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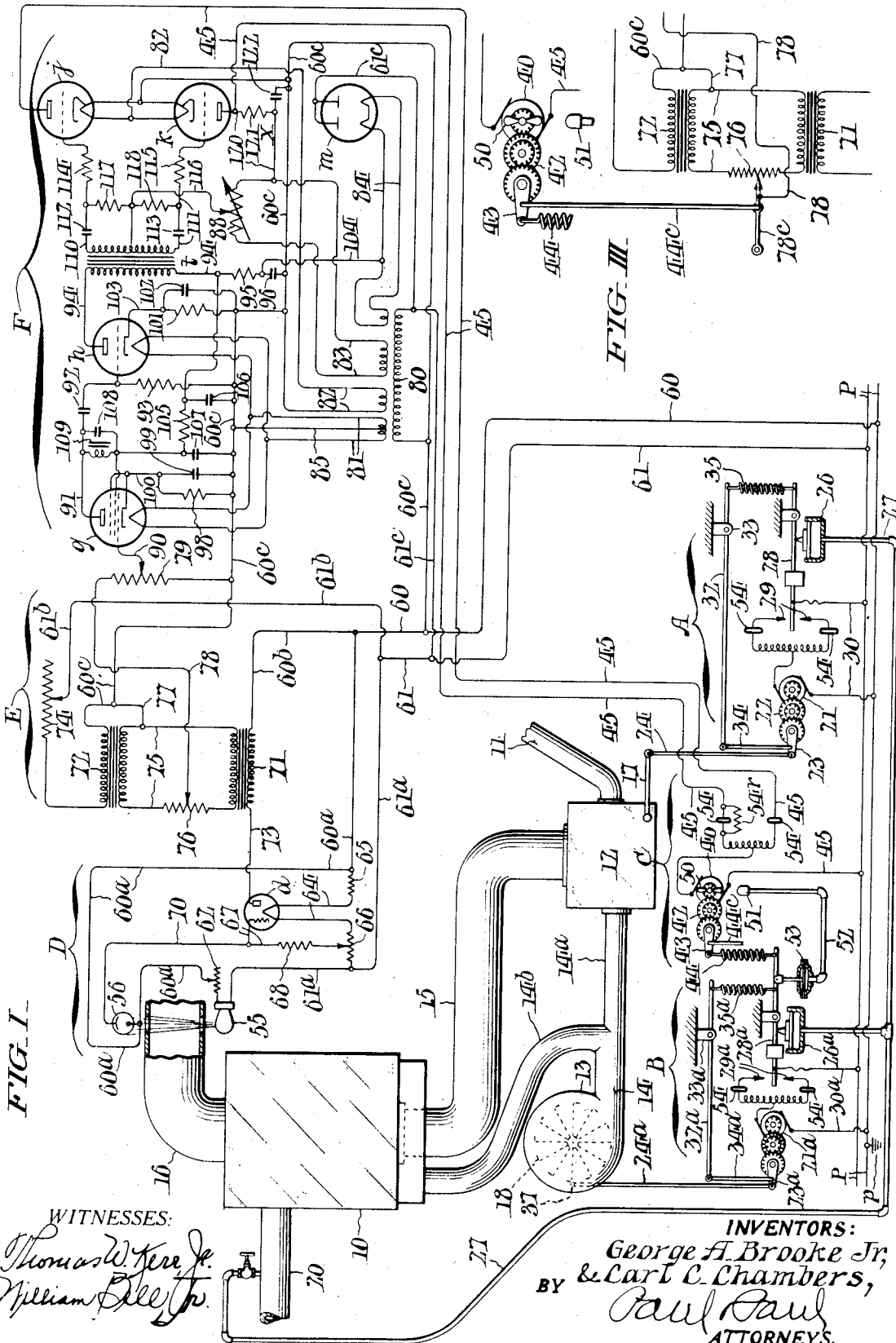
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COMBUSTION CONTROL

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COMBUSTION CONTROL

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This invention relates to combustion control, and is especially advantageous for furnaces using fluid fuel or the like, such as gas, oil, or powdered coal. The invention permits of controlling combustion fluid (whether fuel or air, or both) according to the quality or character of the furnace gases, in a reliable, accurate, and satisfactory manner, and without continual overaction and reaction of the control, such as is commonly termed "hunting." The control can be effected electrically, substantially without any moving parts except those directly involved in moving the means which directly control the combustion fluid supply. I have hereinafter explained an embodiment of the invention as applied to control the supply of air, though it may if desired be applied to control the supply of fuel.

