

June 2, 1942.

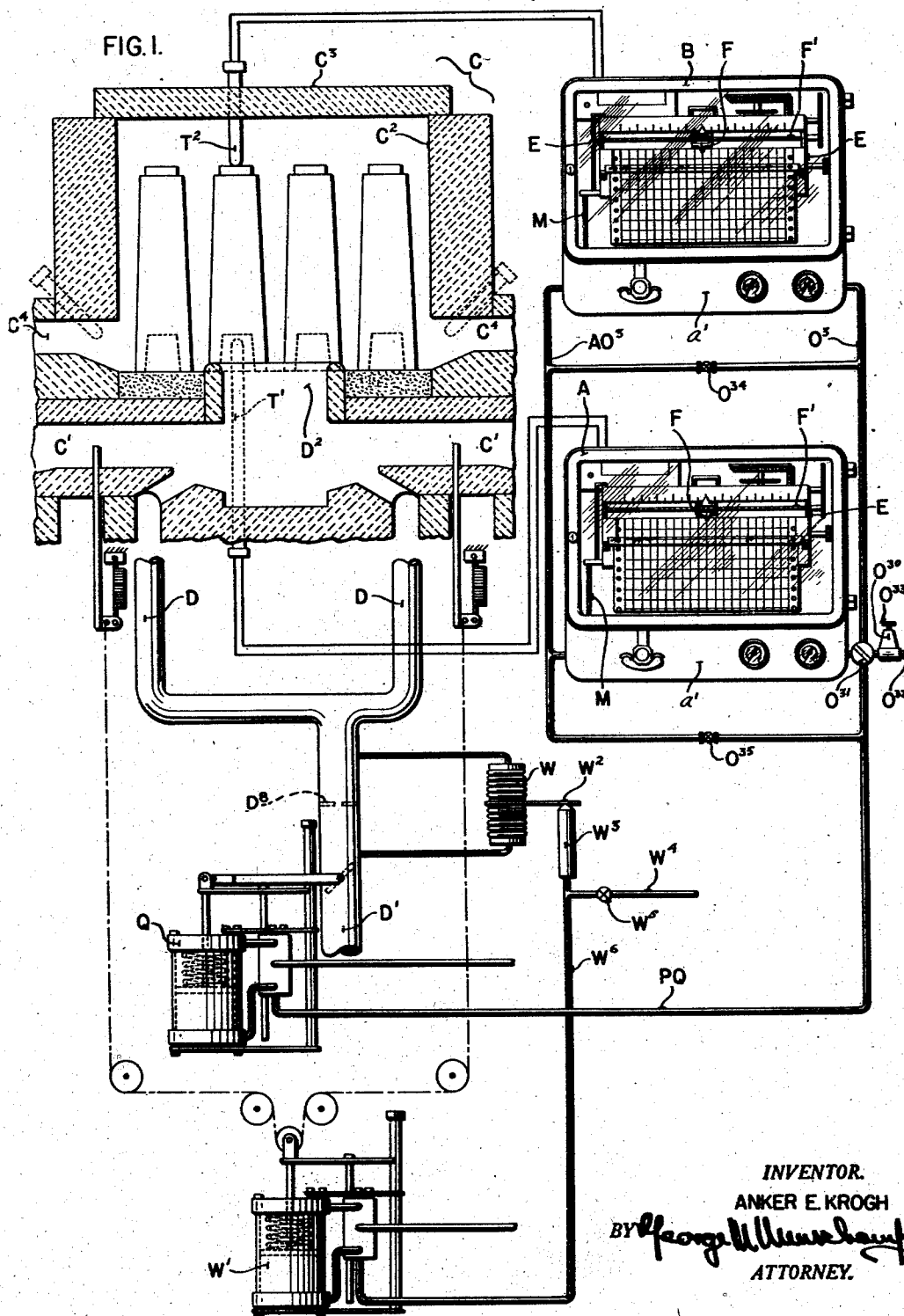
A. E. KROGH

2,285,288

AUTOMATIC CONTROL APPARATUS

Filed April 15, 1938

6 Sheets-Sheet 1



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AUTOMATIC CONTROL APPARATUS

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FIG. 2.

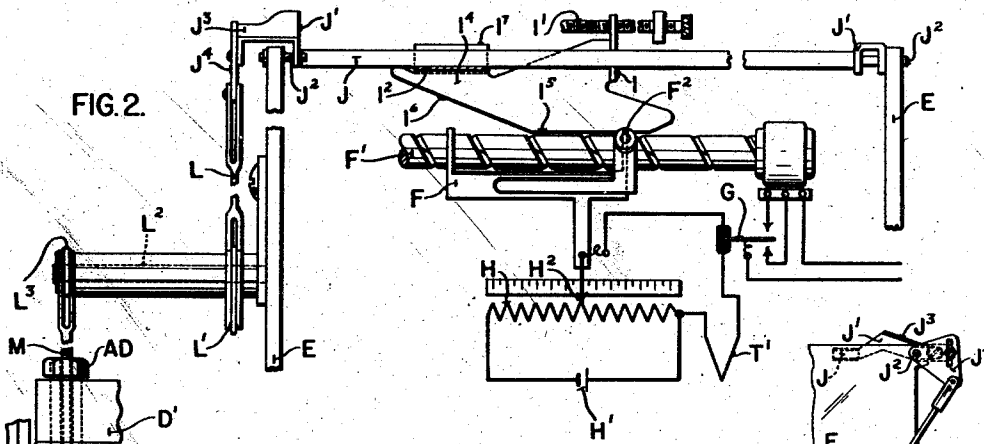


FIG. 2B.

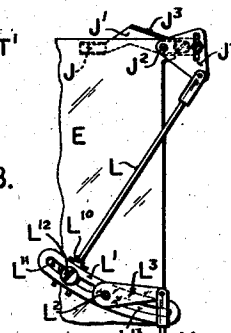
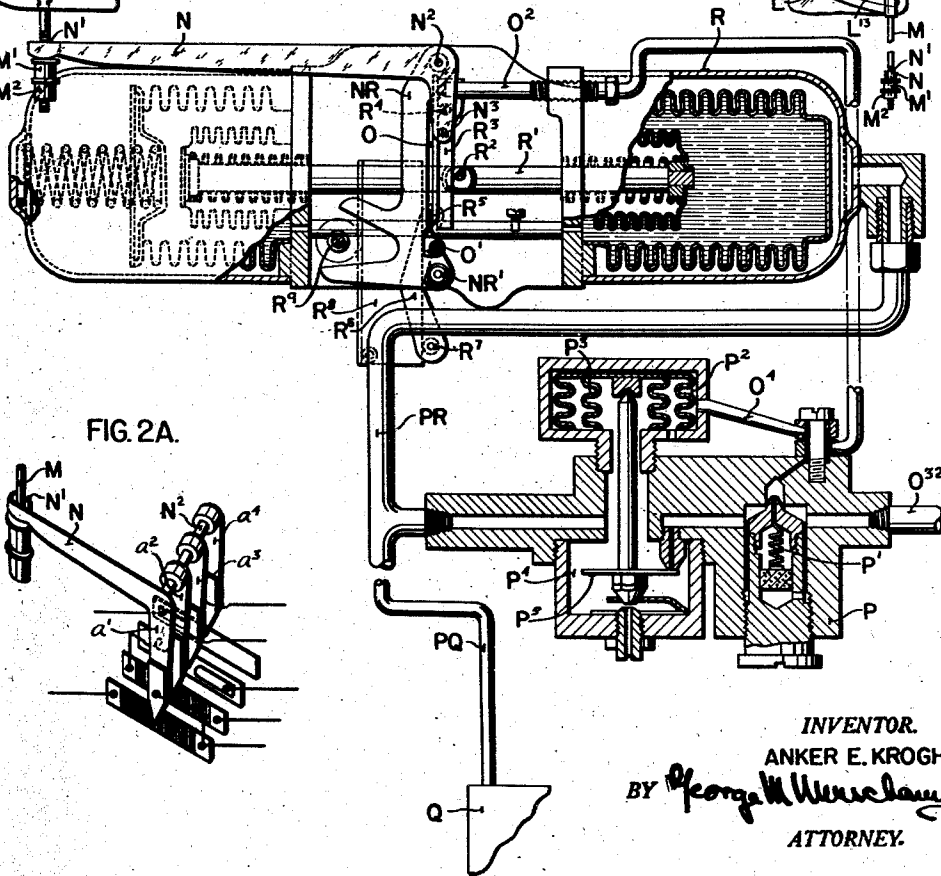


