 120, a circuit is closed which may be traced as follows:—Line wire 22, conductor 124, con-

ductor 123, contacts 122 and 120, conductor 119, conductor 118, bridge 106, contact 108, contact 111, spring contact arm 113, contact 115, conductor 128, solenoid winding 129, and conductor 127 to line wire 23. When solenoid winding 129 is energized connector 180 is brought into engagement with contacts 181, thereby closing a circuit on field winding 19 which may be traced as follows:—Line wire 22, conductor 174, armature of motor 17, conductor 175, field winding 19, conductor 182, switch arm 183, conductor 184, contacts 181, and conductor 127 to line wire 23. This operates motor 17 in a direction to increase the amount of resistance in the armature circuit of motor 11, thereby decreasing its speed which results in decreasing the speed of blower 10 and hence decreasing the amount of air supplied to the furnace.

When the air flow and steam flow varied, as just explained, there will not be effected, under ordinary operating conditions, an unbalancing of the pull of the two solenoid windings 32 and 51 on lever arm 95. When the steam flow decreased it was followed immediately by a decrease in the flow of current in the circuit of flow meter M which includes solenoid winding 32. This has a tendency to unbalance the pull of solenoid windings 32 and 51 on lever 95, tending to turn contact arm 72 in a direction to increase the amount of resistance 71 in the fuel circuit which includes solenoid winding 69. However, retarding device 96 serves to delay this movement and since the decrease in steam flow is followed fairly promptly by a decrease in air flow, then the balance of solenoid windings 51 and 32 will not be destroyed to such an extent as to effect a change in the amount of resistance 71 in circuit.

When connector 121 bridges contacts 120 and 122 to effect adjustment of the air supply to the furnace, as just explained, it at the same time again closes the circuit on solenoid winding 162 whereby causing connector 165 to bridge contacts 166 and again close the circuit on solenoid winding 168, as explained above. Dashpot 167 serves to retard the upward movement of connector 165 so that the circuit through solenoid winding 168 is not closed until after a predetermined interval of time, such time interval being sufficient to permit of or effect the desired adjustment of the air supply. For example, the interval may be of a length such as to effect an adjustment of resistance 12′ one notch or one unit.

In other words, when connector 121 bridges contacts 120 and 122 at a time when contact 108 is in engagement with contact 111, two circuits are closed, one through solenoid winding 129 and the other through solenoid winding 162. In the case of solenoid winding 129 its plunger is moved to bring connector 180 into contact immediately with contacts 181 thus effecting closing of the circuit of motor 17, while in the case of solenoid winding 162 its plunger is moved slowly under the retarding action of device 167 so as to give motor 17 time to adjust resistance 12′ before it causes connector 165 to bridge contacts 166 to again close the circuit on solenoid winding 168.

As soon as the circuit on solenoid winding 168 is completed, plunger 156 is raised, thereby moving connector 121 away from contacts 120 and 122. This opens the circuit on solenoid winding 129 whereupon connector 180 moves away from contacts 181 thus opening the circuit on air-adjusting motor 17. Air adjustments of only a limited amount, therefore, take place before the circuit on solenoid winding 129 is opened, permitting connector 180 to move away from contacts 181.

After plunger 156 reaches the top of its movement, it again begins to descend under the action of the retarding device 151 and after a certain predetermined interval of time connector 121 again bridges contacts 120 and 122. If now contact 108 is in engagement with contact 111, which indicates that the steam pressure is still above normal and is either increasing or at least has not started to decrease, the circuit through solenoid winding 129 will be completed again, effecting a second adjustment of the air by a predetermined amount, as already explained. If, however, during the period that plunger 156 is descending, the steam pressure has started to return toward normal, thereby moving contact 108 away from contact 111, then an adjustment of the air will not take place.

With the above-described arrangement, therefore, it will be seen that air adjustments are effected in small steps at predetermined intervals of time, the adjustments continuing until the tendency of the pressure to increase has been overcome and the pressure has started to return toward normal.