It has long been understood that the quality of character of the stack or flue gases from a fire in a furnace varies according to the conditions of combustion in the furnace. If the supply of air or oxygen for combustion of the fuel is deficient, the furnace gases contain an unduly large proportion of products resulting from incomplete combustion of the fuel, and even a certain proportion of unburned fuel, while their proportion of the products of complete combustion is unduly low. In the case of carbonaceous fuels such as wood and the like, coal, oil, natural gas or producer gas—i. e., practically all commercial fuels—the furnace gases from complete combustion are rich in CO_2 (carbon dioxide), contain almost no CO (carbon monoxide), contain very little free oxygen, and are nearly colorless; while the gases from incomplete combustion due to deficiency of air and oxygen contain less CO_2 , more CO , and a proportion of unburned carbon particles, which characteristically darken the smoke more or less, according to the degree of air deficiency in the fire. In cases of excessive air supply, the furnace gases are likewise relatively deficient in CO_2 because of the presence of more free oxygen in them, but are white or nearly colorless as they issue from the stack into the atmosphere.

For most commercial purposes, complete combustion without excess of air is the desirable condition; although for some industrial purposes, combustion with a deficiency or an excess of air may be desired. In all cases, however, the desired condition gives rise to furnace gases of definite quality or character, and any deviation from the desired conditions of combustion produces changes in the quality of the furnace gases whence the fact and the direction of variation

(deficiency or excess of air as compared with the desired norm) is readily determined.

It has been proposed to take advantage of these facts to regulate the conditions of combustion by and according to the quality or the furnace gases, by allowing the radiation from a uniformly radiating source (e. g. an incandescent electric lamp) to pass through a definite stream of the gases and fall upon a sensitive responsive device (such as an emission type photo-cell), and utilizing the electrical output or effect from this device to regulate the supply of combustion fluid (air or fuel) to the furnace. In the case of a steam boiler furnace, the uptake or outlet flue by which the spent gases are led from the heating surfaces of the boiler to the stack or chimney usually affords the most convenient stream of gases for the purpose. While such regulation has not proved practically satisfactory for a variety of reasons which it is not here necessary to discuss, we have devised a regulatory method and system of this character which in practice operate successfully and satisfactorily. Various important features and advantages of the invention will appear from the following description of a species or form of embodiment thereof, and from the drawings. Indeed, all the features and combinations shown or described are of our invention, so far as novel over the prior art.

In the drawings, Fig. I is a general diagrammatic view of a control system for a furnace, conveniently embodying the invention; Fig. II is a fragmentary diagrammatic view illustrating a modification; Fig. III is a fragmentary diagrammatic view illustrating yet another modification; and Fig. IV is a fragmentary diagrammatic view illustrating a modification involving other parts of the system.

Fig. I illustrates the application of our invention to a furnace 10 fired with fluid fuel, for example, powdered coal. As here indicated, the coal is supplied through a conduit 11 to a pulverizer 12. The air for combustion is supplied from any suitable source, such as a centrifugal blower 13, through a conduit 14 whose (smaller) branch 14a delivers primary or carrying air to the pulverizer 12, whence the mingled air and fuel pass through a conduit 15 to the furnace 10, while the (larger) branch 14b of conduit 14 delivers secondary air for combustion directly to the combustion chamber of the furnace 10, as usual. The (spent) furnace gases or products of combustion leave the furnace 10 through the flue or uptake 16. The amount of fuel supplied to the pulverizer 12 (and thence to the furnace 10)

may be controlled by any usual or suitable means, here diagrammatically indicated by a control lever arm 17; and the supply of air through the conduit 14 may be controlled by any suitable valve or damper means, such as a vortex damper 18, shown as associated with the blower 13. In the present instance, the invention is shown as applied to operate the air damper 18, while the fuel control 17 is operated by a system of mechanism A responsive to the demand on the furnace 10 or the output therefrom.

