Jan. 17, 1933. E. G. BAILEY 1,894,616

AUTOMATIC CONTROL SYSTEM

Filed Nov. 13, 1924 3 Sheets-Sheet 1

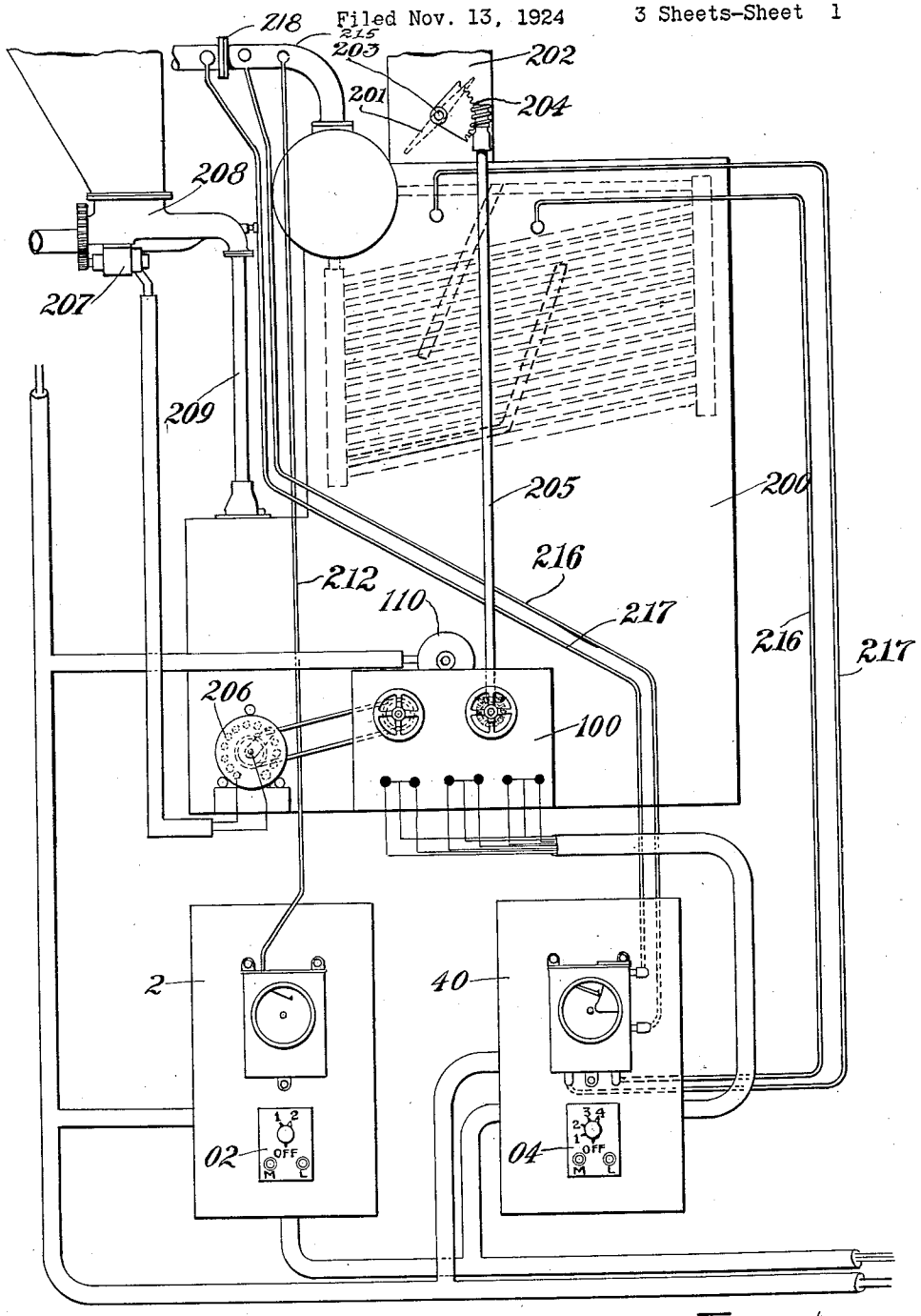


Fig. 1

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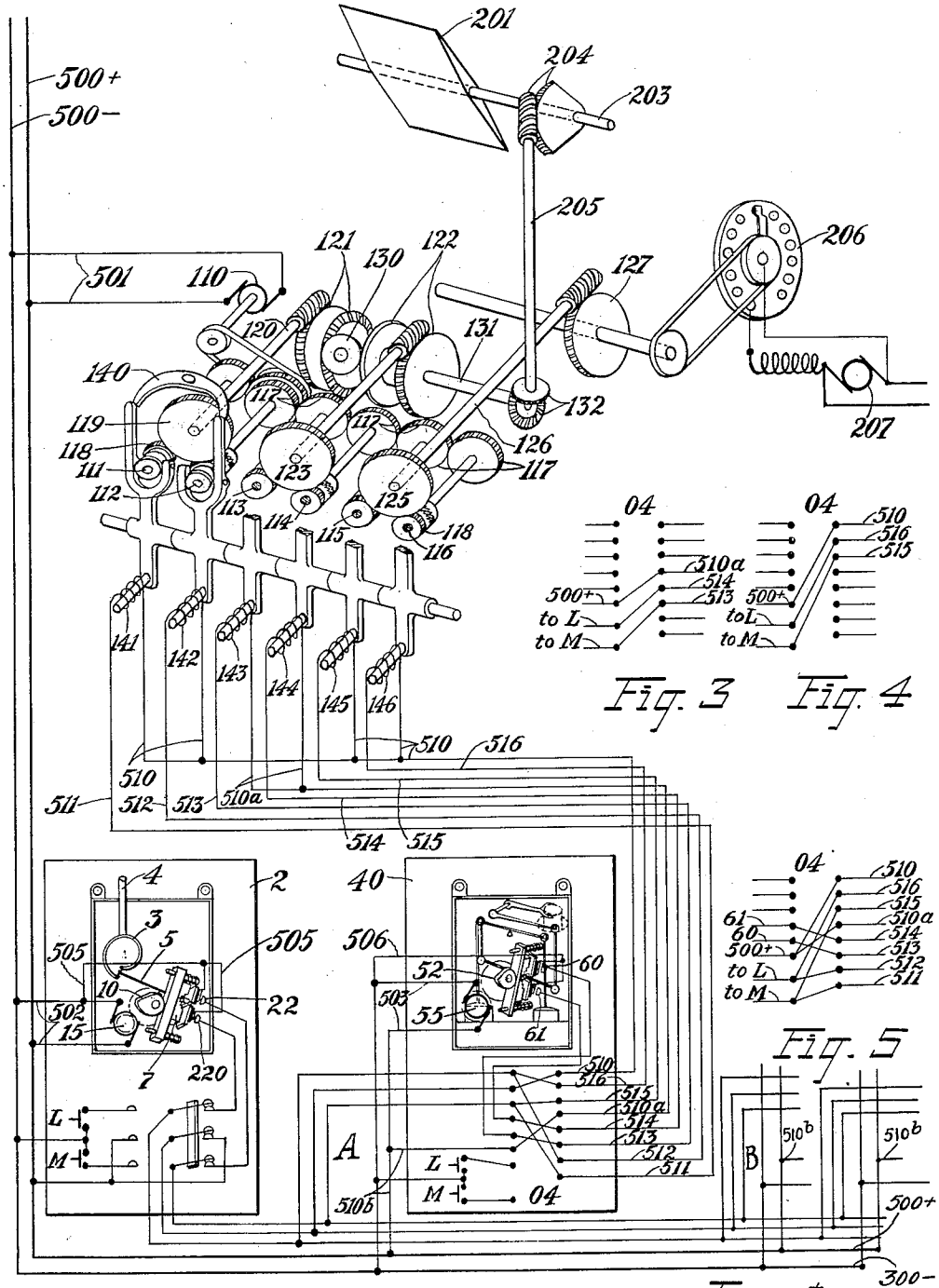