In connection with the operation just described, it was assumed that the increase in steam pressure in header 4 was of comparatively small value so that roller 131 remained in engagement with the flat portion of the cam on segment 130. Assume now that the increase in pressure is comparatively large so that the turning movement of shaft 102 is sufficient to bring the rising portion of the cam surface on segment 130 under roller 131 so as to raise contact arm 132 and move contact 133 away from contact 134. When contacts 133 and 134 are separated, the circuit through the windings 147 of the magnetic clutch is opened so that plunger 156 is free to move independently of the magnetic retarding device 151. As a result therefore, with a comparatively large increase in steam pressure, the retarding device is disconnected from plunger 156 and the plunger immediately drops, bringing connector 121 into

engagement with contacts 120 and 122. There is thus effected an adjustment of the air in the manner already described. Also in the manner already described, plunger 156 will be raised again and if contacts 133 and contacts 134 are still separated, then it will drop immediately again to effect a second adjustment of the air providing contact 108 is still in engagement with contact 111. It follows, therefore, that as long as contacts 133 and 134 are out of engagement with each other, and contacts 108 and 111 remain in engagement with each other, a series of rapid adjustments of the air will take place. However, as soon as the pressure starts to return toward normal value, contact 108 will be moved away from contact 111 whereupon no further air adjustments will occur.

In this connection, it is pointed out that a boiler has considerable heat storage capacity which tends to retard its response to air and fuel changes so that while a change in air flow may be followed promptly by a change in the rate at which steam is being generated, still the change may not be rapid enough to effect promptly a restoration of the pressure to normal value. And particularly is this true where the pressure change is of comparatively large value. As a result, in case of a comparatively large increase in steam pressure, the change in the air supply will not begin to effect an actual decrease in the steam pressure, until possibly several successive adjustments have taken place. However, as soon as the pressure begins to decrease, then because of the several successive adjustments which have occurred, the pressure will continue to decrease until it reaches its normal value again. The arrangement and adjustment of the mechanism is so correlated with the lag of the boiler that for any departure of the steam pressure from normal value the adjustments which occur will be such ordinarily as to bring the pressure back to normal once the point is reached at which the pressure begins to return toward normal value.

In connection with the operation of the device, the cam surface 139 which acts on arm 135, comes into action to determine the rapidity with which successive adjustments of the air will be effected. It will be seen that when plunger 156 is raised, cam 139 is moved away from the arm 135 while when the plunger is lowered the cam is moved toward arm 135. This movement of the cam serves to permit contact arm 135 and contact 134 to move toward contact 133 and to be moved away from contacts 133. As solenoid plunger 156 moves downward, therefore, cam 139 tends to come into action to move contact 134 way from contact 133 and whenever it moves ontact 134 away from contact 133, magnetic retarding device 151 is put out of action due to the circuit on windings 147 being opened which serves to disconnect shaft 142 from shaft 144. If, for example, cam 139 moves contact 134 away from contact 133 when plunger 156 has descended, one half of its total movement, then it will be seen that the magnetic retarding device will be in action during the first half of the movement of the plunger and will not be in action during the second half. As a result, the plunger will move from its uppermost position to its lowermost position in one-half the time required when the retarding device is in action during the entire downward movement. The instant when cam 139 comes into action to separate contacts 134 and 133 depends upon how much the cam surface on segment 130 has lifted contact 133. If it has been lifted comparatively high, the result of a comparatively large increase in pressure in header 4, then the retarding device will be in action practically not at all, plunger 156 falling immediately to bring contact 121 into engagement with contacts 120 and 122. On the other hand, as first explained, if the increase in pressure is small, then the retarding device 151 is in action during the entire descending movement of plunger 156. Between these two extremes, there may be any degree of retarding action, depending upon the relative positions of contacts 133 and 134 with relation to cam 139.