As here shown, the furnace 10 is a steam boiler furnace, and the fuel supply control system A is responsive to the demand or load on the boiler furnace and to the output or supply of steam therefrom, as represented by the pressure in the steam pipe or manifold 20. For operating the fuel control 17, the system A may include electro-magnetic means, such as a reversible electric motor 21, with connections such as reduction gearing 22, a crank 23 on the last shaft of the gear train, and a link 24 connected to the fuel control arm 17; and the electro-magnet means may be controlled by a pressure device 26 directly actuated by and responsive to the steam pressure in the pipe or manifold 20, to which it is connected by a valved pipe line 27. As shown, the pressure device 26 actuates an adjustably weighed switch lever 28 coacting with contacts 29, 29 to close the circuit 30 for the motor 21 and operate the same one way or the other to open or close the fuel control 17. The motor circuit 30 may be connected to any suitable source of energization, such as an ordinary 110-volt 60-cycle A. C. light or power circuit P, shown as having one side grounded at p. As shown, there is a follow-up connection for opening the switch 28 and putting the motor 21 out of action after the fuel control 17 has been sufficiently opened or closed, comprising a lever 32 fulcrumed at 33 and connected by a link 34 to the crank arm 23, and also connected to the lever 28 through a connection including a helical tension spring 35. The helical tension spring 35 opposes the action of the pressure device 26 in response to increased pressure, and vice-versa. The tension in the spring is reduced by operation of the motor 21 and movement of the crank arm 23 to increase the fuel supply, and is increased by the reverse operation and movement of these parts. Thus the supply of fuel to the furnace is increased or reduced according to the relation between the demand and the output of the furnace, as represented by the steam pressure in the pipe 20.

While any of the supplies of combustion fluid (fuel or air) to the furnace 10 may be controlled by the quality or character of the (spent) furnace gases in the flue or uptake 16, in the present instance it is the supply of air that is so controlled. As shown in Fig. 1 the air supply is controlled jointly by the quality of the furnace gases, through a unit D responsive thereto, and by the relation between demand and output affecting the furnace 10, as represented by the steam pressure in the pipe 20. The system of mechanism B whereby the steam pressure acts on the air damper 18 may be largely similar to the control system A for operating the fuel control 17, and its corresponding parts and features are marked with the same reference numerals (with the addition of a letter for purposes of distinction), in order to dispense with repetitive description. As here shown, the link-rod 24a of this mechanism B is pivotally connected at 37 to the damper 18. The system of mechanism C through which the

unit D ultimately affects the air damper 18 is shown as somewhat similar to the systems A and B already described, comprising a reversible electric motor 40 acting through a train of reduction gearing 42 to turn a crank arm 43 that is connected to the lever 28a through a connection including a helical tension spring 44. Like the spring 35a, the spring 44 opposes the pressure device 26a. The energization of the motor circuit 45 to operate the motor 40 one way or the other is controlled by the unit D through means such as hereinafter described.

When the air supply to the furnace 10 is less than required for the desired conditions of combustion, the resulting change in the quality of the furnace gases at 16 brings about operation of the motor 40 to increase the tension of the spring 44, so as to overcome the steam pressure in the device 26a and open the air damper 18, thus supplying more air for the combustion of the fuel and correcting the condition; while when the air supply is in excess of the requirements for the desired conditions of combustion, a reverse corrective action is produced. In order to render the lever 28a more sensitive to brief operation of the motor 40, resulting in small changes of tension in the spring 44, provision may be made for this motor 40 to exert an additional effect on the lever 28a in aid of the spring 44, as by means of a fan 50 on the motor shaft arranged to blow or suck air (according to the direction of rotation of the motor) into or out of the open mouth of a T-fitting 51 at the end of a pipe line 52 connected to a pressure diaphragm device 53 acting on the lever 28a as well as the steam pressure device 26a. As already stated, this fan 50 is so arranged that its energization of the pressure device 53 tends to produce the same effect as the spring 44—or, in other words, to exaggerate the effect of a slight change of tension in the spring—thus causing the switch 28a to close and bring the motor 21a into action more readily. The fan 50 and the pressure device 53 may be calibrated to compensate for friction and inertia which might otherwise prevent response of the lever 28a to slight changes in the quality of the furnace gases, and may even tend to produce an overaction (in excess of that properly due to the spring 44) which will be corrected by the latter as soon as the motor 40 stops and the pressure device 53 is thus de-energized, so as to be no longer effective on the lever 28a.

As here shown, all of the motor circuits 30, 30a and 45 may be provided with suitable pairs of interlocking limit switches 54, 54 for preventing overaction of the motors in either direction under any circumstances. As shown, the limit switch 54 in one side of the motor circuit 45 is shunted by a high resistance 54r (e. g. about 50,000 ohms), for a purpose explained hereinafter.