Fig. 2

Fig. 3

Fig. 4

Fig. 5

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Fig. 6

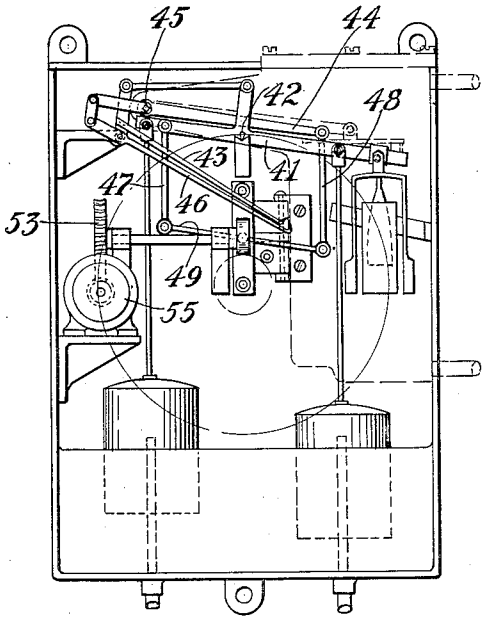


Fig. 7

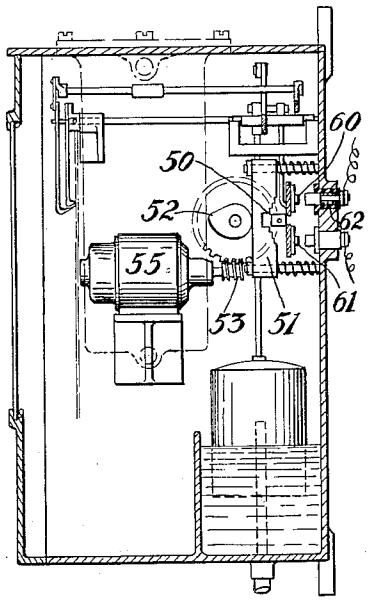


Fig. 8

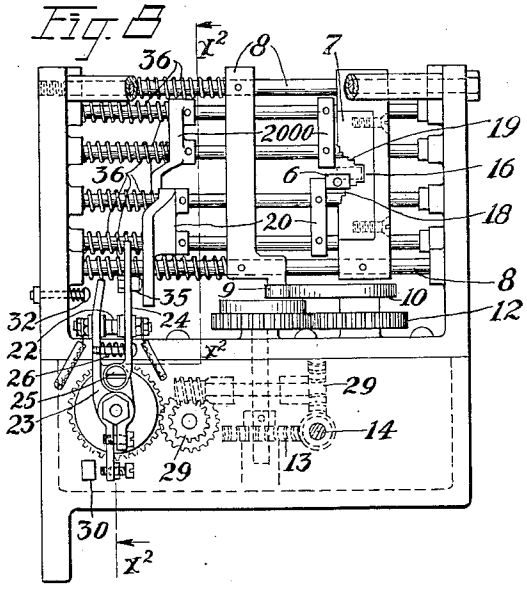
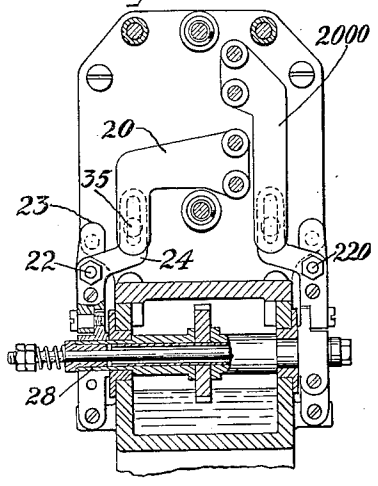


Fig. 9



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UNITED STATES PATENT OFFICE

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AUTOMATIC CONTROL SYSTEM

Application filed November 13, 1924. Serial No. 749,769.

This invention relates to an automatic control system wherein several factors require independent or individual control for the attainment of the desired result.

The invention is shown embodied in an automatic control for boiler plants by which the action of the furnace is automatically regulated to maintain a substantially constant, or desired, steam pressure under all conditions of use, while also maintaining an efficient action of the furnace so that the requisite power is supplied with a minimum consumption of fuel.

The proper and efficient control of the action of the firing of a steam generator depends upon certain well known factors, or natural laws, which will be briefly stated to facilitate the description or understanding of the appliances involved in the automatic control forming the subject of this invention.

The pressure of the steam in a boiler plant may be taken as an indication of the sufficiency of the heat input to meet the various demands for power, for if the heat input is insufficient the pressure will fall, and, on the other hand, if the pressure rises it shows that more heat is being supplied, or more fuel is being consumed, than is required to meet the demand. This condition has been availed of for automatic regulation of boiler furnaces by appliances of various kinds responsive to the boiler pressure, which act to diminish the draft or the supply of fuel, or both, when the pressure rises, or to increase the draft or supply of fuel when the pressure falls.

In such automatic systems as have been employed prior to my invention, the fire has been controlled to maintain an approximately constant steam pressure, but there is no control of the factors which are involved in efficient combustion of the fuel, and while sufficient heat may be produced to meet the varied demands upon the plant, there is no automatic regulation to prevent excessive combustion of fuel as compared with what would be required if the conditions for efficient combustion were maintained.

Furthermore, in the usual type of regulating apparatus the corrective action depends upon the result to be regulated (the steam pressure) being and remaining abnormal. When the demand for power is above the average or normal, the boiler pressure falls and brings about an increase of the fire and heat input until it becomes sufficient to supply the increased demand. It cannot, however, so long as the demand remains above normal restore the pressure to normal for in so doing it would again cause the fire or heat input to be reduced, tending to decrease the pressure and calling for further or continued correction. Thus, with the usual type of regulator the boiler remains at a pressure below normal so long as the rating or demand for power is above normal or average, and the pressure remains above normal when the demand for power or rating is below the normal.

In the regulating system forming the subject of the present invention, the pressure is restored to normal by the corrective action whatever the demand for power or rating of the boiler at the time may be.

There is a definite relation, not necessarily a constant ratio, between the quantity of steam output and the quantity of fuel required for its generation, and in the case of the fuels in common use, such as gas, oil, or coal in various forms, the quantity of air required for perfect or highly efficient combustion is so nearly proportional to the quantity of fuel that it may be taken as a measure of the fuel consumed. If an increased demand for steam calls for increased heat input, or consumption of fuel, there will obviously be a corresponding increase in the supply of air or oxygen required to maintain the proper combustion of said fuel. There is, therefore, a definite relation between the flow of air through the furnace, (corresponding to heat input) and the outflow of steam (heat output) when the combustion is efficient, and a departure from this relation indicates that the conditions, or factors, involved in the combustion of the fuel are not correct. If the air flow exceeds the proper proportion for any given steam flow, it indicates that an excess of air over what

is required for proper combustion is being supplied to the furnace, which involves a waste or loss of heat, and if, on the other hand, the proportion of air is less, it indicates an excess of fuel, resulting in imperfect combustion and waste of heat is unconsumed smoke or gases.

In Reissue Patent No. 15,080, dated April 12, 1891, I have described a method of indicating the relation of steam flow to air flow, and in Patent No. 1,257,965, I have shown an indicator of the kind now well known as the Bailey air-flow steam-flow meter, which indicates when the proper relation of steam flow and air flow exists at any rate of output of steam, and also indicates any departure from such relation, such indications having been used to inform the fireman of the condition of the furnace in order that if efficient conditions were not prevailing a proper correction could be made either by increasing the fuel supply or the air supply, or, in the case of solid fuel, by correcting the condition of the fuel bed.

In the present invention the automatic control system causes the proper corrections to be made automatically, or itself performs what the fireman was called upon to perform when only the indicator or meter was used.

The present invention is applicable to a plant containing a number of individual boilers and furnaces affording a common supply of steam and the apparatus serves to maintain the pressure of the steam output substantially constant at all ratings, and also to maintain the combustion in each of the individual boiler furnaces at a state of high efficiency.

The appliances involved in the control system forming the subject of this invention include a primary controlling device responsive to variations in steam pressure and acting to increase or decrease the combustion in all of the furnaces simultaneously, and a secondary controlling appliance, or readjustment control, including and responsive to a Bailey air-flow steam-flow meter, or some equivalent appliance, cooperating with the main control to govern the supply of air and fuel to each individual boiler, so as to maintain the same in a condition of highly efficient operation.

The flow of air may be varied in the usual way, as by a damper, or blower, or both, and where liquid or gaseous fuel is used the delivery of fuel may be determined by a suitable valve, and where, as in the embodiment of the invention herein shown, the fuel is pulverized coal, the rate of fuel supply may be varied by the action of a coal feeding applance, the air supply being automatically regulated under control of the Bailey air-flow steam-flow meter, concurrently with the primary control of fuel and air in response to a pressure gauge, or element responsive to variations in steam pressure.

There are various other features involved in the proper action of the automatic controlling apparatus forming the subject of this invention which will be best understood when explained in connection with the concrete embodiment of the invention illustrated in the drawings forming a part of this specification, in which

Fig. 1 is a diagrammatic view representing the general relation of the various components of the control system to one another and to the steam plant to be regulated, a sufficient portion of one boiler and furnace being shown to indicate the relation of the other appliances thereto.

Fig. 2 is a diagrammatic view showing the cooperative relations to one another of the several instrumentalities, and the provision for transmitting the action from one to another of the several instrumentalities.

Figs. 3, 4, and 5 are diagrammatic views indicating different conditions of the circuit connections, which will be hereinafter explained.

Figs. 6 and 7 rear and end elevations, respectively, of the secondary controller showing a sufficient portion of a steam-flow air-flow meter for an understanding of its relation to the other components of the secondary controlling instrument, and

Figs. 8 and 9 are side and end elevations of a portion of the primary controlling instrument, a portion of Fig. 9 being shown in section to illustrate a feature of construction which will be explained.

General organization

The general organization of the components in their working relation to one another is shown in Fig. 1 as applied to a boiler furnace, 200, which may be one of a battery or number of boilers generating steam for a common supply, the intensity of the fire or input of heat being as shown in this instance governed primarily in part by a damper, 201, in the uptake, 202, the shaft, 203, of which damper is adapted to be operated by a worm and sector, 204, actuated by a shaft, 205, itself actuated by the control or corrector driving mechanism shown at 100, which also operates a rheostat, 206, governing the operation of a motor, 207, for a powdered coal feeding appliance, 208, from which the powdered coal or fuel is delivered through a duct, 209, to the furnace. The input of heat from the furnace may thus be increased by increasing the speed of the fuel feed motor, 207, and thus supplying the fuel at a more rapid rate, and also increasing the draft or supply of air by giving a wider opening to the damper in the uptake, 202. Conversely the input of heat is diminished by reducing the speed of

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the motor, 207, and reducing area of the passage for the air in the uptake, 202.

The primary controlling device, which pertains to the whole battery of boilers, is indicated at 2 and comprises a steam gauge, or indicator responsive to changes in the pressure of the steam from the boiler thus indicating the character and amount of departure from normal and consequently the character and amount of correction required, and appliances which govern in part the action of the corrector driving mechanism, 100, in such manner as to increase the feed of fuel and flow of air in response to a reduction of steam pressure from normal, or to diminish the feed of fuel and flow of air in response to an increase in boiler pressure.