Thus it will be seen that the interval between successive adjustments of the air depends upon the amount of the departure of the pressure in header 4 from normal value. If the departure is comparatively small as first described, then the retarding device is in action all the time and the interval between successive adjustments of the air is comparatively long. This serves to give the boiler time to respond to the first adjustment before a second adjustment occurs. If the departure is comparatively large as last explained, then the retarding device is in action not at all and the successive adjustments follow each other comparatively quickly. This serves to vary the supply of air more rapidly to correct for the large departure of the pressure from normal. For values of the departure of the pressure in header 4 from normal between these two extremes, there will be intervals between successive adjustments of a duration depending upon the amount of the departure, that is, on the amount which cam segment 130 has lifted contact 133.

In connection with the foregoing it will be seen that if at first there is a comparatively small departure of the pressure from normal but that in spite of the first adjustment or adjustments, the departure continues to increase in value then the time between successive adjustments will decrease and will continue to decrease until such time as the pressure starts back toward normal value.

When due to adjustments which have taken

place, the steam pressure starts to return toward normal, value, that is, starts to decrease, shaft 102 is turned in a counter-clockwise direction and contact 108 is moved away from contact 111, thereby opening the circuit on solenoid winding 129. When this occurs, contact 107 will be moved into engagement with contact 110 but a circuit through spring arm 112 and solenoid 126 will not be closed because of the fact that the spring arm was moved off inset 114 and onto the insulated portion of disk 116 when bridge 109 turned in a clockwise direction during the former operation of the device.

When the pressure has returned to normal, the parts will stand in a position wherein contact 107 is in engagement with contact 110 but wherein contact arm 112 is out of engagement with inset 114.

Assume now that the demand for steam increases so that there is an increase in the rate of steam flow from boiler 2. This increase in steam flow is recorded immediately on steam flow meter M, the current through the steam flow meter circuit which includes solenoid windings 30 and 32 being increased to a value corresponding to the increased rate of steam flow. The pull of solenoid winding 30 on its plunger is thus increased whereupon contact 84 is moved into engagement with contact 85. This serves to close the circuit through field winding 79 of motor 78, operating it in a direction to turn contact arms 59 and 65 in a clockwise direction. This serves to increase the amount of resistance 60 in the field winding 9 of the motor 7, thereby decreasing the field strength and effecting an increase in the speed of motor 7 and hence an increase in the amount of fuel being fed to the furnace. At the same time arm 65 moves in a direction to decrease the amount of resistance 66 in the circuit including solenoid winding 69 thereby effecting an increase in the full of solenoid 69 on its plunger and a movement of contact 84 away from contact 85. The fuel flow and steam flow are thus again brought to the desired relation relatively to each other.

The increase in steam flow which has been assumed to have taken place will be accompanied by a decrease in the steam pressure in header 4, whereupon pressure responsive device 100 will effect turning movement of shaft 102 in a counter-clockwise direction. This will effect turning movement of bridges 106 and 109, contacts 107 and 110 being in engagement and as soon as contact arm 112 engages contact inset 114, a circuit will be closed through solenoid winding 126, whenever connector 121 again bridges contacts 120 and 122. This operation is similar to and will be understood from that already described in connection with solenoid winding 129. When the circuit is closed on winding 126, connector 172 thereupon bridges contacts 173 and a circuit is closed on field winding 18 of motor 17 which may be traced as follows:—Line wire 22, conductor 174, armature of motor 17, field winding 18, conductor 176, contact arm 177, conductor 178, contacts 99, conductor 179, contacts 173, and conductor 127 to line wire 23. This effects operation of motor 17 in a direction to decrease the amount of resistance 12 in the armature circuit of motor 11, thereby effecting an increase in the speed of the motor and therefore in the amount of air supplied to the furnace.