As shown in Fig. 1, the responsive unit or device D comprises a source of radiation 55, such as an incandescent electric lamp, and a sensitive device or cell 56, such as an emission type photocell or any suitable type of electric eye. The radiation source 55 is shown arranged at one side of the smoke flue 16, so that its rays traversing the smoke or furnace gases in said flue fall on the device 56 directly across the flue. The output or voltage of the sensitive device 56 is unidirectional, though it varies in strength according to the lightness or density of the smoke in the flue 16. Nevertheless, I provide for operating the motor 40 either way under the control of the device 56, by balancing the output or voltage of

the device 56 (preferably after amplification) against opposing electromotive force, and utilizing the resultant to control the direction of action and duration of the current in the motor circuit 45, and the resulting effective speed of the motor 40. The unit D is shown in Fig. I as including an amplifier *d* of vacuum-tube type (e. g., a triode) for amplifying the small electrical output or voltage of the cell 56 due to excitation by the rays from the source 55, and there are associated with this unit D a balancing system E receiving the amplified output or voltage from said unit D and a further amplifying and control system F for supplying current to the motor circuit 45 to operate the motor 40 one way or the other.

Power for the unit D, for the systems E and F, and for operating the motor 40 may be supplied from the power line P through leads 60, 61 having branches 60a, 60b, 60c and 61a, 61b and 61c, respectively. The lead 60 being connected to the grounded side of the power circuit P, it follows that all points on the circuit branches 60a, 60b, 60c are grounded. As shown in Fig. I, the source of radiation 55 is connected across the power circuit branch 60a, 61a, an adjustable calibrating resistance 62 being interposed adjacent the device 55. The cathode of the triode vacuum tube *d* is connected in a circuit 64, between resistances 65 and 66 therein, and this circuit 64 is connected across the circuit branches 60a, 61a. The plate of the vacuum tube *d* is connected as hereinafter described to the branch 60b of the lead 60, while its grid is connected through a lead 67 including a resistance 68 to a shiftable point on the resistance 66. One side of the sensitive device or cell 56 is connected by a lead 70 to the circuit 67, between its resistance 68 and the grid of the tube *d*, so as to feed the cell voltage to the grid. By shifting the connection of the circuit 67 along the resistance 66, the current through the tube *d* between the circuits 60b and 61a and through the primary of the transformer 71 may be kept in desired phase relation with the current through the circuit 61b and the primary of the transformer 72.

The balancing system E shown in Fig. I comprises transformers 71 and 72 connected as hereinafter described. The primary of the transformer 71 is connected between the circuit branch 60b and a lead 73 from the plate of the tube *d*, whose cathode is connected to the circuit branch 61a through the side of circuit 64 that includes resistance 66. Accordingly, impulses amplified under control of the sensitive device 56 traverse the transformer primary. The primary of the transformer 72 is connected between the circuit branch 60c and the circuit branch 61b, and adjustable resistance 74 being interposed in this latter connection. The secondaries of the transformers 71 and 72 are connected in a "balancing" loop circuit 75, which includes a resistance 76 in one side of the loop. The other side of the loop 75 is connected by a lead 77 to the circuit branch 60c. A point shiftable along the resistance 76 is connected by a lead 78 including a resistance 79 to a point of the circuit 60c further from the transformer 72 than the connection of the lead 77 to said circuit 60c. By adjusting the resistance 74, the system is calibrated roughly to balance the impulses in circuit 75 (due to the A. C. impulses in the primary of transformer 72) against the opposing impulses in said circuit due to the impulses in the primary of transformer 71 (from the sensitive device 56 and tube *d*) when

the quality of the furnace gases in flue 16 corresponds substantially or approximately to the desired conditions of combustion. A finer calibration may be made by adjusting the connection 78 along the resistance 76.

The phase relation between the impulses in the primary of transformer 71 and the A. C. current in the primary of transformer 72 should be 180°, or such that the resulting A. C. impulses or currents in the secondaries of these transformers essentially balance one another when the quality of the flue gases at 16 is that desired—neglecting minor irregularities of the A. C. in the secondary of transformer 71 (due to the fact that it is produced by unidirectional impulses in its primary, rather than by A. C.), which are damped out in the system F as hereinafter described. Under this condition, points on the resistance 76 at one side of the connection 78 are always plus when points on said resistance 76 at the other side of said connection 78 are minus, and vice versa. As long as the quality of the flue gases at 16 is just as desired, there is essentially no voltage or flow in the lead 78; but whenever the quality deviates from the desired, there is a differential or signal (voltage and electrical impulses) one way or the other in said lead 78, according to the magnitude and character of the deviation, which is transmitted to the system F as hereinafter described. The phase or sign of these signal impulses varies according to whether the influence from transformer 71 or that from transformer 72 predominates in producing them, i. e., according to which way the quality of the furnace gases deviates from the desired normal.