The secondary or readjustment control is afforded by the appliance shown at 40 in Fig. 1, one of which pertains to each individual boiler and furnace and is herein shown as comprising a Bailey steam-flow air-flow meter, of substantially the character of that shown in Patent No. 1,257,965, dated March 5, 1918, to which reference may be had for an understanding of said instrument, it being sufficient for the purposes of the present case to state that the instrument shown at 40 in Fig. 1 also comprises mechanism of a character similar in some respects to that contained in the primary control instrument, 2, which also governs in part the action of the corrector driving mechanism, 100, and modifies the action thereof which would result from direct control by the primary control instrument, 2, if acting alone.

The above mentioned components are so organized that a fall of boiler pressure, indicating deficiency of input of heat, causes the primary controlling device to affect the corrector driver in such manner as to increase the fire, by acting through the rheostat, 206, to increase the speed of the fuel feed motor, 207, and at the same time by acting through the shaft, 203, on the damper, 201, to increase the air supply, and conversely a rise in boiler pressure causes less fuel and less air to be supplied.

The secondary controller is at all times responsive to the steam-flow air-flow meter and acts to adjust the air flow through the action of the shaft, 203, upon the damper, it being possible for this action to take place, when required, concurrently with the action of the primary controller by reason of a differential connection in the driver between the air correcting mechanisms under control of the primary and secondary controllers, respectively.

The effect of the corrective action brought about by the primary controller continues until the pressure has been restored to normal, and the operation of the steam generator will continue at the higher rating under normal pressure and with the fuel supply sufficient to maintain the higher rating.

When, on the other hand, the pressure rises above normal, indicating a lower rating or demand for power, the primary control acts through the corrector driver, 100, in a similar manner to reduce the supply of fuel and air until the heat input is only sufficient to maintain the boiler at the lower rating but with the pressure brought back to normal and maintained there until further change of rating is called for, the secondary controller insuring that the supply of air is corrected to maintain efficient combustion.

Before describing the various instrumentalities by which the desired results are attained, it may be stated that the action is such that the effect of the primary controller is to increase the supply of air in advance of, or more rapidly than, the supply of fuel is increased when increasing the heat input of the furnace to meet a larger demand for power, and, on the other hand, in the operation of reducing the output of power the supply of fuel is reduced in advance of, or more rapidly than, the supply of air, so that an abnormal excess of air is present when any change, either increase or decrease, is being made in the rate of supply of fuel.

It may be noted that, especially in the case of gaseous or liquid fuel or of pulverized solid fuel, any one of which is consumed practically concurrently with its entrance to the combustion chamber, it is desirable to maintain at all times a slight excess of air over that which theoretically just combines chemically with the fuel, and it is especially desirable to insure that such excess should exist while changes in the rate of supply of fuel are being made, as any excess of fuel over what will combine with the oxygen supply is wasteful, smoke producing, and otherwise objectionable, and may even be dangerous or cause an explosion to take place.

While the controlling apparatus is so constructed as to cause an increase in the excess of air while changes are being made, the action of the secondary, or readjustment, controlling means at 40 is such as to bring about a readjustment of the air flow to the proper relation to the fuel for efficient combustion, this being responsive to the steam-flow air-flow meter, which indicates when the relative flow of steam and air is correct for efficient action at any rate of generation of steam within the capacity of the plant. Thus when an adjustment of the rate of fuel consumption is made in response to the action of the primary controlling appliance, 2, the flow of air will be further adjusted by the secondary, or readjustment, appliance, 40, to the proper relation to the then rate of fuel supply for efficient combustion.

The construction of the controlling devices furthermore, is of such character that the rate

of corrective action, or readjustment increases the greater the amount of readjustment required. That is, of the steam pressure should be rather suddenly reduced by the amount of two or three per cent, the increase of delivery of fuel and air to the furnace would be much larger or more rapid than would be the case if the pressure had fallen off only one per cent or a fraction thereof.

The construction of the primary controlling device, furthermore, is such that the corrective action depends upon whether the change of steam pressure is towards or away from normal, the construction being such that account is taken of the lag or necessary lapse of time between the moment when a correction, such as an increase of fuel, is made, and the time when the boiler pressure responds thereto, which will be some time later as the water cannot instantly absorb and respond to the increase of heat. The controller thus anticipates the result that will follow its action, and awaits the appearance of the result before taking further action.

Primary control instrument

The primary control instrument, shown in its entirety at 2 in Fig. 1 and somewhat diagrammatically at 2 in Fig. 2, a portion of the mechanism being shown more in detail in Figs. 8 and 9, comprises an indicator or appliance responsive to variations in steam pressure in the boiler, the heat input to which is to be controlled, which appliance may be likened to an ordinary steam gauge and is shown in Fig. 2 as comprising a Bourdon tube, 3, connected by a pipe, 4, with the battery of boilers to be controlled, and as operating, in response to the changes of pressure, an arm or pointer, 5, which will be referred to as the indicator, which carries at its extremity a bearing piece, 6, best shown in Fig. 8, the position of which indicates the pressure in the boiler.

Cooperating with the indicator is a feeler, 7, also best shown in Fig. 8, which has a continuous slow to and fro periodic movement relative to the contact piece, 6, of the indicator.

Said feeler is carried by a sliding frame, 8, (see Fig. 8) having a cam roller, 9, acted upon by a cam, 10, which is continuously rotated at a slow speed by gearing, 12, driven by a worm and worm gear, 13, from the shaft, 14, of a continuously running motor indicated diagrammatically at 15 in Fig. 2.

The feeler, 7, thus periodically moves towards the indicator bearing piece, 6, but when the indicated pressure is normal and said indicator is in its intermediate or normal position said indicator is in the path of a deep notch or recess, 16, in the feeler, which consequently does not have any effective engagement with the indicator and does not have any effective action upon the correcting instrumentalities, as obviously no correction is needed so long as the pressure remains at normal.

If, however, there is a rise or fall in boiler pressure the indicator, 5, in responding thereto will move the bearing piece, 6, away from the notch, 16, in the feeler to one side or to the other, it being shown in Fig. 8 as having been moved in response to a decrease in boiler pressure indicating a call for increased fuel.

In this movement of the indicator the bearing piece, 6, is brought between a transmitter actuator and a portion, 18, of the feeler, 7, at one side of the deep notch, so that in the next movement of the feeler towards the indicator bearing piece, 6, the feeler will move the said bearing piece with it and through the said bearing piece will move an actuating frame or slide, 20, which operates the controller proper or the transmitter of the control action to the correcting device which is to be operated, in this case to increase the input of heat.

As shown in this instance, the transmitter is a circuit closer, 22, having the anvil contact carried by the main or body member, 23, of the circuit closer, while the other or relatively movable contact is carried by a finger, 24, pivotally connected with the said body member at 25 and acted upon by a spring, 26, tending to separate the contacts and keep the circuit open.

The said transmitter, in this case simultaneously controls two responsive instruments, (electro magnets or solenoids in the control driving instrument, 100,) which act one upon the fuel supply, and the other upon the air supply, and concurrently effect a gradual increase of the fuel and air supplies as long as the circuit remains closed at 22, as will be hereinafter described.

The action of the driver, 100, on the correcting devices is slow and gradual so that the amount of corrective action depends upon the time during which the driver is actuating the correcting devices, which in turn depends upon the length of time that the circuit remains closed at 22, by the transmitter of the primary controller.

Referring again to the feeler, 7, it will be seen at the parts 18, 19, that the sides of the inactive notch, 16, are cam shaped or of varying height, being shown in this instance as formed in a series of steps one or another of which engages the indicator bearing piece, 6, according as the indicator is moved a greater or less distance from normal position.

As shown in Fig. 8, the bearing piece, 6, is in position to be engaged by the second step from the notch and thus produces a greater movement of the actuator, 20, than would be the case if it were moved only to the first step

but less than if it were moved to the third step or anything beyond.

Thus the amount of movement imparted to the actuator, 20, and the length of time of closure of the circuit at 22, varies according to amount of change in boiler pressure from normal, affecting the indicator, 5, which accrues in the period between successive movements of the feeler.

This variation in amount of movement of the actuator, 20, produced by the feeler effects the variation in the time duration of the contact of the circuit closer, 22, and consequently the amount of corrective action in the following manner.

The body member, 23, of the circuit closer is fixed to a tubular shaft, 28, which is frictionally driven at a slow speed relative to the speed of the feeler driving cam, 10, by gearing, 29, from the shaft, 14, of the motor, 15, which actuates the feeler, the action being to tend to turn the circuit closer bodily (both members together whether in contact with one another or not) in the direction to carry the movable member, 24, towards the actuator, 20, this bodily movement of the circuit closer being limited by a stop, 30, (see Fig. 8) in such position that it normally remains standing with the contacts separated by the action of the spring, 26, when the actuator, 20, is in normal position, as is the case when the feeler, 7, receives the bearing piece, 6, in its notch, 16, or when the said feeler is at or near the end of its movement away from the said contact piece.

When the indicator is away from normal position as shown in Fig. 8, and the feeler, 7, makes its movement towards the bearing piece, 6, of the said indicator, the latter will be engaged by a step of the raised portion, 18, of the feeler and will in turn engage and move the actuator slide, 20, which will first move the movable circuit closer member, 24, towards the body member until the contacts come together at 22, closing the circuit, after which the further movement of the actuator, 20, will overcome the frictional engagement between the circuit closer and its driving mechanism and will then produce a bodily pivotal movement of the entire circuit closer around the axis of the shaft, 28, in the reverse direction to that in which the circuit closer is carried by the frictional drive of said shaft, 28, the circuit remaining closed during the period in which the actuator, 20, is thus turning the said circuit closer about its axis.