With the arrangement described, it will be seen that the rate of fuel flow to the furnace is balanced directly against the rate of steam flow from the boiler so that there will be supplied to the furnace always an amount of fuel sufficient to generate the steam flowing from the boiler. Also it will be seen that air is supplied to the furnace to effect increase or decrease in the rate of combustion so as to maintain the steam pressure constant. In this connection, it will be understood that when a boiler is supplying steam to a steam consumption device, the uniformity of the pressure at which the steam is supplied to the consumption device is an indication of how nearly the heat supplied by the furnace equals the heat required to generate the steam necessary to meet the requirements of the consumption device. A falling steam pressure means that insufficient heat is being supplied by the furnace to generate the required amount of steam, a rising pressure means that too much heat is being supplied to generate the required amount of steam, while a constant steam pressure means that the heat input is correct for generating the required amount of steam. Adjustment of the air supply irrespective of any immediate change in fuel supply serves promptly to vary the rate of combustion in the furnace. By adjusting the air supply, therefore, in accordance with the steam pressure so as to maintain the steam pressure constant and at the same time adjusting the fuel supply to conform always to the amount of steam actually being generated, efficient operation of the boiler is obtained.

In addition to the foregoing, we provide also an arrangement for adjusting the rate of fuel supply so as to maintain a desired relation between the rate of steam flow and the rate of fuel supply and the rate of steam flow and the rate of air supply, the arrangement serving also to maintain a fuel bed of the desired thickness and to prevent at any time the air supply being increased at too rapid a rate.

If the air flow is too great compared to the amount of steam being generated, solenoid winding 51 will overbalance the pull of solenoid winding 32 on lever 95 and turn lever 95 in a direction to move contact arm 72 toward the right, thereby increasing the amount of resistance 71 in the fuel circuit which in-

cludes solenoid winding 69. This serves to effect a decrease in the amount of current flowing in the fuel circuit and hence a decrease in the pull of solenoid winding 69 on the right hand end of lever 81. As a result contact 84 is brought into engagement with contact 85 to effect operation of motor 78 in a direction to increase the speed of fuel supply motor 7 and adjust resistance arm 65 to bring it to a position such that the current through solenoid winding 69 will be of a value such that the pull of solenoid winding 69 will again balance the pull of solenoid winding 30, contact 84 being then moved from engagement with contacts 85. This gives a balanced condition again but with a different ratio of fuel flow to air flow. On the other hand, if the air flow is too small compared to the amount of steam being generated, then solenoid winding 32 will overbalance the pull of solenoid winding 51 on lever 95 thereby turning lever 72 toward the left and decreasing the amount of resistance 71 in the fuel circuit whereupon the rate of fuel supply is decreased in a manner similar to that just described.

Assume that the boiler is operating and that there occurs an increase in demand for steam of substantial amount, so that the boiler cannot supply it without first building up both the fuel supply and the air supply to a considerable extent. Under these circumstances, the steam pressure may be decreased by a considerable amount whereupon there will be a tendency to effect rapid, successive adjustments of the air. On the other hand, the fuel supply to the furnace will be increased only as fast as the rate of steam flow increases. In the operation of a stoker fired furnace, there is a certain amount of lag in building up the fire, it being impossible to increase the fuel and air and obtain immediate response from the furnace and boiler. Under these circumstances, the arrangement comprising solenoids 32 and 51 serves to temporarily increase the fuel supply at a rate faster than that indicated by the rate of steam flow, the result being that the fuel will be supplied faster than it is being burned which serves to thicken the fuel bed, this being a desirable thing upon increase in boiler load. This result is accomplished due to the fact that the increased air flow causes solenoid winding 51 to overbalance solenoid winding 32, thereby moving contact arm 72 toward the right to increase the amount of resistance 71 in the fuel circuit. This results in decreasing the current in the fuel circuit, thereby weakening the pull of solenoid 69 and permitting solenoid 30 to hold contact 84 in engagement with contact 85 when otherwise the steam flow would not be sufficient to effect this result. Fuel is thus supplied to the furnace temporarily at a rate greater than that necessary for generating the steam flowing from the boiler so that the fuel bed gradually thickens. If, as the result of successive adjustments of the steam pressure responsive mechanism, the air flow increases, to a value too great as compared with the steam flow, then pin 97 will engage connector 98 and move it away from contacts 99. This opens the circuit of field winding 18 and motor 17 and prevents further adjustment of rheostat 12' for motor 11 until the fuel supply and the steam flow have had an opportunity to build up. By this arrangement, the air supply is prevented from building up at a rate so rapid that it might blow the fire full of holes.