As here shown, the system F involves two stages of amplification, which may be effected by vacuum tubes *g* and *h*. The tube *g* is shown as a triple grid detector amplifier, while the tube *h* is shown as a single grid detector amplifier. The system F here shown also comprises two alternatively acting agencies for supplying unidirectional current impulses, such as grid glow tube rectifiers *j* and *k* of "Thyratron" type, which may receive the output of amplifier *h* through a transformer *t*, and are shown connected to feed the leads of the motor circuit 45. To provide the required plate voltages for the tubes *g* and *h*, the system F may include a rectifier, shown as a vacuum tube *m*.

The system F may receive power from the circuit P through a transformer 80 whose primary is connected between the circuit branches 60c, 61c, and whose secondary is in sections. The first section of the transformer secondary is connected in a heating circuit 81 with branches to the heaters of the indirectly heated cathodes of vacuum tubes *g* and *h*. The second section of the transformer secondary is connected in a heating circuit 82 with branches leading to the heaters of the indirectly heated cathodes of the tubes *j* and *k*, one side of this circuit 82 including a portion of the grounded circuit branch 60c, and being thus grounded. The third section of the transformer secondary is connected in a circuit 83, which is further described hereinafter. The fourth section of the transformer secondary is connected in the heating circuit 84 of a vacuum tube *m* whose cathode heaters are in series with one another and whose anode plates are shown connected to the circuit branch 61c in parallel. The mid-point of the first section of the transformer secondary is shown as connected to the (grounded) circuit branch 60c by a lead 85; and the circuit 83 of the third transformer

section is shown as including an adjustable variable resistance 88.

The system F may receive the signal (voltage) from the lead 78 of the system E through a lead 90 connecting the (first) grid of the amplifier tube *g* to a shiftable point on the resistance 79. The adjustment of the connection 90 along the resistance 79 controls the magnitude of the signal (voltage) fed to the tube *g*; and this resistance may therefore have a relatively high value, such as some 50,000 ohms. The plate of the tube *g* is connected by a lead 91 (including a condenser 92) to the grid of the amplifier tube *h*, and this lead extends and is connected to the circuit branch 60c through a resistance 93, which serves to control the amplified signal (voltage) fed to the tube *h*. The plate of the tube *h* is connected to the circuit branch 60c through a lead 94 which includes the primary of the transformer *t*, a resistance 95, and a condenser 96; and thus the further amplified signal voltage is fed through the transformer primary. The grid bias for the amplified tube *g* may be obtained by means of a self-bias resistor 98 and a by-pass condenser 99, which are connected in parallel in a lead 100 from the (third) grid and the cathode of tube *g* to the circuit branch 60c; and the grid bias for the amplifier tube *h* may be obtained by means of a self-bias resistor 101 and a by-pass condenser 102, which are connected in parallel in a lead 103 from the cathode of tube *h* to the circuit branch 60c. The plate voltage for the tubes *g* and *h* may be obtained from the rectifier tube *m*, through the lead 94, resistance 95, and a lead 104, connecting the latter to one side of the circuit 84. Ripples and frequency surges in the rectified plate voltages derived from the rectifier *m* may be smoothed out by means of the resistances 93 and 105 in conjunction with the condensers 106, 107, 108. A choke 109 is shown connected in shunt with the condenser 108, to allow the tube *g* to operate with relatively high gain or amplification at the frequencies in the power line P (e. g. 60 cycles), and with relatively low gain at all other frequencies. The resistances, condensers, and choke just referred to also serve (one or all) to damp out irregularities in the signal impulses due to the unidirectional impulses in the primary of transformer 71.