The moment when the actuator, 20, begins its return movement, in the return stroke of the feeler, 7, the movable member, 24, of the circuit closer separates from the main member and opens the circuit, the period of closure of which thus depends upon the length of movement of the actuator, 20, by the feeler, 7, which in turn depends upon the step or portion of the cam or modifier, 18, of the feeler which has engaged the indicator bearing piece, 6, depending upon the amount of departure from normal of the pressure indicated in the time occupied by the to and fro movement of the feeler. Thus a slow drop in pressure, moving the indicator from normal only to the first step of the feeler in the time occupied by one backward and forward movement of said feeler, would produce only a very short period of closure of the circuit, and consequently a very short period of corrective action, which might be sufficient to correct for the slight change in output indicated by the slow change in pressure; but a larger change in pressure, in the same interval of time, indicating the need for a greater correction, would produce a longer movement of the actuator, 20, and consequently a longer period of closure and a correspondingly greater corrective action resulting therefrom.

Inasmuch as there is some time lag between the correction, or change of fuel feed and draft, and the change of pressure responsive thereto, it may not be necessary to make any further correction even though the indicator does not at once return to normal position, as it may be found that the correction already made without further addition will restore the pressure to normal as soon as the correction has had time to take effect in the generation of steam.

Consequently the control instrument is so devised that upon the next action of the feeler, 7, upon the actuator, 20, there will not be a further correction corresponding to that made at the first corrective action of the feeler, this being due to the slow return movement of the circuit closer towards its normal position in engagement with the stop, 30.

Consequently if there has been no further departure of pressure from normal at the next operation of the feeler, the contacts of the circuit closer will be brought together only for a very short interval of time near the extreme end of the movement of the actuator, 20, towards the circuit closer, but the circuit closer will again be moved to the same distance from normal and consequently at the next action of the feeler, assuming no change of pressure to have been indicated, the circuit closer will be closed for only a very short interval, usually insufficient to produce any substantial effect upon the correcting devices. There would, however, be a small corrective action sufficient ultimately to restore the pressure to normal if the initial corrective action was insufficient to do so.

If, however, the pressure should drop further before the next operation of the feeler, 7, the bearing piece, 6, would be engaged by a higher step and the actuator, 20, would be moved to a greater distance thus again closing the circuit at 22 and moving the circuit

closer bodily still further from the normal position, the time of contact being substantially the same for the second step as for the first, because the circuit closer is not operated in the second step until after the actuator has made a movement about equal to that derived from the first step.

Thus a continued but relaively slow variation of pressure from normal in the same direction will produce a further but relatively small correction in the same direction, and such corrections would continue to be made so long as the variation continued slowly in the same direction, but when the result of the correction begins to appear and the indicator begins to return towards normal, its movement presents the bearing piece, 6, to successively lower steps of the modifier, 18, of the feeler, and consequently no further corrective action takes place during the return movement of the indicator towards normal, although the actual departure of pressure from normal in the same direction might continue for some little time.

If the change in pressure had been sudden and relatively large as in the case of a sudden large increase in demand for power, the indicator in the interval between movements of the feeler would move to a position relative to the feeler which would cause the actuator, 20, to produce a relatively long continued movement of the circuit closer and closure of the circuit.

At, or near, the extreme or maximum movement imparted by the feeler, due to an indication of a very large change in pressure, the circuit closer will be carried against a yielding stop 32, which will yield to permit of the relatively extensive movement of the circuit closer, but in the return movement of the actuator, 20, will overcome the frictional connection between the circuit closer and its driving mechanism and thus carry the circuit closer back towards normal position sufficiently to cause another substantial closure of the circuit to take place at the next succeeding movements of the actuator, 20, unless, or until, the indicator begins to respond to the correction and begins to move back towards normal position.

The primary controlling instrument includes another circuit closer, 220, (see Fig. 9) in all respects similar to the circuit closer 22, which has been described, except that its actuator, 2000, is operated by the indicator bearing piece, 6, and the modifier or step surface, 19, of the feeler when the departure of the pressure from normal is in the other direction to that which operates the circuit closer, 22.

This second circuit closer, 220, similarly transmits to and controls responsive instruments in the corrector driver, 100, which produce the opposite change or correction in the fuel and air supply from that which is produced by the parts responsive to the circuit closer, 22.

The actuator, 20, engages the movable member, 24, of the circuit closer by a bearing piece, 35, adjustably fixed at a desired point in a slot in said circuit closer member, so that by setting it at a greater or less distance from the axis of movement of the circuit closer a correspondingly less or greater angular movement of the circuit closer will result from the same movement of the actuator.

The actuators and feeler have their return movement produced by springs, 36, which hold the cam roller, 9, against the actuating cam, 10.

The patterned or stepped acting portions, 18, 19, of the feeler constitute a modifier of the corrective action, by which the amount of correction is made to depend upon the rate of variation of the steam pressure or variable factor for which the correction is made. If the variation is at a slow rate the corrective action will be small, but if much greater variation takes place in the same period of time the correction is correspondingly larger.

The retarder or provision for effecting the relatively slow return movement of the circuit closer to normal position after each operation constitutes an anticipator, as it delays further operation of the corrector in anticipation of and while awaiting the result due to the correction which has been made.

By these expedients, the modifier in the initial corrective action, and the retarder for subsequent actions, over-correction is usually prevented, and when a change of rating, or increase or decrease of demand for power relative to normal or average, takes place there is a correction of the fuel supply sufficient to make up for the change of rating, and to restore the pressure to normal, after which all parts remain in normal position until some further change in the factor to be controlled takes place, when the corresponding correction is made.

Corrector driver

The proper corrections are made in the fuel and air supply to provide for increased or decreased input of heat by an actuating machine indicated as a whole at 100 in Fig. 1, one such machine pertaining to each individual boiler furnace. The essential components of the machine are shown in perspective in Fig. 2, the general character of the mechanism being such that it causes a corrective action or movement of the thing or things to be corrected (in this case fuel feed and air supply) to be made in one or the other direction at a comparatively slow rate and during periods of time that are under control of the primary controlling instrument, 2, above described, and of the second-

ary controlling instrument, 40, as will be explained hereinafter.

Referring to Fig. 2 the corrector driver comprises a connected train of mechanism normally kept in continuous operation by a motor, 110, which primarily drives a shaft, 112, which is one of six shafts numbered from 111 to 116 respectively (which, with associated parts will be hereinafter referred to as first, second, and so on, for convenience and brevity) all of which are driven by the train of gearing, 117, in such manner that the shafts of each of the several pairs, 111, 112, and 113, 114, and 115, 116, are rotated in opposite directions and at an effective relative speed that will be explained hereinafter.

The said shafts all have loose upon them clutch members, 118, each provided with gears and the gears of the pair of clutches on the first and second shafts mesh with a gear, 119, on shaft 120, connected by worm gearing with one member, 121, of a differential gearing, the other member, 122, of which is similarly connected with a shaft having a gear, 123, meshing with the clutch gears of the intermediate pair of shafts, 113, 114.

The differential gearing may be of the usual well known character, the members, 121 and 122, being loose upon the shaft, 131, and comprising bevel gears meshing with opposite sides of the intermediate, 130, which rotates on an axis fixed to the shaft, 131. Consequently, if one of the members, 121 or 122, is stationary while the other rotates the intermediate will roll around the periphery of the stationary one and will cause the shaft, 131, to rotate at one-half the speed of the movable member. If both members turn at equal speeds but in opposite direction the intermediate, 130, will merely rotate upon its axis without turning the shaft, 131, while if both members turn at the same speed in the same direction the intermediate will act merely as a key connecting them to the shaft, 131, which will then rotate in the same direction and at the same speed as the two members of the differential. For all intermediate speed and direction relations between the two members, 121, 122, the shaft, 131, will be rotated accordingly, at the average, or one-half the algebraic sum of the rotations of the two members.

The third pair of clutches are similarly geared to a gear, 125, on the shaft, 126, connected by worm and worm gear, 127, and suitable further connections with the controlling shaft of the rheostat, 206, which varies the speed of the fuel feed motor, 207, and is thus the corrector for the fuel supply to meet the demands put upon the furnace and boiler.

The shaft, 131, carrying the intermediate member, 130, between the differential gears, 120, 122, is connected through any suitable gearing, such as that conventionally shown, at 132, 204, with the damper, 201, or control of the air supply and is thus the corrector for the flow of air to be used with the supply of fuel which is corrected by the rheostat, 206.

By this construction it will be seen that if one of the clutches of the first pair is engaged and consequently connected with the corresponding shaft it will cause the corresponding gear, 119, to be turned in one direction (the other clutch member then idling on its shaft) while if the clutch of the other shaft of said first pair is engaged, the said gear, 119, will be turned in the opposite direction, the same being true of the second and third pairs of clutches and the gears, 123 and 125, driven by them respectively.

In the construction of the machine an interlocking stop is provided, as shown (for the first pair only) at 140, between the clutches of each pair which operates to prevent the second clutch of a pair from being thrown into engagement while either one is in engagement and thus prevents possibility of clashing of the gears and the damage or breakage that would be likely to ensue therefrom.