In case the demand for steam decreases by a considerable amount, which means that the rate of fuel supply and the rate of air supply should be substantially decreased, then under these circumstances, when several successive adjustments of the air have taken place, solenoid winding 32 will overcome the pull on solenoid winding 51, thereby moving contact arm 72 toward the left. This serves to reduce the amount of resistance in the fuel circuit, thereby strengthening the current in the fuel circuit and moving contact 82 into engagement with contact 83, thereby decreasing the rate at which fuel is being supplied to the furnaces; or, on the other hand, if contact 82 is in engagement with contact 83 already as a result of a decrease in the steam flow, then the contact 82 will be held in engagement with contact 83 for a period longer than would be the case otherwise, so as to continue to reduce the rate of fuel supply even after the steam flow has reached a value corresponding to the fuel supply for such steam value. This serves to temporarily supply fuel to the furnace at a rate slower than it is being burned which results in a decrease of the thickness of the fuel bed.

From a consideration of the foregoing, it will be seen that the mechanism operates to maintain automatically the desired fuel bed thickness.

Assume that the boiler is operating at a certain load, that everything is in balance, and that the quality of the fuel supplied to the furnace improves. This will cause an increase in the steam pressure in conduit 4 whereupon the pressure responsive device 100 will operate to decrease the amount of air supplied to the furnace. Due to the decreased amount of air, solenoids 32 and 51 will become unbalanced and contact arm 72 will be moved to the left thereby cutting some of the resistance 71 out of the fuel circuit. In the manner already described, this will effect a decrease in the amount of fuel supplied to the furnace to bring about a new fuel-air ratio of a value economical for the new grade of fuel. On the other hand, if the quality of the fuel gets poorer then in a corresponding manner the supply of fuel will be increased and the supply of air decreased to again bring about a new fuel-air ratio which

will effect burning of the poorer quality of fuel economically.

If the fuel gets larger in size, the fuel bed resistance decreases whereupon more air will flow through it. This increase in air flow will be registered on air flow meter N whereupon solenoids 32 and 51 will become unbalanced in a direction to effect temporarily an increase in the rate of fuel supply so as to thicken the fuel bed and bring its resistance to air flow to the desired value. Similarly, if the fuel bed resistance increases, the air flow will be decreased which will result in temporarily decreasing the rate of fuel supply until the fuel bed is thinned so that the desired amount of air will flow through it.

If holes occur in the fuel bed, air flow meter N will register too much air relatively to the steam flow whereupon the rate of fuel supply will be increased temporarily until the holes are filled up.

Should the air flow increase too much relatively to the steam flow, then finger 97 will move connector 98 away from contacts 99, thus opening the circuit through conductor 179 and preventing any increase in the air supply if, due to the holes in the fire bed there should occur a drop in the steam pressure.

Soot or slag on the outside of the boiler tubes will cause air flow meter N to register more air than it would if the boiler tubes were clean even though no more air is actually flowing. This is due to the higher resistance of the boiler tubes to the air passing over them which causes a greater pressure drop across the tubes. As a result solenoid windings 32 and 51 will become unbalanced in a direction to increase the rate of fuel supply relatively to the rate of air supply to make up for the slightly lower boiler efficiency due to the dirty boiler.

Scale on the inside of the boiler means that for a given quantity of air the steam will not be generated that should be which means that the fuel flow must be increased somewhat relatively to the steam flow. This result is brought about by the fact that the decreased steam flow relatively to the air flow results in an unbalance of solenoid windings 32 and 51, the pull of solenoid winding 32 being slightly weakened, so that solenoid winding 51 pulls contact arm 72 toward the right thus cutting more of resistance 71 into circuit and so increasing the rate of fuel supply in the manner already explained.