The secondary of the transformer *t* is shown with its opposite ends connected to the grids of the "Thyratron" tubes *j*, *k* by leads 110, 111 including condensers 112, 113 and resistances 114, 115, respectively. Intermediately, at its midpoint, the secondary of transformer *t* is connected by a lead 116 to a point shiftable along the adjustable resistance 88. Resistances 117, 118, are shown connected between the lead 116 and the leads 110, 111, respectively, shunting the transformer secondary and the condensers 112, 113. In conjunction with the resistances 117, 118, the condensers 112, 113 store the grid charges of the tubes *j*, *k*. By adjusting the variable resistance 88, the bias of the tubes *j*, *k* may be adjusted so that these tubes will deliver current or "fire" only when a suitable determinate critical voltage is impressed across or through the primary of the transformer *t*. When the tube *j* fires, the reversible motor 40 rotates in one direction; and when the tube *k* fires, it rotates in the other direction.

In operation, the signal voltage received by the system F from the system E varies in phase according to the condition in the systems D and E determined by the quality of the gases in the

flue 16 and the resulting output voltage of the sensitive device 58. The phase of this signal voltage ultimately determines which of tubes *j* and *k* will fire, since these tubes are out of phase with one another, owing to their circuit connections as shown in Fig. 1. Thus the direction of rotation of the motor 40 and its corrective action on the supply of combustion fluid to the furnace 10 depends on the quality of the flue gases as reflected in the phase characteristic of the signal voltage, while its operating or not operating depends on the strength of the amplified signal voltage as it affects these tubes *j*, *k*.

As shown in Fig. 1, there is a "feed-back" *x* in the system F, comprising a connection 120 from one side of the motor circuit 45 through a resistance 121 to one side of the circuit 83, which is connected through the adjustable resistance 88 and the lead 116 and resistances 117, 118 to the grids of the tubes *j* and *k*, together with a condenser 122 connected between the circuit 60c and a point on the lead 120 intermediate the resistance 121 and the circuit 83. (It may here be remarked that with the shunt 54r shown in Fig. 1, the circuit for the grid bias of the tubes *j*, *k* is complete with either limit-switch 54 of the motor 40 open.)

While the motor 40 is in operation or is being energized, the portion of its circuit between its armature and its field coils is negative with respect to the potential at the cathode of the tube *j* or *k* which is firing to energize the motor. As a result, a negative charge is progressively stored by the condenser 122 in conjunction with the resistance 121, representing a counter-electromotive force opposing the signal voltage in the circuit to the grid of the tube *j* or *k* that is firing. Hence this tube *j* or *k* will temporarily cease firing, and the motor 40 will stop sooner than would otherwise be the case, i. e., before the signal voltage itself falls below the critical value at which the tube will just fire, and before the corrective action on the supply of combustion fluid to the furnace 10 has made itself fully felt in the flue 16, and so reduced the signal voltage to zero. When the tube *j* or *k* thus ceases firing and the motor 40 stops, firing of the tube and operation of the motor will not, of course, be resumed until the charge stored in the feed-back *x* has built up to the point of (spontaneous) discharge—which, of course, removes or reduces the counter-electromotive force that has been opposing the signal voltage and preventing firing of the tube. If after such discharge the tube *j* or *k* resumes firing and the motor 40 runs again, a negative charge will again be gradually stored by the feed-back *x*; and thus the tube and the motor will again be put out of action till this charge again discharges. In this way, the supply of electric energy from tube *j* or *k* to operate the motor 40 is pulsated when the signal voltage approaches the critical value.

As the corrective action of the motor 40 on the supply of combustion fluid to the furnace 10 gradually makes itself felt, and the signal voltage affecting the tube *j* or *k* thus gradually diminishes, the negative charges in the feed-back *x* will not have to build up to so great a value each time before stopping the firing of the tube *j* or *k* and the operation of the motor; or, in other words, the periods of tube-firing and of operation of the motor will gradually become shorter and shorter, while the periods of tube inactivity and of motor stoppage will grow longer

and longer, relatively, or even absolutely. Thus the effective or net rate of operation or speed of the motor 40 and its corrective action on the combustion fluid supply will be graduated according to the magnitude of the signal voltage. It may even happen, indeed, that the pulsations of energy supply to the motor 40 may be of such great frequency that the motor will virtually run more or less continuously, but at gradually diminishing speed.

The feed-back x is intended to be so calibrated or adjusted that the motor will be operated in such a way as to compensate for the time lag in its corrective action on the quality of the flue gases, and to prevent overtravel of the motor after the tube j or k stops firing, as more fully explained hereinafter. Thus the corrective system C can be operated rapidly to restore approximately the desired conditions of combustion, without danger of overcorrection and hunting in the final finer correction.