FIG. 2A.



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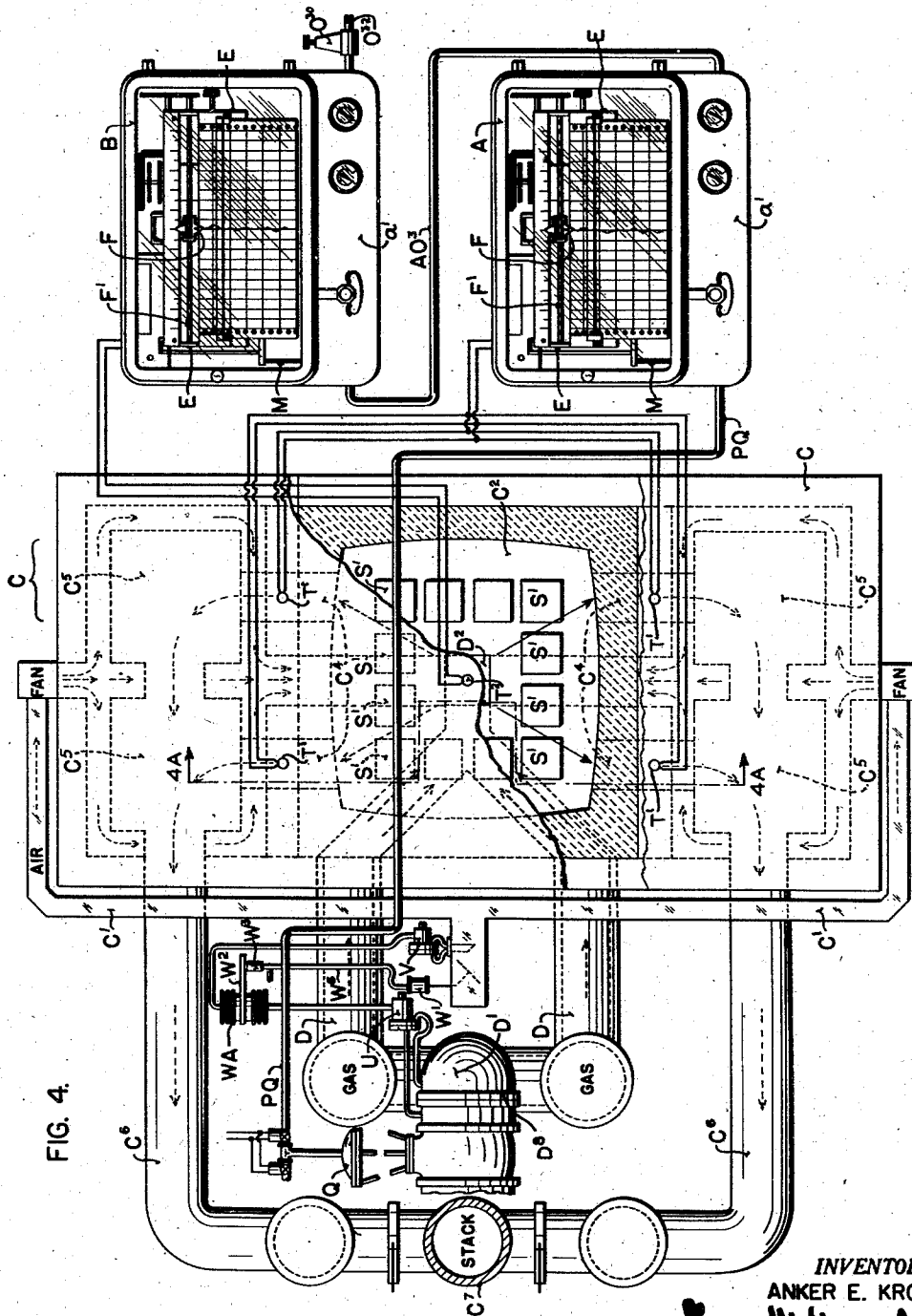
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AUTOMATIC CONTROL APPARATUS

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6 Sheets-Sheet 4



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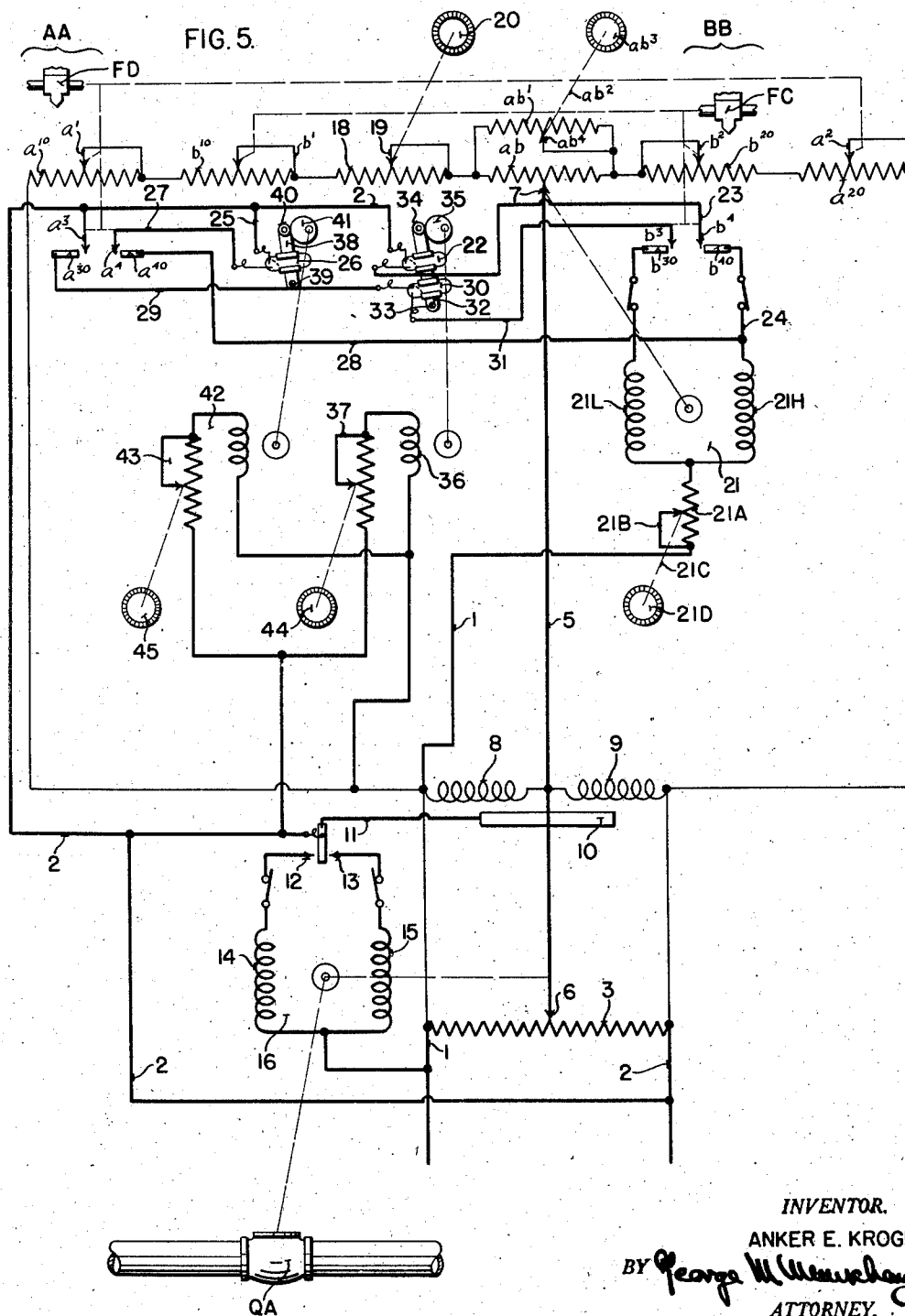
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AUTOMATIC CONTROL APPARATUS