Any change in operating condition of the boiler other than demand for steam which causes a change in steam pressure acts through device 100 to effect a change in the air flow thereby unbalancing solenoid windings 32 and 51, thus effecting a corresponding adjustment in the rate of fuel flow.

From a consideration of the foregoing, it will be seen that the balanced relay arrangement comprising solenoid windings 32 and 51 operates to maintain always an economical ratio between the fuel and air under varying operating conditions. For this reason, the arrangement may be termed an efficiency device in that it functions to maintain always efficient operating conditions. The adjustments of the fuel required due to changes which effect an unbalance of solenoid windings 32 and 51 are not large and under ordinary conditions will not amount to more than about 10%. Resistance 71, therefore, is chosen of a value such that the total changes in fuel flow which may be effected by it is of the order of 10%. On the other hand, resistances 60 and 66 must be of values such that they may effect change in fuel flow over the entire range of operation of the furnace.

In accordance with the provisions of the patent statute, we have described the principle of operation of our invention, together with the apparatus which we now consider to represent the best embodiment thereof, but we desire to have it understood that the apparatus shown is only illustrative and that the invention may be carried out by other means.

What we claim as new and desire to secure by Letters Patent of the United States, is—

1. The combination with a boiler, of means for supplying combustible thereto, means responsive to departure of an operating condition of the boiler from normal value for effecting successive adjustments of the combustible supplying means, and means whereby the length of time between successive adjustments is governed by the extent of the departure of the operating condition from its normal value.

2. The combination with a boiler, of means for supplying combustible thereto, means responsive to departure of an operating condition of the boiler from normal value for effecting successive adjustments of the combustible supplying means, and means whereby the time between successive adjustments becomes shorter as the operating condition departs further from its normal value.

3. The combination with a boiler, of means for supplying combustible thereto, means responsive to departure of an operating condition of the boiler from normal value for effecting successive unit adjustments of the combustible supplying means, and means controlled by the amount which the operating condition has departed from normal for determining the time between successive adjustments.

4. The combination with a boiler, of means for supplying combustible thereto, means including an electric circuit and a circuit closer for effecting adjustments of the combustible supplying means, means operable upon the departure of an operating condition of the boiler from normal value for rendering said circuit closer operable to effect

successive unit adjustments of the combustible supplying means, and means controlled by the amount which the operating condition has departed from normal for determining the time between successive adjustments.

5. The combination with a boiler, of means for supplying combustible thereto, means including an electric circuit for effecting adjustments of the combustible supplying means, a circuit closer in said circuit which is closed upon a departure of an operating condition of the boiler from normal value, a second circuit closer in said circuit which is closed at successive intervals, and means controlled by the amount which the operating condition has departed from normal for determining the length of the successive intervals.

6. The combination with a boiler, of means for supplying combustible thereto, means responsive to departure of an operating condition of the boiler from normal value for effecting successive adjustments of the combustible supplying means, and means for progressively decreasing the interval between successive adjustments as the value of the operating condition departs further from normal value.

7. The combination with a boiler, of means for supplying combustible thereto, motor means for adjusting the combustible supplying means, an electric circuit which when closed effects movement of said motor means, a circuit closer means in said circuit which is closed upon the departure of an operating condition of the boiler from normal value, a second circuit closer means in said circuit, and means for effecting successive closures of said second circuit closer means.

8. The combination with a boiler, of means for supplying combustible thereto, motor means for adjusting the combustible supplying means, an electric circuit which when closed effects movement of said motor means, a circuit closer means in said circuit which is closed upon the departure of an operating condition of the boiler from normal value, a second circuit closer means in said circuit, means for effecting successive closures of said second circuit closer means, and means responsive to the extent of the departure of the operating condition of the boiler from normal value for determining the period of time between successive closures of the second circuit closing means.

9. The combination with a boiler, of means for supplying combustible thereto, motor means for adjusting the combustible supplying means, an electric circuit which when closed effects movement of said motor means, a circuit closer means in said circuit which is closed upon the departure of an operating condition of the boiler from normal value, a second circuit closer means in said circuit, means for effecting successive closures of said second circuit closer means, retarding means for delaying the closing of said second circuit closing means, and means responsive to the extent of the departure of the operating condition of the boiler from normal value for determining the period during which said retarding means is in operation.