Referring to the third pair of actuating shafts, 115, 116, and clutches thereon, it will be seen that with the clutch of shaft 115 engaged, the rheostat, 206, will be operated in one direction, say to increase the supply of fuel, while if the other clutch, on shaft 116, is engaged, the rheostat will be operated in the opposite direction to make the reverse correction or provide less fuel per unit of time.

The several clutches are shown as operated by instruments, 141, 142, 143, 144, 145, 146, which are responsive to the transmitters from the primary and secondary control instruments, being shown as solenoids under control of the circuit closers, 22, and 220, of the primary controlling instrument, 2, above described, and of a somewhat similar transmitter forming a part of the secondary control instrument, or, when desired, under manual control by an attendant as will be hereinafter described.

If it be assumed that the member, 122, of the differential is kept stationary, rotation of the member, 121, under the actuation of the shaft, 120, will cause a movement of the shaft, 131, and corresponding movement of the damper or correction of the air flow and it will be seen that the movement will be in one or the other direction, to increase or decrease the air flow, according as the clutch on one or the other of the first and second shafts, 111, 112, is engaged.

In the present example the operation of the air control under actuation from the first shaft, 111, increases the air supply, and from

the second shaft, 112, diminishes the air supply, and similarly the actuation of the shaft, 126, by the fifth shaft, 115, increases the rate of fuel supply while actuation from the sixth shaft, 116, diminishes the rate of fuel supply.

The solenoids, 141, 145, corresponding to the shafts, 111 and 115, are connected to the circuit closer, 22, of the primary controlling instrument so that at the time when said circuit closer is closed the clutches on said shafts will be in engagement and correction will be made in the way of increasing both the fuel and air supply concurrently.

Similarly the solenoids, 142 and 146, associated with shafts, 112 and 118, are connected with the circuit closer, 220 of the primary instrument (which responds when boiler pressure rises above normal) and when said circuit closer is closed said shafts will operate to reduce the supply of fuel and air concurrently.

Furthermore, the relative speed of rotation of the several shafts is such that in the operation of increasing the supply of fuel and air by the action of the first and fifth shafts, 111, 115, the increase of air is made at a relatively higher rate than the increase of fuel, and conversely the relative speed of the second and sixth shafts, 112 and 116, is such in reducing the supply of air and fuel that the supply of fuel is reduced at a relatively greater rate than the supply of air, so that in making any change, either to increase or to diminish the fire, the excess of air above that required for perfect combustion is increased, while the change is being made, so far as the effect of the instrumentalities under control of the primary controlling instrument are concerned.

The gearing connections between the shafts 112 and 116 and from said shafts respectively to the air control corrector or damper, 201, and the fuel control corrector or rheostat, 206, are such that when the clutches on said second and sixth shafts, 112 and 116, are engaged the operation of the rheostat, 206, would be relatively faster than the operation of the damper, 201, so that the fuel supply will be reduced at a relatively greater rate than the air supply.

The shaft, 111, which when its clutch is engaged causes an increase of the air supply, is driven from the gearing, 117, at a higher rate of speed than the others (by a somewhat smaller driving gear than the others in the train) and consequently when the first and fifth shafts are operating to increase the air and fuel respectively, the air correcting device will be moved at a relatively greater rate to produce a relatively greater increase of air than of fuel.

The intermediate pair of shafts, 113 and 114, are under control of the secondary controlling instrument, which will be described later, although it may be noted at this point that it contains two circuit closers, similar in character to those of the primary controller, one of which governs the solenoid, 143, which operates the clutch associated with the third shaft, 113, while the other solenoid, 144, operates the clutch associated with the fourth shaft, 114. Thus when one of the clutches of the second pair is in operation the member, 122, of the differential will be operated in the direction to increase the air flow, while the other clutch of said pair when engaged with its shaft will similarly cause a diminution in the air flow, and through the differential connection the movement, or the modification of the movement, of the damper, due to the action of either shaft 113 or 114, may take place concurrently with the action of either shaft 111 or 112, under control of the primary controlling instrument, or may take place at any time while the clutches of shafts 111 and 112 are not in operation.

Thus, while the primary controlling instrument, 2, as above stated, always tends to increase the excess of air flow while any change is being made, the secondary controlling instrument acting through the differential is always under control of the steam-flow air-flow meter forming part of the secondary instrument pertainng to each boiler, and operates to correct the air flow for its own boiler furnace, and it may operate concurrently with the operation due to the primary control or after that operation is completed. It, in fact, stands ready at all times to correct the flow of air according to requirements for efficient combustion, as indicated by the secondary controlling instrument, whether an increase or a decrease of air is required.

Secondary control instrument

The secondary control instrument designated as a unit, 40, in Fig. 1 is best shown as to its working components in Figs. 6 and 7.

Like the primary instrument, it comprises an indicator the change of position of which indicates the character and extent of correction required, in this case increase or decrease of air supply to the furnace.

It also comprises a feeler similar in character to that of the primary instrument already described, and actuators and circuit closers operated thereby in a similar manner, except that there is no retarder or appliances for providing for time lag in the response to correction, as none is needed in the case of the adjustment of the air supply when fuel of the nature of pulverized coal is used.

Referring to Fig. 6, which shows the working components of a Bailey air-flow steam-flow meter of the kind forming the subject of Patent No. 1,257,965, the component responsive to the air flow through the furnace oper-

ates upon a lever, 41, pivoted at 42 and acting through suitable linkage upon a pointer, 43, said lever, 41, being rocked in one direction by increase and in the opposite direction by decrease in the air flow through the furnace.

The part responsive to steam flow acts upon a lever, 44, pivoted at 45 and acting through suitable linkage upon a pointer or indicator, 46.

The levers, 41 and 44, which respond to air flow and steam flow respectively are connected by links, 47, 48, with a floating bar or link, 49, having a bearing piece, 50 (see Fig. 7) interposed between the feeler, 51, and carriers or actuators for the movable members of two circuit closers, 60, 61, the normally stationary or anvil members of which are yieldingly supported, as indicated in the case of the upper one at 62 in Fig. 7.

The feeler, 51, is operated with a continuous slow back and forth movement by a cam, 52, operated through suitable gearing indicated at 53, by the continuously running motor, 55.

The Bailey steam-flow air-flow meter, which itself forms no part of the present invention, is devised to indicate the relation between steam flow and air flow at which efficient combustion is maintained, the steam-flow air-flow pointers or indicators, 43, 46, being in substantially coincidence when the proper relation exists and being both movable in response to changes in steam flow and air flow.

So long as the movement of the pointers is practically coincident, as is the case when the proper relation is maintained, (although both factors may be individually undergoing change) the floating link, 49, will be merely turned about its central point where the bearing piece, 50, is located and will not change the position of said bearing piece vertically, but if one of the pointers moves when the other does not, or moves at a different rate from the other, thus indicating a departure from the proper relation between the steam flow and air flow, one end of the link, 49, will rise or fall to a greater extent than the other and consequently the bearing piece, 50, at or near the middle of the link will be raised or lowered as the case may be.

If, for example, the air flow is less than it should be for the existing rate of steam flow the bearing piece will be moved upward, and on the other hand if the air flow is greater than required for the combustion to maintain the existing steam flow, the bearing piece will be moved downward.

The feeler, 51, has a central notch, and stepped or cam shaped engaging portions at the side of said notch, being similar to the feeler of the primary controller in this respect and consequently needing no further description, and it will be seen by referring to Fig. 7 that when the indicator bearing piece, 50, is in normal position, as when the relation between steam flow and air flow is correct, said bearing piece will be received in the notch of the feeler when moved towards it by the cam, 52, and no effect will be produced.

If, however, the air flow is greater than it should be for normal combustion, as is the case when a change is being made in response to the primary control instrument, as before explained, the bearing piece, 50, will be moved downward and will come between the modifier or stepped portion of the feeder and the actuator or bearing piece of the lower circuit closer, 61, moving the said bearing piece and circuit closer member towards the anvil member of the circuit closer and thus closing the circuit during a portion of the movement of the feeler, and energizing the solenoid, 144, of the fourth shaft of the corrector driver which responds with the tendency to supply less air.

The anvil is shown as yielding and spring pressed towards the movable member of the circuit closer and consequently will maintain the contact during the further movement of the movable member after the contact has been made and in the return movement until the anvil member arrives at normal position and the contacts are again separated.

Thus the time duration of the circuit closure is varied in accordance with the distance the bearing piece, 50, of the indicator is moved from normal position, giving a longer period of corrective action the greater the deviation of the air flow from the proper relation to the steam flow.

In case of deficiency of air the bearing piece, 50, of the indicator would be moved upward and the actuator for the other circuit closer, 60, would be operated in a similar manner to make a correction in the way of increasing the air flow to the furnace.

Referring now to the relation of the secondary control instrument to the corrector driver, the circuit closers, 60, 61, control the responsive instruments or solenoids, 143 and 144, pertaining to the clutches on the intermediate pair of shafts, 113, 114. Thus, according as one or the other circuit closer is operated, one or the other of the clutches will be connected to the intermediate gear, 123, and will drive the member, 122, of the differential in the proper direction to operate the shaft, 131, and connections to the damper or air controlling device in such manner as to increase or decrease the air flow as is called for, this operation taking place through the differential connection regardless of the action of the other member, 121, of the differential due to the primary control instrument.

Transmitting connections

In the embodiment of the invention herein shown the transmitting connections between the several instruments are electrical, although the invention is not limited to such construction, as obviously other transmitting mechanism, such for example as pneumatic or even mechanical connections or linkage, might be employed.

The electrical connections employed in the present example of the invention are well shown in Fig. 2 and require no detailed explanation or analysis, as they will be readily understood by those familiar with the art.