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6 Sheets-Sheet 5



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2,285,288

AUTOMATIC CONTROL APPARATUS

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6 Sheets-Sheet 6

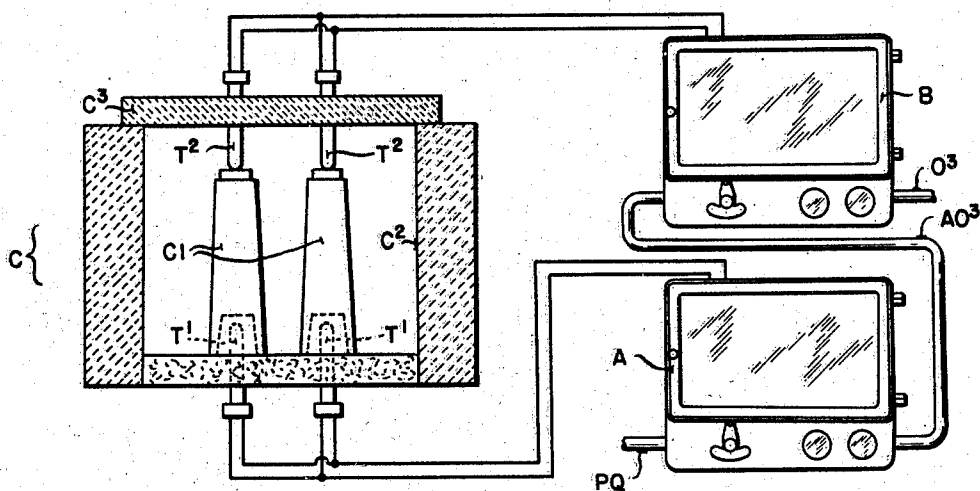


FIG. 1C.

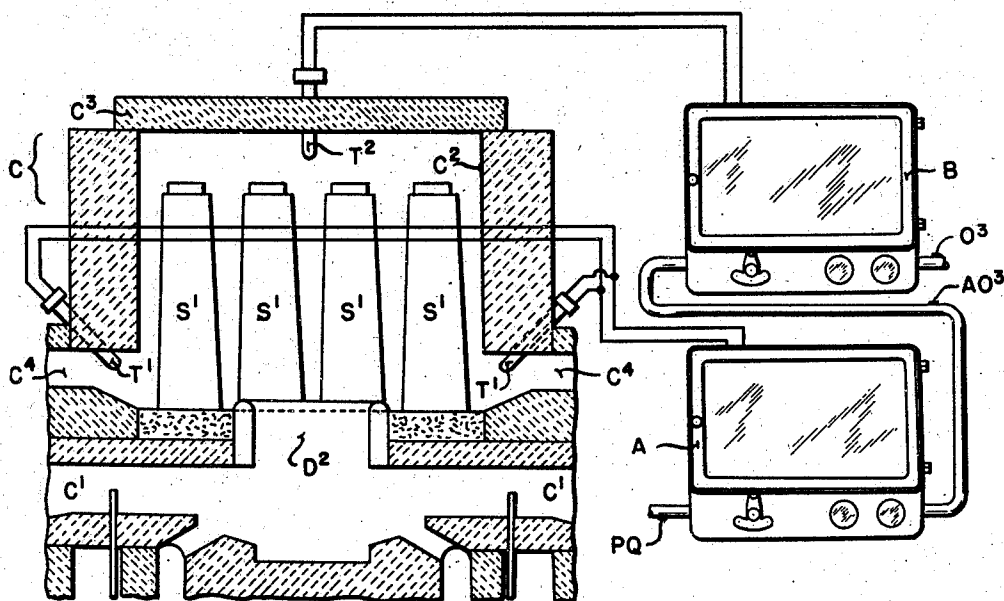


FIG. 4A.

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UNITED STATES PATENT OFFICE

2,285,288

AUTOMATIC CONTROL APPARATUS

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Application April 15, 1938, Serial No. 202,307

4 Claims. (Cl. 263—2)

This invention relates to automatic control apparatus and especially to the automatic control of metallurgical furnaces such as soaking pits and the like, in which large ingots of steel or other metal are heated preparatory to a rolling or other subsequent processing operation.

In the control of soaking pits and other metallurgical furnaces, it is desirable to heat the charge to the desired temperature with a minimum consumption of fuel, in the quickest possible time and without damage to the charge. Specifically, a soaking pit is in the form of a large covered pit to which fuel, mixed with the proper proportion of combustion supporting air, is supplied through a burner port which may be at the center and bottom of the pit from which the flame sweeps upward, impinging upon the top of the pit. The products of combustion thereafter move downward along the vertical pit walls and exhaust through a plurality of ducts, the path of the gases thereby substantially surrounding the charge. The soaking pit may be of the type shown and described in Morton et al. Patent Number 2,079,560.

The regulation of the supply of fuel and air to the pit burner should be carried out in such a manner as to prevent the attainment of an excessive temperature by the ingots, to the end of preventing "washing" or burning of the ingot oxide coating or scale, such "washing" being undesirable both from the standpoint of the loss of metal, and increased frequency of pit repair, and also because severe cases of "washing" may give rise to imperfections in the subsequently fabricated metal. On the other hand, relatively high ingot temperatures must be finally attained and sometimes held for a period in order to prepare the ingots for rolling or the like, and this operation should, in the interest of fuel economy, steel structure and mill efficiency, be carried out as rapidly and uniformly as possible.

In order to attain uniform heating of all the charge to the desired temperature, including the portions most remote from the heating medium, and without overheating or "washing" any portion of the charge, I control the fuel supply to the furnace in significant response to the portion of the charge most remote from the source of heat, as well as in significant response to the portion of the charge most likely to be overheated.