10. The combination with a boiler, of means for supplying combustible thereto, motor means for adjusting the combustible supplying means, an electric circuit which when closed effects movement of said motor means, a circuit closer means in said circuit which is closed upon the departure of an operating condition of the boiler from normal value, a second circuit closer means in said circuit, means for effecting successive closures of said second circuit closer means, retarding means for delaying the closing of said second circuit closing means, and means for progressively increasing the period during which said retarding means is in operation as the operating condition departs further from normal value.

11. The combination with a plurality of boilers operating in parallel, of means for supplying combustible to each boiler, means responsive to an operating condition appurtenant to all the boilers for effecting successive adjustments of all the combustible supplying means, and means whereby the length of time between successive adjustments is governed by the extent of the departure of the operating condition from its normal value.

12. The combination with a boiler, of means for supplying combustible thereto, means rsponsive to departure of an operating condition of the boiler from normal value for effecting successive substantially equal unit adjustments of said combustible supplying means, and means whereby said successive unit adjustments are caused to occur at intervals of predetermined duration.

13. The combination with a plurality of boilers operating in parallel, of means for supplying combustible to each boiler, means responsive to an operating condition appurtenant to all the boilers for effecting successive unit adjustments of all the combustible supplying means, and means whereby said successive unit adjustments are caused to occur at intervals of predetermined duration.

14. The combination with a boiler, of means for supplying air and fuel thereto, means comprising an air circuit in which is effected a flow of current proportional to the air supply, means comprising a fuel circuit in which is effected a flow of current proportional to the fuel supply, means comprising a vapor circuit in which is effected a flow of current proportional to the rate of flow of vapor from the boiler, and means actuated by the currents in said circuits for adjusting the fuel supplying means to maintain a pre-

determined relation between the current flow in the air current and the vapor circuit and in the fuel current and the vapor circuit.

15. The combination with a boiler, of means for supplying air and fuel thereto, means comprising an air circuit in which is effected a flow of current proportional to the air supply, means comprising a fuel circuit in which is effected a flow of current proportional to the fuel supply, means comprising a vapor circuit in which is effected a flow of current proportional to the rate of flow of vapor from the boiler, means responsive to departure of an operating condition of the boiler from normal value for effecting adjustment of the air supplying means, and means actuated by the currents in said circuits for adjusting the fuel supplying means to maintain a predetermined relation between the current flow in the fuel circuit and the current flow in the vapor circuit.

16. The combination with a boiler, of means for supplying air and fuel thereto, means comprising an air circuit in which is effected a flow of current proportional to the air supply, means comprising a fuel circuit in which is effected a flow of current proportional to the fuel supply, means comprising a vapor circuit in which is effected a flow of current proportional to the rate of flow of vapor from the boiler, means responsive to departure of an operating condition of the boiler from normal value for effecting successive unit adjustments of the air supplying means, and means actuated by the flow of currents in said circuits for adjusting the fuel supply in accordance with the flow of vapor from the boiler.

17. The combination with a boiler, of means for supplying air and fuel thereto, means comprising an air circuit in which is effected a flow of current proportional to the air supply, means comprising a fuel circuit in which is effected a flow of current proportional to the fuel supply, means comprising a vapor circuit in which is effected a flow of current proportional to the rate of flow of vapor from the boiler, means responsive to departure of an operating condition of the boiler from normal value for effecting successive unit adjustments of the air supplying means, means whereby the length of time between successive adjustments is governed by the extent the departure of the operating condition from its normal value, and means actuated by the flow of currents in said circuits for adjusting the fuel supply in accordance with the flow of vapor from the boiler.