To secure the desired action of the feed-back x as described above, suitable relations must exist amongst the capacities C of the condensers 112, 113, 122 and the values R of the resistances 117, 118, 121: viz., $C112 \times R117 < C122 \times R121 >$ and $C113 \times R118$: in other words, $C112 \times R117$ and $C113 \times R118$ are each $< C122 \times R121$. Under these conditions, the condenser 112 or 113 will discharge more rapidly than the condenser 122, and the voltages V across the discharging condensers will change in like manner. Accordingly, the bias on the grid of the tube j , which is $(V122 - V112)$, will increase negatively during the discharge of the condensers 112 and 122, so that a signal voltage higher and higher above the critical voltage for firing this tube will be required to make the tube j continue firing. However, the condenser 112 will reach a condition of substantially complete discharge before the condenser 122 does; and so there will be a point beyond which the condenser 122 will discharge more rapidly than the condenser 112. After this point, the negative bias on the grid of the tube j will decrease, and a point may be reached at which the signal voltage may sufficiently counteract the voltage due to the feed-back x to cause the tube j to resume firing, and the motor 40 to operate again awhile, until again stopped by similar feed-back action. Hence the supply of energy to the motor 40 is periodically interrupted, or, in other language, pulsed. Thus the correction of the combustion conditions in the furnace 10 proceeds intermittently with pauses during which the change may make itself sufficiently felt in the system D to reduce the amplified signal voltage impulses in the primary of the transformer t below the critical value for firing the tube j . Of course the action is similar when the tube k is involved instead of the tube j .

Fig. II illustrates a modification in which the steam-pressure responsive air-regulating means of Fig. I (including the parts 26a to 35a) of the system B is omitted, as well as the spring 44 and the friction-compensating or spring-reinforcing system (including the parts 50-53), so that the motor 40 acts directly and alone to control the supply of air to the furnace 10. Accordingly, the crank arm 43 operated by the motor 40 is connected to the air damper 18b, through (unyielding) link rods 44b and 24a and a bell-crank lever 123. Thus the air supply to the furnace 10 is here controlled entirely by the quality of the furnace gases, totally unaffected

by the steam pressure. In other respects, the operation is the same as already explained in connection with Fig. I; and various parts and features in Fig. II are marked with the same reference numerals as in Fig. I (with a distinctive letter added, where such distinction appears necessary) in order to dispense with repetitive description.

Fig. III shows a feature which is applicable to the regulatory system of Figs. I and II, but is illustrated separately in order to avoid confusion. Accordingly, various parts and features are marked with the same reference numerals as in Fig. I (with a distinctive letter added, where such distinction appears necessary) as a means of dispensing with repetitive description.

As shown in Fig. III, the connection 78 of Fig. I includes a contact arm 78c that is automatically moved along the resistance 78 by a link-rod connected 44c from the crank 43, which is operated by the motor 40. This results in a follow-up action tending to reduce the signal voltage as the motor 40 operates to correct the combustion conditions that have given rise to the signal. However, the system of Figs. I and II is fully operative as hereinbefore described without the follow-up feature of Fig. III.

Fig. IV illustrates a modification, involving the units D and E of the control system, wherein the opposing electro-motive force against which the output or voltage of the device 56 is balanced is provided in a different way from that shown in Fig. I. For this purpose, besides the sensitive device 56, the unit D includes a similar or counterpart sensitive device or cell 56d exposed directly to the radiation from the source of radiation 55 (preferably the very same source that affects the device 56), without the intervention of the flue gases. For this device 56d, there is an amplifier dd similar to the amplifier d for the device 56, with similar connections and resistances 64d, 65d, 66d, 67d, 68d, to the circuit branches 60a and 61a; and the two sides of the device 56d are connected (like those of the device 56) to the circuit branch 60a and (through a lead 70d) to the corresponding circuit 67d. Thus the sensitive devices 56, 56d are subject to radiation from the same source 55, and are therefore affected just alike by voltage fluctuations or other variations affecting this source; and they have identical parallel circuit connections, including counterpart amplifiers d and dd. As regards effects on the devices 56, 56d, fluctuations of the source 55 balance perfectly; so that only variations in the quality of the gases at 10 affect the system.