The various features of novelty which characterize the present invention are pointed out with particularity in the claims annexed to, and forming a part of this specification, but for a better

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

Of the drawings,

Fig. 1 is a more or less diagrammatical view of one embodiment of the invention;

Fig. 1A is a more or less diagrammatical view showing one modification of the invention;

Fig. 1B is a more or less diagrammatical view showing another modification of the invention;

Fig. 1C is a more or less diagrammatic view showing still another modification of the invention;

Fig. 2 is a detailed fragmentary view, partially diagrammatical, of apparatus shown in Fig. 1;

Fig. 2A is a detailed modification of a portion of Fig. 2;

Fig. 2B is a detailed modification of another portion of Fig. 2;

Fig. 3 is a diagrammatical view of another embodiment of the invention;

Fig. 4 is a diagrammatical view of still another embodiment of the invention; and

Fig. 4A is a sectional view taken substantially along the line 4A—4A of Fig. 4;

Fig. 5 is a diagrammatical view of alternate apparatus for carrying out the embodiment of Fig. 4.

Referring first to Figs. 1, 4 and 4A, a soaking pit C is illustrated which has fuel gas ducts D supplied from a common main D', whereby fuel is supplied to a burner port D² at the bottom of the pit. Combustion supporting air is supplied through ducts C' and recuperators C⁵, one at each side of pit or chamber C² to the chamber. Such air may be mixed with the gas fuel before the latter leaves burner port D², as in Fig. 1. Products of combustion pass from the chamber C² to the waste gas passages of recuperators C⁶ through outlet ducts C⁴, and pass therefrom to the stack or exhaust pipe C⁷ (Fig. 4) through stack ducts C⁸.

The top of the pit chamber C² is usually covered by a cover C³, which is removed to permit the insertion and removal of ingots CI by a crane hoist. The cover, in the case of a batch heating operation as is contemplated herein, is removed when the batch of hot ingots is removed, and replaced after a batch of cold ingots is inserted in the pit. The cold ingots may be copper, steel or other metal depending upon the circumstances; and should be heated to a tem-

perature dependent upon the nature of the subsequent operation such as rolling or drawing, and upon the desired nature of the final product. The fuel by which the pit is heated may vary widely in B. t. u. content, as for example it may be coke oven gas, blast furnace gas or other gas, or may be a mixture of several available gases. The different variables thus encountered result in widely varying conditions and disturbances contributing to the control difficulties, which the control system now to be described in detail, is intended to minimize.

The control system of Fig. 1 includes two control instruments B and A, each of a form described more in detail in connection with Fig. 2, and responding respectively to the temperature on the top surface of an ingot within the pit, and to the temperature of the bottom and inside of an ingot within the pit. With suitably distributed heating of the pit it is immaterial which ingot is selected for either thermocouple T' or T², which thermocouples are the temperature sensitive elements respectively responsive to ingot top temperature and ingot inside bottom temperature, and connected to instruments A and B. If the heat distribution is uneven, special ingots may be selected for the thermocouples. If for example the ingots S' (see Fig. 4) which are in the path of the hot gases between the burner port and outlet ducts, are under some conditions hotter than the other ingots, the thermocouple T² should be associated with one of those, and preferably with the hottest of those ingots. Under those conditions the thermocouple T' should be associated with an ingot other than ingots S', and preferably with the coolest of the remaining ingots. It should be understood that the use of the terms "hottest" or "coolest" ingots is made for convenience of description, and actually contemplates respectively the ingot most quickly affected on a change in fuel supply and the ingot most slowly affected on a change in fuel supply.

The instruments A and B together control the position of a fuel valve by means of the fluid operated motor Q, the latter under direct control of the instrument A, which regulates the control pressure in pipe PQ accordingly as the temperature of the ingot butts or bottoms varies from a predetermined value. Fluid under pressure is supplied to instrument A from a pipe AO³. If the supply of fluid pressure to the instrument A were constant, the control of valve Q would be solely in accordance with the butt temperature, but the supply pressure to instrument A is not constant under all conditions, but at times is regulated by the instrument B. Instrument B is supplied with a substantially constant fluid pressure through a pipe O³ and four way valve O³¹. The valve O³¹ normally connects the pipe PQ with instrument A, and places supply pipe O³ in communication with a suitable source of pressure O³² regulated by pressure regulator O³⁰. Instrument B through means later described, regulates the pressure in pipe AO³, supplying instrument A, in accordance with the variations in temperature at the ingot top, whereby the final regulating effect upon valve motor Q is in joint accordance with the ingot top and ingot butt temperatures.

It is desirable to maintain the ratio between the volume of fuel supplied and the volume of air supplied. To this end either the "semi-metered" controller of Fig. 1 or the "fully metered" controller of Fig. 4 may be used. In Fig. 1, a device W is employed which is responsive to the differ-

ential pressure across an orifice D⁸ in the fuel line D' and responsive therefore, to the rate of flow of fuel, to move a flapper valve W² with respect to a nozzle W³ and thereby control the supply of fluid pressure to a damper motor W' supplying combustion supporting air to chamber C². Nozzle W³ is supplied with pressure from a suitable source W⁴ through restriction W⁵ to control the pressure in pipe W⁶ connected to the damper motor W'. In Fig. 4 a flow metering device U is employed to measure the fuel flow and a flow metering device V is employed to measure the air flow, these meters being adapted to actuate a ratio flow controller WA and adjust fluid pressure motor W', controlling the supply of air as necessary to maintain the desired volumetric ratio between fuel and air. Since the present invention is not concerned with ratio flow control means such apparatus need not be described in detail here, but is generally described to make plain that it is immaterial in respect to this invention whether as shown, the fuel valve is controlled by the novel control apparatus, and the supply of air is proportioned thereto, or whether the air valve is controlled by this apparatus and the fuel proportioned to the air. Limitations in the field, arrangement of fuel and air lines and the like will normally determine which arrangement is used, so that in referring to control of fuel either air or gas or other fuel in contemplated.

The instruments A and B may take different forms, and as shown in Fig. 1, each comprises a potentiometer recorder pneumatic controller. The potentiometer instrument shown comprises a recorder carriage F movable horizontally in one direction and the other by the rotation of a helically grooved or screw threaded shaft F' in threaded engagement with the carriage F. A potentiometer instrument of the type shown, comprises a relay mechanism controlled by the deflection of a galvanometer pointer G for automatically adjusting a potentiometer measuring circuit resistance H when and as required to rebalance the measuring circuit, and for rotating the shaft F' to adjust the carriage F longitudinally of the shaft into positions corresponding to the different values of the quantity measured, and the variations of which produce deflections of the galvanometer pointer G. For example the galvanometer of the instrument A is connected in circuit with the thermocouple responsive to the ingot butt temperature, and is arranged so that the voltage of the thermocouple is opposed to a variable portion of a source of standard voltage H' depending on the adjustment of the contact H² along the resistor H.

The mechanism by which the potentiometer measuring circuit is rebalanced and the shaft F' is rotated to adjust the carriage F, need not be further described herein as its particular form constitutes no part of the present invention, which is adapted for use with measuring and control instruments of very different forms. It is noted however, that the particular potentiometer instrument mechanism shown, may be of the form employed in the "Brown potentiometer" instrument which is in extensive commercial use, and the characteristics of which, in the precise form herein illustrated, are disclosed in my pending application Serial No. 75,704 filed April 22, 1936, now Patent No. 2,159,971, issued May 30, 1939.