18. The combination with a plurality of boilers operating in parallel, of means for supplying fuel and air to each boiler, means responsive to an operating condition appurtenant to all the boilers for effecting successive unit adjustments of all the air supplying means, means whereby said successive unit adjustments are caused to occur at intervals of predetermined duration, and means for effecting adjustment of the fuel supplied to each boiler in accordance with the flow of vapor from such boiler.

19. The combination with a plurality of boilers operating in parallel, of means for supplying fuel and air to each boiler, means responsive to an operating condition appurtenant to all the boilers for effecting successive unit adjustments of all the air supplying means, means whereby the length of time between successive unit adjustments is goverened by the extent of the departure of the operating condition from its normal value, and means for effecting adjustments of the fuel supplied to each boiler in accordance with the flow of vapor from such boiler.

20. The combination with a plurality of boilers operating in parallel, of means for supplying fuel and air to each boiler, means responsive to an operating condition appurtenant to all the boilers for effecting successive unit adjustments of all the air supplying means, means whereby said successive unit adjustments are caused to occur at intervals of predetermined duration, and means for maintaining for each boiler a desired ratio between the fuel supplied to and the vapor flowing from each individual boiler.

21. The combination with a boiler having fuel supplying means, air supplying means, and means responsive to an operating condition of the boiler for controlling automatically said supplying means, of means forming a part of said automatic controlling means for effecting increase and decrease in the fuel bed thickness with increase and decrease in the load on the boiler.

22. The combination with a boiler having fuel supplying means and air supplying means, of means responsive to the pressure in the boiler for adjusting the air supplying means only, and means responsive to resulting changes in the rate of flow of vapor from the boiler for adjusting the fuel supplying means.

23. The combination with a boiler having fuel supplying means and air supplying means, of means responsive to an operating condition of the boiler for adjusting the air supplying means, means responsive to the rate of flow of vapor from the boiler for adjusting the fuel supplying means, and means for preventing the ratio of air flow to vapor flow from exceeding a predetermined value.

24. The combination with a boiler having fuel supplying means and air supplying means, of means responsive to an operating condition of the boiler for adjusting the air supplying means, means responsive to the rate of flow of vapor from the boiler for adjusting the fuel supplying means, and means for effecting a temporary increase or decrease in the rate of fuel supply to the boiler when

the ratio of vapor flow to air flow passes certain limits.

25. The combination with a battery of boilers each having a fuel supplying means and an air supplying means, of means responsive to an operating condition appurtenant to all the boilers for adjusting the air supplying means of all the boilers, and means responsive to the rate of flow of generated vapor from each individual boiler for adjusting its fuel supplying means.

26. The combination with a battery of boilers each having a fuel supplying means and an air supplying means, of means responsive to an operating condition appurtenant to all the boilers for adjusting the air supplying means of all the boilers, means responsive to the rate of flow of vapor from each individual boiler for adjusting its fuel supplying means, and means associated with each boiler for preventing the ratio of air flow to vapor flow from exceeding a predetermined value.

27. The combination with a boiler, of means for regulating the rate of air supply to the boiler in accordance with the pressure of the vapor flowing from the boiler and means for regulating the rate of fuel supply to the boiler in accordance with the rate of flow of vapor from the boiler.

28. The method of automatically regulating the supply of fuel and air to a boiler, which comprises regulating the air supply only in response to changes in pressure of the vapor flowing from the boiler to maintain such pressure constant, and regulating the fuel supply to correspond to the rate of flow of vapor from the boiler.

29. The method of automatically regulating the supply of fuel and air to a boiler, which comprises regulating the air supply only in response to changes in pressure of the vapor flowing from the boiler to maintain such pressure constant, regulating the fuel supply to correspond to the rate of flow of vapor from the boiler, and further regulating the fuel supply in accordance with the ratio of vapor flow to air flow.

30. The method of operating a boiler which comprises adjusting the fuel supply in accordance with the rate of vapor flow from the boiler, and adjusting the air supply solely in accordance with the vapor pressure.

In witness whereof, we have hereunto set our hands this 2nd day of December, 1926.

FRANK S. BENNETT.
LEONARD R. BIGGS.