As there shown, a main supply line, 500+, 500−, has a branch, 501, for supplying the motor, 110, of the corrector driver machine, and a branch, 502, supplying the motor, 15, of the primary instrument, and a branch, 503, supplying the motor, 55, for the feeler of the secondary instrument.

The primary and secondary instruments have provision for changing from automatic to hand operation when required under control of switches indicated as a whole in Fig. 1 at 02 for the primary instrument, 2, and at 04 for the secondary instrument, 40.

The primary instrument in the normal automatic operation of the apparatus controls only the fuel and air correctors, producing through the action of the first and fifth shafts of the corrector driver an increase in supply of fuel and air concurrently, or through the action of the second and sixth shafts causing less fuel and less air to be supplied.

The switch 02 merely changes the connection from the automatic circuit closers, 22 and 220, to two corresponding push buttons, M, L, (see Fig. 1) so that when the said switch is in the No. 1 position the push buttons control the circuit, and the operator by pressing the button "M" will cause the corrector driver to give more fuel and more air, or by pressing the button "L" will cause less fuel and less air to be fed to the furnace.

The switch 04 of the secondary controlling instrument has four working positions, the one numbered 4 being normal, or for complete automatic operation and making the connections as indicated diagrammatically in Fig. 2, while if the switch is placed at the No. 3 position it makes the connections indicated diagrammatically in Fig. 5, with the push buttons M, L, such that operation of push button M gives more fuel and more air concurrently, while operation of the push button L gives less fuel and less air concurrently, these hand operations thus being brought within control of an attendant at any one of the secondary instruments, which may be located at a place in the plant more or less remote from the primary instrument and from one another.

Other changes in the connections produced by the switch 04 at the secondary instrument are indicated diagrammatically in Figs. 3 and 4, that shown in Fig. 3 being the position in which the air supply only may be operated by the push buttons, while that shown in Fig. 4 is such that the fuel only is controlled by the push buttons, increasing or diminishing the fuel feed according as the button M or L is operated.

With the connections as shown in Fig. 2 the push buttons of both instruments are out of circuit and the operation is automatic throughout.

Referring to the diagram, wire 510 connects with one terminal of each of the solenoids, 141, 142, 145 and 146, pertaining to the first and second and the fifth and sixth shafts of the corrector driver.

When the switches 02 and 04 are in normal position for complete automatic operation the connection from wire 510 of the switch 04 in the secondary instrument is continued on to the positive side of the main supply circuit, 500, so that a connection in some way from the negative side of the main circuit to the other terminal of any one of the solenoids of the corrector driver will complete the circuit through said solenoid and energize the same.

The wire, 510*a*, similarly connects to one terminal of each of the middle pair of solenoids, 143 and 144, pertaining to the third and fourth shafts, which are under control of the secondary controlling instrument.

Wires 511, 512, etc., extend from the other terminal of each of the several solenoids to the correspondingly marked connections at the switch 04 of the secondary controlling instrument, (Figs. 3, 4 and 5) and in the normal position of said switch the said connections 511 and 515 are continued to one member of the circuit closer, 22, of the primary instrument, so that when said circuit closer is operated the first and fifth clutches are operated, and the fuel supply and air flow are corrected by an increase of each.

Similarly the wires 512 and 516 connect to one member of the other circuit closer, 220, of the primary instrument, so that when closed by the action of the feeler and actuator, as hereinbefore described, the clutches of the second and sixth shafts of the controller driver will be operated to give less fuel and air.

The other member of each of the circuit closers, 22, 220, is connected by a branch, 505, (see Fig. 2) with the negative lead, 500−, of the main supply circuit, thus completing the circuits of the corresponding solenoids, 141, 145, and 142, 146, when said circuit closers are operated.

Similarly the wires 513, 514, connect to one member of each of the respective circuit closers, 60, 61, of the secondary instrument, the

other members of which are connected by branch 506 to the negative lead, 500−, so that the circuit of the third or fourth solenoid is closed by the circuit closer, 60, or 61, according as more or less air is required.

As shown in Fig. 2, the main supply circuit, 500, and the control circuits from the primary controlling instrument, extend beyond the secondary instrument, this being to indicate that they may lead to other secondary instruments pertaining to other boilers, all of which form a single steam generating unit or battery under control of the single primary instrument, 2.

Referring to Fig. 2, the switch 02 of the primary instrument is shown as a three-pole or three-arm switch and it will be seen that if thrown to the other position it will merely transfer the connections from the automatic circuit closers, 22, 220, to the push buttons, M, L, which will then operate the first and fifth or the second and sixth clutches concurrently, according as the push button M or L is operated.

So far as the control by the primary instrument is concerned, the circuit connection might lead directly from the circuit closers or push buttons thereof to the terminals, 511, 512, 515 and 516, of the solenoids of the corrector driver. They are, however, passed by branches through the switches 04 of the secondary instruments, so that the correction or change of fuel and air supply either concurrently or individually, may be made by an attendant at any of the secondary instruments.

When the switch, 04, is in the position numbered 1, in Fig. 1, the connections are as indicated in Fig. 3 in which it will be seen that the wires leading from the first and second and the fifth and sixth solenoids are not connected with anything beyond the switch, so that control is taken entirely away from the primary instrument. Furthermore, the connections, 513 and 514, from the third and fourth solenoids are shifted from the connection with the automatic circuit closers, 60, 61, of the secondary instrument to the push buttons, M and L, thereof, while the connection 510*a* from the positive terminals of the said third and fourth solenoids is connected by branch 510*b* (see Fig. 2) to the positive main lead, 500+. Consequently in this position of the switch of the secondary instrument the attendant at that instrument can effect an increase or decrease in the air supply, that being for the time being the only control afforded.

In the No. 2 position of the switch 04 of the secondary instrument the connections are as shown in Fig. 4 in which the wires leading from all of the solenoids except the fifth and sixth are disconnected and the latter (wires 515, 516) are connected to the push buttons M and L of the secondary instrument, while the positive connection, 510, from said solenoids is connected to the branch 510*b* leading to the positive main lead, 500.

In this position, therefore, the operator at the secondary instrument where the switch 04 is set in the No. 2 position, can increase or diminish the fuel supply by pressing the button M or L, and no other control is provided for.

Thus it will be seen that with the switch 04 either in the No. 1 position as shown in Fig. 3, or the No. 2 position as shown in Fig. 4, or alternately in either of these positions, the boiler whose ratio of fuel and air may be automatically controlled by this particular controller 40 will be entirely cut off from automatic control of both the primary instrument 02 and the secondary instrument 40 while the switch is either in the No. 1 or No. 2 position. As many boilers of the battery as may be desired can thus be cut off from automatic control, while the remaining boilers of the battery are being automatically controlled by the primary controller 2 and the controller 40 appurtenant to the particular furnace as heretofore described. In this way it is possible to operate a battery of boilers so that the boilers of the battery that are disconnected from the automatic control can have their fuel and air manually set to take care of a constant load, or so that the output of these boilers so manually set will be constant, while the variations in the total load will be taken care of by the boilers of the battery that are still being controlled by the automatic controllers 2 and 40. For example, the boiler to which the connections A (Fig. 2) appertain may be cut off entirely from automatic control by leaving the switch 04 in the No. 1 position (Fig. 3) or in the No. 2 position (Fig. 4), thus permitting this boiler to care for the steady load, while other boilers to which connections B and C (Fig. 2) that are like connections A appertain, may be kept under automatic control by leaving their corresponding switches 04 in the No. 4 position as shown in Fig. 2 to permit these other boilers to care for the variations in loads. In this way any desired number of the boilers of a battery may be isolated from the automatic control and be caused to operate with constant output, while the remaining boilers are left susceptible to the automatic control in order to have their output varied with varying loads.

In the No. 3 position (Fig. 5) of the switch 04, the corresponding boiler is also disconnected from the primary instrument so that its output can be manually set by the push buttons M and L of the secondary instrument to care for steady load conditions, while the boilers of the battery that have their switches 04 in the No. 4 position (Fig. 2) will care for the variations in load. At the same time the secondary instrument 40 of the boiler or boil-

ers set for steady load conditions will, with the switch or switches thereof 04 in the No. 3 position (Fig. 5), readjust the air for proper proportion to the fuel regardless of the steady load for which the boiler is manually set by the switches M and L.

In the No. 3 position, the connections for which are shown in Fig. 5, the positive leads 510, 510*a*, from all of the solenoids are connected through branch 510*b* with the positive main lead, while the connections 511, 515, from the first and fifth solenoids are connected to the push button M of the secondary instrument, and the connections 512, 516, from the second and sixth solenoids are connected to the push button L, so that the attendant at that instrument may bring about a simultaneous increase of fuel and air, or a simultaneous decrease of fuel and air, the circuits to the primary instrument for automatic operation being disconnected.

In this No. 3 position (Fig. 5) the connections from the third and fourth solenoids (wires 513 and 514) are to the main leads through the automatic circuit closers, 60, 61, of the secondary instrument, so that the automatic readjustment control of the air is maintained.

The operation of the apparatus will be readily understood from the foregoing description. With the switches 02 and 04 in normal position and with the indicators of the primary and secondary instruments in normal position, that is, the steam gauge indicating the normal pressure which it is desired to maintain, and the steam-flow air-flow meter indicating by coincidence of its pointers that the relation of steam flow to air flow is such as prevails when the combustion is efficient, there will be no effective operation of the parts and the condition of the fuel supply and air supply will remain the same and in proper amount to generate the steam required at whatever demand then exists or whatever the power rating at the time may be.