The control provisions of the instrument shown include a so-called control table I cooperating

with the recorder carriage F. The table I is a sheet metal structure supported by a shaft I'. The control table I normally occupies a fixed position along the path of movement of the recorder carriage F, but may be adjusted along that path. To affect its adjustment, the shaft I' may be a rotatable helically grooved or threaded shaft in threaded engagement with the table I. A control member I² is pivotally connected to the table I, to turn about an axis parallel to the shafts F' and I'. The part I² carries a lateral extension I⁴, preferably detachably connected to the part I², and formed with an engaging edge which comprises a horizontal portion I⁵ and an inclined portion I⁶, and which normally rests on a supporting part F² of the carriage F. As shown the part F² is a roller.

As the recorder carriage F moves to the left, as seen in Fig. 2, no movement is given to the control table part I² so long as the horizontal edge portion I⁵ is in engagement with the roller F², but as the roller F² moves away from the left hand end of the edge portion I⁵, the control table part I² turns down under the action of gravity or other suitable bias force, to the extent permitted by the engagement of the inclined edge portion I⁶, with the roller F². The normal control range of the instrument, in which its control effect varies with the position of the carriage F, is that required for movement of the roller F² into and out of engagement with the edge portion I⁶. When its movement to the left carries the roller F² out of engagement with the edge portion I⁶, further down movement of the control table part I² is prevented by means hereinafter described.

On a movement of the pen carriage to the right of the position in which it engages edge I⁵, part I⁴ will be retained in its adjusted position by means described in my above-mentioned copending application Serial No. 75,704, and need not be described here.

The up and down movement of the control table part I² gives corresponding movement to a control bar J having its underside bearing against the control table part I² and prevented from separating from the latter by a guide part I'. The control bar J extends between the two end plates E and is connected at its ends to arms J', each pivotally connected to the adjacent edge plate E by a pivot J² coaxial with the pivot for the control table part I². The left arm J', shown in Fig. 2, is provided with a transverse portion J³ adapted to engage the upper edge of the adjacent end plate E, and thus arrest the down movement of the control bar J and control table part I², as the recorder carried roller F² moves to the left, as seen in Fig. 2, of the edge portion I⁶.

The measuring and control instrument actuates the associated control apparatus, as hereinafter described, through a link L having its upper end pivotally connected to an extension J⁴ connected to transverse member J³, and having its lower end pivotally connected to the arm L' of a rocking element. The latter comprises a hub portion surrounding shaft L² carried by the adjacent member E. The rocking element has a second arm L³ to which the upper end of a vertically disposed link M is pivotally connected. Advantageously the link M is in the form of a round bar or shaft and extends through an axial passage in the hinge pintle AD, and an opening A⁴ in the bottom wall of the casing of, for example, instrument A, and in register with said

passage. The lower end of the link M carries an actuating abutment formed by a nut M', which is adjustably secured in place on the link by a lock nut M².

The vertical movements of the abutment M' give movements to the actuating elements N of the control apparatus located in the compartment a'. As shown, the actuating element N is a lever having a horizontally disposed arm formed with a slot N' at its free end through which the link M passes. The lever N has a gravitational bias for movement in the counter-clockwise direction, as seen in Fig. 2, so that its slotted end is supported by the abutment nut M' and follows the up and down movements of the latter.

The control apparatus through which the longitudinal movements of the link M produce control effects by giving movements to the actuating element N, may take various forms. As shown the control apparatus is an air actuated controller, of a form which is fully disclosed in the Coleman B. Moore Patent No. 2,125,081, granted July 26, 1938, and is now in extensive commercial use. The lever N is pivoted at N² to an adjustable fulcrum member NR, in the form of a lever having a stationary fulcrum pivot NR'. The movements of the lever N produce control effects by moving a flapper valve O away from or permitting it to approach a nozzle or bleed orifice member O². The flapper valve O is mounted on a stationary pivot O' and is biased for movement in the direction in which it approaches and restricts the discharge through the nozzle O². The lever acts on the flapper O through a pin N³ carried by a depending arm of the lever.

The nozzle O² receives air from a pipe O³², through a restricted passage formed by a small bore pipe P' included in a pilot valve mechanism P, so that the pressure in the nozzle O², which constitutes the primary control pressure of the control apparatus, increases and decreases as the flapper valve O moves toward and away from the nozzle. The primary control pressure is transmitted by a pipe O⁴ to a chamber P² of the pilot valve mechanism. One wall P³ of that chamber is movable, and separates the chamber P² from a second pilot valve chamber P⁴. The pressure in the latter is regulated by a valve P⁵ actuated by the said movable wall P³. The pressure in the chamber P⁴ is thus maintained in constant proportion to the primary control pressure in the chamber P², and constitutes the ultimate control pressure of the apparatus. The ultimate control pressure of instrument A is transmitted by pipe PQ to the device to be controlled, which as shown in Fig. 2, is the fluid pressure motor Q controlling the supply of fuel to the furnace C. The ultimate control pressure of the instrument B does not control a fluid pressure motor as does instrument A, however, as previously indicated, but controls the supply of fluid to the instrument A, the pipe AO³ of the instrument B corresponding to the pipe PQ of instrument A being connected to pipe O³² of the instrument A. As will be understood, pipe O³² of the instrument B is connected to a suitable source O³ of constant fluid pressure.

The ultimate control pressure in both instruments A and B is also transmitted by pipe PR to mechanism R, forming a part of the control apparatus, and adapted, following and as a result of each initial change in the ultimate con-

trol pressure, effected through link M, to give the lever NR an initial follow up adjustment, and a delayed compensating adjustment. The follow-up adjustment neutralizes a portion of the initial adjustment of the flapper valve O effected by the link M. The delayed compensating adjustment slowly neutralizes more or less of the effect of the preceding follow up adjustment.

The mechanism R comprises bellows elements two of which are connected by a connected rod R', which carries a projection R². The latter acts on lever NR through a lever R³ pivoted at R⁴, and a pin R⁵ interposed between the levers R³ and NR. The pin R⁵ is supported by a lever R⁶ pivoted at R⁷ to a member R⁸ adjustable to vary the leverage with which the lever R³ acts on the lever NR. The latter is biased for movement in the clockwise direction, as seen in Fig. 2. Adjustment of the member R⁸, which may be effected by rotation of member R⁹, is a so-called throttling adjustment by means of which the ratio of a movement of carriage F to the resulting ultimate pressure change is determined.

Details of the construction and operation of the mechanism R, not specifically referred to herein, will be understood by those skilled in the art from the drawings, and need not be described herein, particularly as that mechanism is not only fully disclosed in said Patent No. 2,125,081, but is in extensive use.