The balancing system E shown in Fig. IV comprises a resistance 71d that is connected between the circuit branch 60b and the lead 73 from the plate of the tube d, and a resistance 72d that is connected in a loop with the secondary of a phase-displacing or reversing transformer w whose primary is connected through a resistance r between the circuit branch 60b and the lead 73d from the plate of the tube dd. The resistance r plus that of the transformer primary should be equal in value to the resistance 71d. As shown, the resistance 72d and the secondary of the transformer w are both connected to the lead 60b. The resistance 71d and 72d are connected in a balancing loop circuit 75d that includes the lead 60b as one side of the loop and a resistance 76d at the other side of the loop. As shown, the connections of the resistance 76d to them are shiftable or adjustable along the resistances 71d, 72d, which are thus in effect potentiometer re-

stances. From a point shiftable along the resistance 78d extends the connection 78d (through the resistance 79) to the circuit 80c: whose adjustment of the connection 78d along said resistance 78d serves (like the adjustment of the connection 78 in Fig. I) to calibrate the system for maintaining the quality of furnace gases corresponding to the desired conditions of combustion.

The operation of the modification shown in Fig. IV is essentially like the signal-producing action already described in connection with Fig. I. The system is adjusted so that the impulses from the tubes *d* and *dd* in the resistance 71d and in the primary of the transformer *w* are in phase, and are equal when the quality of the flue gases is as desired. Accordingly, the impulses in the resistances 71d and 72d are 180° out of phase, and balance when the flue gas quality is correct; but when the flue gas quality deviates from normal, signal impulses of sign corresponding to the character of deviation and of value corresponding to its magnitude are transmitted through the connection 78d with the same effects as explained in connection with Fig. I. Slight irregularities in the signal (due to the interposition of the transformer *w* in the circuit of only one of the resistances 71d, 72d) are ultimately damped out about as indicated in connection with Fig. I.

As here shown, there is a spring-opening relay-switch 125 interposed in the lead 78d, with its operating coil for holding the switch closed connected in a circuit 127 between the circuit 60 and the lead 78d, at a point between tube *dd* and resistance *r*. In case of failure of the tube *dd*, which tends to increase the supply of combustion fluid to the furnace 10, the relay switch 125 opens the signal circuit connection 78d (to the system F), so that continued operation of the other tube *d* shall not result in shutting off the supply of combustion fluid to the furnace, and thus perhaps shutting it down altogether.

In Fig. IV, various parts and features are marked with the same reference numerals as in Fig. I, as a means of dispensing with repetitive description, a letter being added where such distinction appears necessary. It will, of course, be understood that the rest of the system with which the modification shown in Fig. IV is used may be the same as in Fig. I or Fig. II—though in Fig. IV there is no exact counterpart for the circuit 61b of Fig. I—and that the modification of Fig. III is applicable to this Fig. IV modification.

Having thus described our invention, we claim:

1. In a system for controlling a supply of combustion fluid to a furnace by means including a

sensitive cell controlled by the quality of the furnace gases, the combination with a source of rays and a sensitive cell exposed to rays from said source passing through the furnace gases, and electro-motive means acting, according to its direction of operation, to increase or reduce the supply of such combustion fluid; of an electronic amplifier for amplifying the output from said cell, and a transformer with its primary connected to receive the amplified output; a source of voltage and a transformer having its primary connected to be affected by the voltage therefrom; a balancing circuit, including the secondaries of said transformers, wherein voltages induced by those in the transformer primaries oppose one another; an electronic amplifying circuit for amplifying the differential voltage from said balancing circuit; means controlled by the amplified differential voltage for supplying electric energy to operate said electro-motive means one way or the other, according to the sign of said differential voltage; and means for pulsating the supply of electric energy to said electro-motive means when the signal voltage approaches a critical value, and for graduating the periods of energy supply according to the strength of the signal voltage.

2. In a system for controlling a supply of combustion fluid to a furnace by means including a sensitive cell controlled by the quality of the furnace gases, said cell having an associated vacuum tube and means for amplifying the output from said cell, the combination of a balancing system, intermediate and connected to said cell and the amplifying system, comprising spaced transformers having the secondaries connected by a balancing loop, said amplifying system being also connected to said loop for controlling the supply of said combustion fluid; the primary of one transformer being connected to a circuit including a source of power and the plate and cathode of said vacuum tube, whereby impulses amplified under control of the sensitive cell traverse the primary of said transformer; and the primary of the other transformer is connected to a circuit including the above mentioned source of power and an adjustable resistance, whereby variations in the output of the sensitive cell are transmitted to the amplifying system.

3. The combination of claim 2, wherein the balancing loop includes a resistance in one side thereof; and a point, shiftable along said resistance, is connected to the amplifying system.

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