The feelers of the controlling instruments will, however, continue to perform their periodic to and fro working movements and the shafts of the corrector driver will continue to run, although without producing any effect as all of the clutches are disengaged.

If, however, there is a change in demand for power, or call for a change in the rating of the steam plant, the indicator of the primary instrument will be moved in one or the other direction according as the steam pressure falls or rises in response to increased or decreased demand. The feeler of the primary instrument will then operate one or the other of the circuit closers, 22, 220, according as an increase or decrease of heat input is called for, thus energizing the first and fifth solenoids of the corrector driver, or the second and sixth, according as the steam pressure had fallen or risen. The energizing of the first and fifth solenoids connects the first and fifth clutches and thus causes the corrector driver to move, by the first shaft, the air controlling device in the direction to give more air supply, and to move, by the fifth shaft, the rheostat, 206, in the direction to cause increase of speed of operation of the fuel feeding motor, 207.

This operation of slowly increasing the fuel and air supplies will continue for a short interval of time, while the feeler is making its forward movement towards the indicator and will then cease when the feeler begins its return movement, so that the corrective action on the fuel and air supplies is discontinued and a new rate of fuel and air feed is for the time being established.

If the change in demand for power is comparatively small and the movement of the pressure indicator consequently comparatively slow the feeler will produce only a relatively short closure of the circuit and the corrective action or change of fuel and air feed will be relatively small. If, however, the change in demand is large and the change of pressure rapid, the amount of correction would be correspondingly increased.

If the change in pressure did not increase further there would be no further correction at the next operation of the feeler if the change had been small, or only a small further correction if the change in pressure had been somewhat more rapid, but if the change had been sudden and large so that the yielding stop, 32, for the circuit closer, 22, had been called into operation, a further correction of the same character would be made at the next and at succeeding operations of the feeler until the pressure began to return towards normal.

The retarder, or provision for delaying the return of the automatic circuit closer of the primary instrument to its normal position would, in the case of the small correction first considered, prevent further corrective action on the next and ensuing operations of the feeler and the appliances would wait for a short period, thus testing, as it were, the effect of the slight correction already made.

If the correction has been sufficient it would, as soon as the increase of combustion had time to take effect upon the generation of steam, restore the pressure to normal with but slight liability of carrying the change beyond normal, so as to require a new correction of the opposite kind.

If, however, the slight correction made were insufficient the pressure would continue to change in the same direction as before and would then bring about an additional corrective action, about the same in amount as the first, which would be followed by another delay to test the effect of the further correction.

In this way the action of the controller anticipates the effect produced by it and waits until the result of an initial correction is made evident before making a further corrective action.

However great and rapid the change of pressure may have been, as soon as the pressure begins to return towards normal the action of the retarder will be to prevent the feeler from bringing about further corrective action, until the pressure is restored to normal.

Thus, except in the case of excessive fluctuations in the demand for power, the correction is usually effected and the pressure brought back to normal at the new rating without overcorrection and carrying the pressure beyond normal so as to require correction of the opposite kind, or hunting.

Owing to the described effective speeds of the first and second shafts of the corrector driver, relative to that of the fifth and sixth, when the first and fifth shafts are operating to increase the fuel and air supply the latter will be increased at a relatively higher rate thus producing an excess of air above what is required for proper combustion, while the change is being made, and similarly when the second and sixth shafts operate to diminish the fuel and air supply the fuel supply is operated more rapidly than the air supply, so that an excess of air is also brought about while making such correction for reducing the input of heat.

The secondary controlling instrument, 40, responds to an excess of air beyond what is required for efficient combustion for the generation of the amount of steam produced, as indicated by the steam-flow component of the meter, or to a deficiency of air if such should at any time arise, and by the action of its feeler and circuit closers causes more or less air to be supplied as the indication calls for.

The differential connection between the shaft, 120, for correcting the air supply under control of the primary instrument, and the shaft, operated by the gear 123, for correcting the air under control of the secondary instrument, permits both corrections to be made concurrently when required, the damper or thing to be corrected responding to the differential or algebraic sum of the corrections due to the action of the primary and secondary instruments.

The invention is not limited to the mechanical details of the various instruments herein shown, as obviously they may be widely varied without departure from the essential matters of organization and cooperation of the instrumentalities hereinbefore described.

Novel features of the mechanical construction which are not herein claimed will form the subject of other applications for patent.

It will be apparent that the organization is such as to lend itself to a great variety of structural organization. Taking into account the fact that the problem of maintaining efficient combustion is exceptionally difficult when powdered coal is the fuel used, the construction herein shown for purposes of illustration is comparatively simple and sufficient only to show a complete adequate organization of the cooperating elements of the controlling apparatus, which obviously might be expanded to include other factors the control of which would be necessary or desirable to complete the effective attainment of the result desired.

The use of the control apparatus forming a subject of this invention is not limited to the control of a steam generating plant such as has been taken to illustrate an embodiment of the invention, as the same or equivalent controlling means might be employed for the regulation of any variable, the variations of which may be regulated or controlled by changing or correcting one or more variable factors, and in which, if required, the variable factors may be correlated to one another as a secondary or readjustment regulation additional to but independent of the variation of all of the factors for controlling the variable which is primarily to be regulated.

I claim

1. An automatic controlling apparatus for maintaining the desired condition of combustion in a steam generator furnace, comprising an indicator responsive to changes of steam pressure; correctors for changing the rate of supply of fuel and air to the furnace, and a controlling instrument comprising a feeler which has a periodic movement relative to the indicator and which causes the correctors to operate during portions of the period of movement of the feeler when the indicator is in abnormal position.

2. An automatic controlling apparatus for maintaining the desired condition of a variable to be regulated, comprising a primary control instrument having an indicator responsive to changes of said variable; correctors for changing correlated factors, by which said variable is regulated, and a controlling instrument which causes the proper correctors to operate concurrently when the indicator is in abnormal position, and a secondary control instrument for varying one or more of said factors independently of the primary control to bring it to proper or normal relation to the others.

3. A control system for regulating the operation of a steam generating plant, comprising a primary instrument having an indicator movable in response to changes of pressure of the steam generated; correctors for changing the rate of supply of fuel and of air concurrently to the furnaces; means responsive to said indicator for causing the said correctors gradually to increase or decrease the rate of supply of the fuel and air

controlled by them, and a secondary control instrument having an indicator responsive to change in the relation of steam output to rate of air supply to the furnace and means responsive to said indicator for effecting an action of the air flow corrector independent of that responsive to the primary control instrument.

4. An automatic controlling apparatus for regulating the ratio of fuel to air in a furnace, comprising an indicator responsive to changes of said ratio; correctors for changing one or more factors by which said ratio is regulated; a corrector driver having a continuously running, but normally inactive, means for operating each of said correctors to change the same gradually in one or the other direction; and a controlling instrument responsive to the indicator and controlling the effective engagement of the driver and correctors.

5. An automatic controlling apparatus for regulating the ratio of fuel to air in a furnace, comprising an indicator responsive to changes of said ratio; correctors for changing one or more factors by which said ratio is regulated and a controlling instrument comprising a feeler which has a periodic movement relative to the indicator and has provision for causing the correctors to operate during greater or less portions of the period of movement of the feeler, dependent upon the amount of change of the indicator in one period of said movement.

6. An automatic controlling apparatus for maintaining the desired condition of a variable to be regulated, comprising an indicator responsive to changes of said variable; correctors for changing one or more factors by which said variable is regulated and a controlling instrument comprising a feeler which has a periodic movement relative to the indicator and has provision for causing the correctors to operate during greater or less portions of the period of movement of the feeler, dependent upon the amount of changes of the indicator in one period of said movement, and retarding means whereby the effect of the feeler on the correctors is diminished at its succeeding periods of operation.

7. An automatic controlling apparatus for maintaining the desired condition of a variable to be regulated, comprising an indicator responsive to changes of said variable; correctors for changing one or more factors by which said variable is regulated and a controlling instrument comprising a feeler which has a periodic movement relative to the indicator and has provision for causing the correctors to operate during greater or less portions of the period of movement of the feeler, dependent upon the amount of change of the indicator in one period of said movement, and retarding means whereby the effect of the feeler on the correctors is annulled during change of indicator from abnormal towards normal position.

8. A control system for regulating the operation of a steam generating plant, comprising an indicator movable in response to changes of pressure of the steam in the boiler; correctors for changing the rate of supply of fuel and air to the boiler furnace, and a controlling instrument comprising a feeler having a periodic movement relative to the indicator and cam surfaces for cooperating with the feeler when moved in response to departure from normal pressure, and means operated by said feeler for causing operation of said correctors dependent upon the direction and extent of change of the indicator in a period of operation of the said feeler.

9. A control system for regulating the operation of a steam generating plant, comprising an indicator movable in response to changes of pressure in the steam boilers; correctors for changing the rate of supply of fuel and air to the boiler furnace; a corrector driver having continuously running means for operating said correctors individually gradually to increase or decrease the supply of fuel and air controlled by them, said operating means being normally disconnected from the said corrector; electromagnetic devices controlling the operative engagement of the driver with the individual correctors for driving the same in either direction, and a controlling instrument responsive to the indicator, comprising a feeler having a cam surface and a circuit closer operated thereby controlling the electromagnetic devices of the driver.