With the temperature to which either instrument A or B is responsive at its normal value, the control table part F² will be in position to engage the edge portion I⁶ intermediate the ends of the latter. On an increase in the ingot butt temperature to which instrument A responds, and movement of the recorder carriage F of instrument A to the right, the bar J will be raised. This will give an up movement to the link M, and will adjust the lever N clockwise, as seen in Fig. 2, whereupon the flapper valve O will move away from the nozzle O² and decrease the primary and ultimate control pressures. The resultant decrease in the pressure in the pressure chamber of the motor Q will give a closing adjustment to that motor, reducing the rate of fuel supply to the furnace and thereby tending to restore the temperature to its normal value. Such an increase in temperature of the ingot top temperature and movement of the recorder carriage F of instrument B to the right will result in a decrease in pressure of the supply fluid to instrument A through pipe AO³ and pipe O³² of instrument A. On a decrease in supply pressure to instrument A the pressure in chamber P² will fall and the net effect of the reduction in pressure in the chamber P² as well as the supply pressure, will be a reduction in the ultimate control pressure in pipe PQ and valve motor Q whereby a reduction in the rate of fuel supply is effected. The relative control pressure change on motor Q resulting from a given movement of the carriage F of instrument A or of instrument B may be separately predetermined by adjustment of the member R⁹ individual to each of those instruments. Such capacity for individual proportioning of the amount of control pressure change on a variation respectively in the ingot top temperature and the ingot bottom temperature is practically important because it is ordinarily desirable to rapidly cut down the fuel supply on a rise in ingot top temperature while a slower decrease in the fuel supply is often permissible on a rise in ingot bottom temperature.

Conversely, on a decrease in either ingot butt or ingot top temperature, the corresponding carriage F will move to the left, as seen in Fig. 2, and thereby give a down movement to the individual link M and a closing adjustment to the individual flapper valve O. The resultant increase in the control pressures will produce an opening adjustment of the valve Q and an increase in the rate of fuel supply to the furnace, tending to restore the temperature to its normal value.

Valve O³¹ may be alternatively adjusted to connect the pipe O³² directly with the pipe PQ and disconnect both instruments A and B from the latter. With such adjustment the position of motor Q is controlled by manual adjustment of screw O³³ of the regulator O³⁰ by means of which the pressure in pipe PQ is manually adjusted as may be necessary under abnormal conditions. In normal operation regulator O³⁰ determines the maximum operating pressure and thereby the limit of movement of motor Q in the opening direction.

A by-pass valve O³⁴ is also provided by means of which instrument B may be eliminated from operation when, as is normally the case, valve O³¹ connects pipe O³² with pipe O³, and pipe PQ with instrument A. Under normal conditions the instrument A may be by-passed or rendered inoperative by opening by-pass valve O³⁵. With valve O³⁴ fully open and valve O³⁵ closed the motor Q will be under sole control of instrument A, while with valve O³⁵ fully open and valve O³⁴ closed the motor Q will be under sole control of instrument B.

The apparatus of Fig. 1, in which only one thermocouple T' is shown, may be modified by installing a thermocouple T' in conjunction with a plurality of or all the ingots, in which case such thermocouples may be connected to respond to the average of the temperatures of the ingot butts as shown in Fig. 1C. The thermocouples may be connected in parallel for this purpose as the thermocouples of Fig. 4 are connected. Thermocouple T² of Fig. 1 may also be supplemented by thermocouples associated with a plurality or all of the ingots and so connected as to give a measure of the average ingot top condition as shown in Fig. 1C. Alternatively, a plurality of thermocouples T² may be associated with respective ingots and connected to independent controllers like the instrument B as shown in Fig. 1A, or may be successively connected to a single instrument as shown in Fig. 1B.

In Fig. 1A, the supply pressure to instrument A is controlled by two instruments B, the latter being connected together as the instruments A and B of Fig. 1 are connected together. In consequence the final control pressure to which motor Q is subjected will depend on the effects produced respectively by all the instruments B and by the instrument A, the throttling adjustment R⁹ of each instrument establishing the respective effect which each instrument will have on the total effect.

In Fig. 1B a motor operated selector switch X is employed, forming a portion of the instrument B and arranged to successively connect thermocouples T² in circuit with the instrument B. By this means the extent to which the supply pressure to instrument A is controlled by instrument B is successively determined by the temperature to which the thermocouple T² then in circuit with the instrument B, is subjected. Selector switch X may be driven by a constantly

rotating motor X' energized from a suitable source of current X^2 , X^3 . If desired a switch X^4 may be opened manually by means of which supply conductor X^2 is interrupted unless a switch X^5 in branch conductor X^6 is then closed. Switch X^5 may be opened by means hereinafter described in connection with Fig. 5 when any thermocouple T^2 reaches a predetermined temperature, preventing the selector switch from making instrument B responsive to another thermocouple T^2 so long as switch X^5 is open. Instrument B in the apparatus of Fig. 1B will thus be successively responsive to thermocouples T^2 and will remain responsive to the first thermocouple to reach a predetermined temperature until said thermocouple again falls below the predetermined temperature.

From the foregoing description of Fig. 1 it will be seen that I have provided control jointly in response to the temperature of the hottest effective portion of the charge, and the temperature of the portion most remote from the source of heat. While the system of Fig. 1 is theoretically most desirable either in the form taking into account the highest temperature of each of the ingots and the lowest temperature of each of the ingots, or in the form using the highest temperature of a representative ingot or the lowest temperature of a representative ingot; common soaking pit construction does not facilitate the proper placing of the thermocouples and it is more practicable to employ the apparatus of Fig. 3 in which radiation pyrometers are employed in lieu of the thermocouples of Fig. 1.

In Fig. 3, radiation pyrometers Y' and Y^2 of known form and comprising a thermal junction focused upon the ingots at the desired points, are used and correspond effectively to the thermocouples T' and T^2 respectively. As will be clear, the radiation pyrometers may be connected in the circuits of Figs. 1, 1A, 1B and of Fig. 4, later described in exactly the same manner as the thermocouples T' and T^2 .

In Figs. 4 and 4A, is illustrated a still further embodiment of the invention in which the thermocouple T^2 of Fig. 1 is arranged, not in contact with an ingot but removed vertically therefrom, and projecting through the cover. So placed, thermocouple T^2 is significantly responsive to the temperatures of the tops of all the ingots. The arrangement of thermocouple T^2 of Fig. 4 has the practical advantage of anticipating a rise in ingot top temperatures following a rise in flame or combustion gas temperature, which will be felt by thermocouple T^2 before the ingot top temperature change takes place.

Also in Fig. 4, the thermocouples T' are placed in the ducts C^4 instead of within the ingots as in Fig. 1, and although when so placed, they are affected by radiation from the recuperators and by the outgoing gases, I find that, in many cases at least, the response is sufficiently significant to the coolest ingot temperature to provide a reliable index corresponding to the thermocouple T' of Fig. 1. The correspondingly identified parts of Fig. 4 correspond to the like parts of Fig. 1, although as previously described the fuel-air control means of Fig. 4 is different from those of Fig. 1.

Fig. 5 illustrates a preferred embodiment of the invention, in which functions attained with the fluid pressure operated apparatus of Fig. 1 are attained with electrical control apparatus, and in addition certain practically important adjustments are provided in a form which con-

tribute to simplification and ease of adjustment in the field. In Fig. 5 the pen carriages FD and FC, incorporated respectively in instruments AA and BB corresponding to instruments A and B, may be adjusted substantially in the manner in which pen carriage F of Fig. 2 is adjusted, responsive respectively to the temperatures of thermocouples T' and T^2 or radiation devices Y' and Y^2 . The deflections of the pen carriages FD and FC, however, do not produce fluid pressure effects through the mechanism including bell crank lever N of Fig. 2, but produce electrical effects generally equivalent to and replacing those fluid pressure effects. The lever N of each instrument AA and BB, the pivot N^2 of which is fixed, is adapted to carry a plurality of contact arms a' , a^2 , a^3 and a^4 or b' , b^2 , b^3 and b^4 (see Fig. 2A) cooperating with the electrical apparatus of Fig. 5, and replacing the fluid pressure apparatus comprising parts O, P, Q, and R of Fig. 2, which are omitted from Fig. 5. In Fig. 5 the dotted lines connecting carriages FD and FC with their respective contacts represent the linkage such as J, L, M and N of Fig. 2, which may be employed to connect the carriages and contacts in the apparatus diagrammatically shown in Fig. 2A.

This linkage should preferably include throttling range adjusting provisions by means of which the extent of the electrical effect produced by a given movement of carriage FC or FD is individually predetermined, because normally the effect resulting from a movement of carriage FC will desirably be different from that resulting from an equal movement of carriage FD. To this end and as will be clear from Fig. 2B, the point of attachment of link L to lever L' is made adjustable toward and away from the axis of shaft L^2 , the extent of up or down movement of link M in response to a movement of link L depending upon that adjustment. As shown, the link L is attached to a part L^{10} adjustable in slot L^{11} of lever L' and clamped in the desired position by screw L^{12} . Another slot L^{13} is provided in the lever L' on the opposite side of the axis of shaft L^2 from slot L^{11} to alternately accommodate part L^{10} , whereby the direction of the control effect produced by movement of link L may be reversed.

The apparatus of Fig. 5 ultimately controls the fuel or air valve QA corresponding to the valve Q of Figs. 1, 2 and 3, such control being effected in part by the cooperation of contacts a' , a^2 of the instrument AA and contacts b' , b^2 of the instrument BB with the same electrical network, whereby continuous responsiveness to each of the significant conditions is attained. Contacts a' , a^2 respectively engage and are adjustable along resistors a^{10} and a^{20} and contacts b' , b^2 respectively engage and are adjustable along resistors b^{10} and b^{20} . Resistors a^{10} and b^{10} are disposed on one side of a mid resistor ab and resistors a^{20} and b^{20} are disposed on the opposite side of the resistor ab , all the resistors being connected in a series circuit across a pair of line conductors 1 and 2, supplying a suitable source of energizing current. Another resistor 3 is connected in parallel with the series resistor circuit and an equalizing conductor 5 extends between a contact 6 engaging and adjustable along resistor 3, and a contact 7 engaging and adjustable along resistor ab . The resistors and conductors just referred to form in effect a bridge circuit adapted to be unbalanced by adjustment of resistors a^{10} , a^{20} , b^{10} , b^{20} or 3, causing a difference in potential

between contacts 6 and 7, which causes an unequal flow of current respectively in a pair of opposed solenoid coils 8 and 9 which are connected each at one end to a line wire 1 or 2 and connected together at their opposite ends and to conductor 5. The coils 8 and 9 are inductively related to an armature 10, which is moved toward coil 8 or toward coil 9 depending upon the direction of unbalance, and is adapted to control a contact member 11. Contact member 11 is connected to line conductor 2, and is arranged to engage one or the other of a pair of contacts 12, 13 when armature 10 is deflected. Contacts 12 and 13 are connected respectively to fields 14, 15 of a reversible electrical motor, and the opposite ends of the field windings are connected together and to line conductor 1. Motor 16 is connected through suitable gearing to actuate valve QA and is also connected to move contact 5 along resistor 3. The direction of rotation of motor 16 on an unbalance of the bridge, is such as to adjust contact 5 in a direction to restore the balance.

If the apparatus did not extend beyond that already described, it would include control of valve QA jointly from instruments AA and BB. On a movement of contacts a' and a^2 to the left in response to a decrease below its predetermined normal value of the bottom ingot temperature, fuel valve QA will be opened to increase that temperature. If the top of ingot temperature simultaneously drops below its normal temperature, the resulting fuel correction will be in the same direction but if the ingot top temperature increases simultaneously and suitably with the decrease in ingot butt temperature, the effects will cancel out and no fuel correction will be made. The total resistance in the arms including resistors a^{10} , b^{10} , a^{20} and b^{20} , will remain constant notwithstanding adjustment of the resistors individually, which feature is made possible by the arrangement of the contacts with respect to their resistors and the symmetrical arrangement of the resistors on either side of contact 7. On an adjustment of contacts a' and a^2 or contacts b' and b^2 , the resistance removed from the arm to one side of the contact 7 will be equal to the resistance added to the arm on the opposite side of the contact, whereby equal movements of the contacts in different portions of their range of movement will produce substantially equal valve movements. A resistor 18 is shown in the circuit to the left of contact 7, which is employed to limit the travel of the valve QA, and is adjustable by means of contact 19 adjusted by a manually adjustable knob 20 connected in a suitable manner to the contact 19. The resistance 18 does not significantly upset the symmetry of the circuit just referred to, but any such effect could be eliminated by placing a similar resistance and adjustable contact on the opposite side of contact 7 and arranged for operation simultaneously with contact 19.

In a stable control system such as the one just described and without the load compensating features now to be disclosed, a furnace load change requiring more fuel will tend to make the system maintain a temperature lower than the desired temperature, while a furnace load change requiring less fuel will tend to make the system maintain a temperature higher than the desired value. Electrical load compensating control apparatus is not in itself new, but I have incorporated in Fig. 5 a novel arrangement making practicable the maintenance of more precise temper-

ature control employing load compensating or reset means not inconsistent with the other requirements of the control system, as is the case with other load compensating means now known. For example, it is desirable, in the control application for which this system is intended, to effect a load compensating adjustment in a direction to reduce the fuel supply if either the ingot butt temperature or the ingot top temperature is too high, but it is desirable to effect a load compensating adjustment in a direction to increase the fuel supply only if both of those temperatures are low.

For purposes of compensating the system for load variations I have shown in Fig. 5, electrical load compensating or reset provisions including a motor 21 coupled to adjust contact 7 which in the apparatus described to this point, has been considered stationary. Motor 21 is provided with two fields 21L and 21H respectively adapted to rotate the motor in a direction to move contact 7 to the left and to the right, thereby increasing or decreasing the fuel supply. The motor 21 is energized through circuits including contacts a^3 , a^4 and b^3 , b^4 of instruments AA and BB, the contacts being deflected in accordance with the variations in ingot top and ingot butt temperatures, and cooperating with stationary contacts a^{30} , a^{40} and b^{30} , b^{40} . When contacts a^3 , a^4 and b^3 , b^4 are undeflected, as they will be when both temperatures are normal, no circuits will be closed. When contact b^4 is deflected to the right on a rise in ingot butt temperature, a circuit will be closed to field 21H from line 2 to switch 22, through the latter when closed to conductor 23, contacts b^4 and b^{40} , conductor 24, field 21H to line 1. When contact a^4 is deflected to the right on a rise in ingot top temperature, a circuit will be closed for field 21H from line 2, conductor 25, switch 26, conductor 27, contacts a^4 and a^{40} and conductor 28, field 21H to the line conductor 1. Thus contact 7 is moved to the right responsively to a rise in either the ingot butt temperature or the ingot top temperature, to thereby effect a closing adjustment of valve QA.

On a deflection of contacts a^3 and b^3 to the left, a circuit is closed from the line wire 2, contacts a^3 and a^{30} , conductor 29, switch 30, conductor 31, contacts b^3 and b^{30} , field 21L to line 1, but this circuit can be effected only upon deflection of both contacts a^3 and b^3 to the left, contacts a^3 and b^3 both being deflected to the left only when both the ingot top and the ingot butt temperatures are low.