10. A control system for regulating the operation of a steam generating plant, comprising an indicator movable in response to changes of pressure of the steam generated; correctors for changing the rate of supply of fuel and of air concurrently to the furnaces; a corrector driver having continuously running, but normally inactive, means for operating said correctors individually gradually to increase or decrease the rate of supply of the fuel and air controlled by them; connecting mechanism between said driver and correctors adapted to increase the air supply at a relatively higher rate than that of the concurrent increase in fuel supply, and to decrease the fuel supply at a relatively higher rate than that of the concurrent decrease in air supply; a controlling instrument responsive to the indicator governing the operative engagement of the driver with the correctors; and a secondary control instrument and an independent connection therefrom to the corrector for the rate of air supply governed thereby to correlate the rate of air supply to that of fuel supply for efficient combustion.

11. A control system for regulating the operation of a steam generating plant, comprising a primary control instrument having

an indicator movable in response to changes of pressure of the steam generated; correctors for changing the rate of supply of fuel and air concurrently to the furnaces; a corrector driver having continuously running, but normally inactive, means for operating said correctors concurrently gradually to increase or decrease the rate of supply of the fuel and air controlled by them; means controlled by the indicator for governing the engagement of the driver with the correctors to be operated; a secondary control instrument having an indicator; and means controlled by the said secondary indicator for governing the engagement of the driver with the corrector for the air supply; and a differential connection between the components of the actuating mechanism of the driver for the air supply corrector which are controlled by the primary and secondaary control instruments respectively.

12. A control system for regulating the operation of a steam generating plant, comprising a primary control instrument having an indicator movable in response to changes of pressure of the steam generated; correctors for changing the rate of supply of fuel and of air concurrently to the furnaces; a corrector driver having a continuously running but normally inactive means for operating said correctors concurrently gradually to increase or decrease the rate of supply of the fuel and air controlled by them; connecting mechanism between said driver and the correctors whereby the air supply is increased at a relatively higher rate and is decreased at a relatively lower rate than the concurrent increase or decrease in rate of fuel supply; said primary controlling instrument having a feeler provided with a modifying cam surface; means for operating said feeler periodically; and means controlled thereby for effecting operative engagement of the connecting mechanism of the driver with the correctors; a secondary control instrument having an indicator responsive to variations in efficiency of combustion and a periodically operated feeler and means operated by said feeler and indicator which control the operative engagement of the driver with the air flow corrector other than that governed by the primary control instrument.

13. A control system for a plurality of steam boilers feeding a main line comprising means for initially correcting the supply of fuel and air to said boilers when the pressure in the main line departs from the normal, and means to prevent further correction of the two until time has elapsed to test the initial correction.

14. A control system for a plurality of steam boilers feeding a main line comprising means for initially correcting the supply of fuel and air to said boilers when the pressure in the main line departs from the normal, and means to vary the amount of initial correction in accordance with the amount of departure from the normal.

15. A control system for a plurality of steam boilers feeding a main line comprising means for initially correcting the supply of fuel and air to said boilers when the pressure in the main line departs from the normal, and means to increase the correction after an interval of time provided the pressure has in the meantime departed farther from the normal.

16. A control system for a plurality of steam boilers feeding a main line comprising means for initially correcting the supply of fuel and air to said boilers when the pressure in the main line departs from the normal, and means to increase the correction after an interval of time provided the pressure has in the meantime departed farther from the normal, the increase in the amount of correction being proportional to the change in boiler pressure during said interval of time.

17. A control system for a plurality of steam boilers feeding a main line comprising means for changing the supply of fuel and air to said boilers when the pressure in the main line departs from the normal, and means to modify the proportion of fuel and air supplied to each boiler independently of the proportion of fuel and air supplied to the other boilers after said change in fuel and air supply has been made.

18. A control system for a plurality of steam boilers feeding a main line comprising means for initially correcting the supply of fuel and air to said boilers and feeding an excess of air during said correction when the pressure in the main line departs from the normal, and means to prevent further correction of the two until time has elapsed to test the initial correction.

19. A control system for a plurality of steam boilers feeding a main line comprising means for changing the supply of fuel and air to said boilers when the pressure in the main line departs from the normal, and means to modify the proportion of fuel and air supplied to each boiler independently of the proportion of fuel and air supplied to the other boilers after said change in fuel and air supply has been made until the proportion reaches the maximum efficiency.

20. A control system for a plurality of steam boilers feeding a main line comprising means for initially correcting the supply of fuel and air to said boilers when the pressure in the main line departs from the normal, and maintaining a correction at least substantially as great as said initial correction until the normal pressure is again reached.

21. A control system for a plurality of steam boilers feeding a main line comprising means for initially correcting the sup-

ply of fuel and air to said boilers when the pressure in the main line departs from the normal, and means to prevent further correction of the two until time has elapsed to test the initial correction and to produce small corrections in the same direction upon further slow departure from the normal.

22. A control system for use with apparatus having a factor which, during operation of the apparatus, tends to vary from the predetermined value, for maintaining said factor at the predetermined value, comprising means which when operated tends to restore said factor to its predetermined value and ceases substantially to operate for additional restoration of said factor for a period of times sufficiently long to test the effect of its last restorative operation, control means comprising mechanism for effecting movement of said means, means whereby the magnitude of said movements is dependent upon the rate of departure of said factor from the predetermined value, means whereby upon departure of the factor an adjustable predetermined amount from the predetermined value, the successive movements of said first-named means will be of a constant magnitude.

23. A control system for use with apparatus having a factor which, during operation of the apparatus, tends to vary from the predetermined value, for maintaining said factor at the predetermined value, comprising means positioned in accordance with variations of said factor from the predetermined value, means which when operated tends to restore said factor to its predetermined value and ceases substantially to operate for additional restoration of said factor for a period of time sufficiently long to test the effect of its last restorative operation, and control means through which said first-named means effects operation of said second-named means, said control means comprising mechanism for effecting movements of said second-named means in each direction, means whereby the magnitude of such movements is dependent upon the rate of departure of said factor from the predetermined value, and means whereby upon departure of the factor an adjustable predetermined amount from the predetermined value, the successive movements of said first-named means will be of a constant magnitude.

24. A control system for regulating the operation of a steam generating plant, comprising a primary control instrument having an indicator movable in response to changes of pressure of the steam generated, correctors for changing the rate of supply of fuel and air concurrently to the furnaces, a corrector driver having normally inactive motor means for operating said correctors concurrently gradually to increase or decrease the rate of supply of the fuel and air controlled by them, means controlled by the indicator for making the driver effective on the correctors to be operated, a secondary control instrument having an indicator, and means controlled by the said secondary indicator for making the driver effective on the corrector for the air supply, and a differential connection between the components of the actuating mechanism of the driver for the air supply corrector which is controlled by the primary and secondary control instruments respectively.

25. A control system for regulating the operation of a furnace, comprising a primary control instrument having an indicator movable in response to a variable factor produced by said furnace, correctors for changing the rate of supply of fuel and air concurrently to said furnace, a corrector driver having normally inactive motor means for operating said correctors concurrently gradually to increase or decrease the rate of supply of the fuel and air controlled by them, means controlled by the indicator for making the driver effective on the correctors to be operated, a secondary control instrument having an indicator, means controlled by the said secondary indicator for making the driver effective on the corrector for the air supply, and a differential connection between the components of the actuating mechanism of the driver for the air supply corrector which is controlled by the primary and secondary control instruments respectively.

26. A control system for regulating the operation of a furnace, comprising a primary control instrument having an indicator movable in response to a variable factor produced by said furnace, correctors for changing the rate of fuel and air concurrently to said furnace, a corrector driver having normally inactive motor means for operating said correctors concurrently gradually to increase or decrease the rate of supply of the fuel and air controlled by them, means controlled by the indicator for making the driver effective on the correctors to be operated, a secondary control instrument having an indicator, means controlled by the said secondary indicator for making the driver effective on the corrector for the air supply, and a differential connection between the components of the actuating mechanism of the driver for one of the elements of combustion for the furnace which is controlled by the primary and secondary control instruments respectively.

27. An automatic controlling apparatus for maintaining the desired condition of a variable to be regulated, comprising an indicator responsive to changes of said variable, correctors for changing one or more factors by which said variable is regulated, a corrector driver having normally inactive motor means for operating said correctors concurrently gradually to increase or de-

crease the factors controlled by them, means controlled by the indicator for making the driver effective on the correctors to be operated, a secondary control instrument having an indicator, means controlled by said secondary indicator for making the driver effective on the corrector of one of the factors, and a differential connection between the components of the actuating mechanism of the driver corrector of one of the factors which are controlled by the primary and secondary control instruments respectively.

28. Combustion control apparatus comprising in combination, a furnace, apparatus for supplying the elements of combustion to the furnace, a gear driven corrector of the rate of supply for each element, means responsive to a factor in furnace operation for concurrently actuating the correctors, means responsive to a second factor in furnace operation for actuating one of the correctors, and a differential gear connection between said means and said last-named corrector.

29. A control system for a vapor generator comprising means for initially correcting the supply of the elements of combustion to the generator when the vapor pressure departs from normal, and means to prevent further correction of the elements of combustion until time has elapsed to test the initial correction.

30. A control system for a vapor generator, comprising means for initially correcting the supply of the elements of combustion to the generator when the pressure departs from normal, and means to increase the correction after an interval of time provided the variable has in the meantime departed farther from the normal.

31. A control system for maintaining the value of a variable, comprising means for initially correcting a factor influencing the value of said variable when the variable departs from the normal, and means to increase the correction after an interval of time only if the variable has in the meantime departed farther from the normal.

32. A control system for maintaining the value of a variable, comprising means for initially correcting a factor influencing the value of said variable when the variable departs from the normal, and means to increase the correction after an interval of time only if the variable has in the meantime departed farther from the normal, the increase in the amount of correction being proportional to the change in said variable during said interval of time.

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