The switches 22, 26 and 30 respectively controlling the circuits above traced, are unnecessary with the proper proportioning of the motor 21 and with the proper gear relation between the latter and the contact 7, but for purposes of adjustment adapting the apparatus to specific practical requirements, those switches are employed and are closed during a relatively fixed but manually adjustable time period. Switches 22 and 30 are mounted on bracket 32 pivoted at 33, and the bracket 32 is provided with a roller 34 in engagement with cam 35. Cam 35 is driven by a unidirectional motor 36 energized from the line wires 1 and 2, and provided with speed adjustment 37. Switch 26 is mounted on a bracket 38 pivoted at 39, a roller 40 of the bracket being adapted to be engaged by cam 41 driven by a second unidirectional motor 42 also energized from line wires 1 and 2. The speed of motor 42 is controlled by an adjustable resistor and con-

tact 43, and the speed adjustment devices 37 and 43 are controlled respectively by manual adjusting dials 44 and 45, the angular adjustment of said dials determining the time period of closure of switches 22 and 30 and 26 respectively, forming in effect means by which the load compensation or reset effect produced by adjustment of the contact 7, and injected into the collective control action, is proportioned to the duration of departure of the ingot top and ingot butt temperatures from their respective normal values. If it is desired to make the extent of movement of the contact 7 dependent not only upon the direction of deflection of moving contacts a^3 , and a^4 , b^3 and b^4 but upon the extent of deflection, the stationary contacts a^{30} , a^{40} , b^{30} and b^{40} may be formed of material of a relatively high electrical resistance, whereby the speed of rotation of the motor 21 will depend not only upon the existing adjustment of devices 37 and 43, but upon the extent of deflection of the movable contacts.

For purposes of manual adjustment of the extent of ultimate control effect resulting from a given movement of the various resistors, a resistor ab' is provided which is shunted about resistor ab and is provided with manually adjustable knob ab^3 connected by suitable means ab^2 to movable contact ab^4 whereby more or less of the resistor ab' is shunted about resistor ab . The rate and/or extent of movement of motor 21 is also preferably individually adjusted by means of speed control adjusting resistor 21A more or less of which is connected in series with motor 21 depending upon the existing adjustment of contact 21B. The latter is adjusted by means of knob 21D through suitable means 21C.

Though I have disclosed in the foregoing, simultaneously operating means for adjusting the fuel valve in joint response to ingot top temperature and ingot butt temperature, such joint response need not be simultaneous but may be successively effected through a single instrument such as instrument A when provided with selector means such as switch X. With such an arrangement the switch X may alternately connect the top thermocouple and the butt thermocouple in circuit with the instrument whereby successive measuring and control is attained such as is disclosed in my copending application Serial No. 167,718, filed October 7, 1937, now Patent No. 2,235,219, issued March 18, 1941. Certain novel features of a control system comprising pneumatic control apparatus controlled by electrical measuring means, which are disclosed but not claimed herein, are claimed in my prior application Serial No. 101,063, filed Sept. 16, 1936, now Patent No. 2,201,946, issued May 21, 1940.

While in accordance with the provisions of the statutes, I have illustrated and described the best form of embodiment of my invention now known to me, it will be apparent to those skilled in the art that changes may be made in the form of the apparatus disclosed without departing from the spirit of my invention as set forth in the appended claims and that in some cases certain features of my invention may be used to advantage without a corresponding use of other features.

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

1. A control apparatus for a metallurgical furnace having a heating chamber in which a plurality of articles to be heated are placed and having

a combustion heating means for passing hot gases of combustion through the chamber and over the articles wherein those portions of the articles which are contacted first by the hot gases of combustion are heated and brought up to temperature at a faster rate than those portions of the articles which are contacted last by the hot gases of combustion, comprising in combination, a plurality of temperature responsive devices positioned respectively to respond significantly to the temperature of a corresponding one of the articles at that portion thereof which is contacted last by the hot gases of combustion, temperature averaging means actuated by said devices to respond to an average of the temperature to which said devices respond, temperature responsive means positioned to respond significantly to the temperature of those portions of the articles which are contacted first by the hot gases of combustion, control means for the combustion heating means, and means controlled by the temperature averaging means and the temperature responsive means for controlling the control means for heating the articles uniformly and rapidly as possible to a desired temperature without injury to the articles.

2. A control apparatus for a metallurgical furnace having a heating chamber in which a plurality of articles to be heated are placed and having a combustion heating means for passing hot gases of combustion through the chamber and over the articles wherein those portions of the articles which are contacted first by the hot gases of combustion are heated and brought up to temperature at a faster rate than those portions of the articles which are contacted last by the hot gases of combustion, comprising in combination, a plurality of temperature responsive devices positioned respectively to respond significantly to the temperature of a corresponding one of the articles at that portion thereof which is contacted last by the hot gases of combustion, temperature averaging means actuated by said devices to respond to an average of the temperature to which said devices respond, a second plurality of temperature responsive devices positioned respectively to respond significantly to the temperature of a corresponding one of the articles at that portion thereof which is contacted first by the hot gases of combustion, second temperature averaging means actuated by said second temperature responsive devices to respond to an average of the temperature to which said devices respond, control means for the combustion heating means, and means controlled by the first and second temperature averaging means for controlling the control means for heating the articles uniformly and rapidly as possible to a desired temperature without injury to the articles.

3. A control apparatus for a metallurgical furnace having a heating chamber provided with a central bottom inlet ground which a plurality of articles to be heated are placed and having a combustion heating means for passing hot gases of combustion through the bottom inlet vertically to impinge the roof of the heating chamber and thereby diverted downwardly along the articles and exhausted through a plurality of bottom outlets wherein the top portions of the articles adjacent the roof are heated and brought up to temperature at a faster rate than the bottom portions of the articles adjacent the bottom outlets, comprising in combination, a plurality of temperature responsive devices positioned adjacent the outlets of the heating chamber respectively to respond significantly to the temperature of a cor-

responding one of the articles at the bottom portion thereof, temperature averaging means actuated by said devices to respond to the average of the temperature to which said devices respond, temperature responsive means positioned adjacent the roof of the heating chamber to respond significantly to the temperature of the top portions of the articles, control means for the combustion heating means, and means controlled by the temperature averaging means and the temperature responsive means for controlling the control means for heating the articles uniformly and rapidly as possible to a desired temperature without injury to the articles.

4. A control apparatus for a metallurgical furnace having a heating chamber provided with a central bottom inlet around which a plurality of articles to be heated are placed and having a combustion heating means for passing hot gases of combustion through the bottom inlet vertically to impinge the roof of the heating chamber and thereby diverted downwardly along the articles and exhausted through a plurality of bottom outlets wherein the top portions of the articles adjacent the roof are heated and brought up to tem-

perature at a faster rate than the bottom portions of the articles adjacent the bottom outlets, comprising in combination, a plurality of temperature responsive devices positioned adjacent the outlets of the heating chamber respectively to respond significantly to the temperature of a corresponding one of the articles at the bottom portion thereof, temperature averaging means actuated by said devices to respond to the average of the temperature to which said devices respond, a second plurality of temperature responsive devices positioned adjacent the roof of the heating chamber respectively to respond significantly to the temperature of a corresponding one of the articles at the top portion thereof, second temperature averaging means actuated by said second devices to respond to the average of the temperature to which said devices respond, control means for the combustion heating means, and means controlled by the first and second temperature averaging means for controlling the control means for heating the articles uniformly and rapidly as possible to a desired temperature without injury to the articles.

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