

May 28, 1968

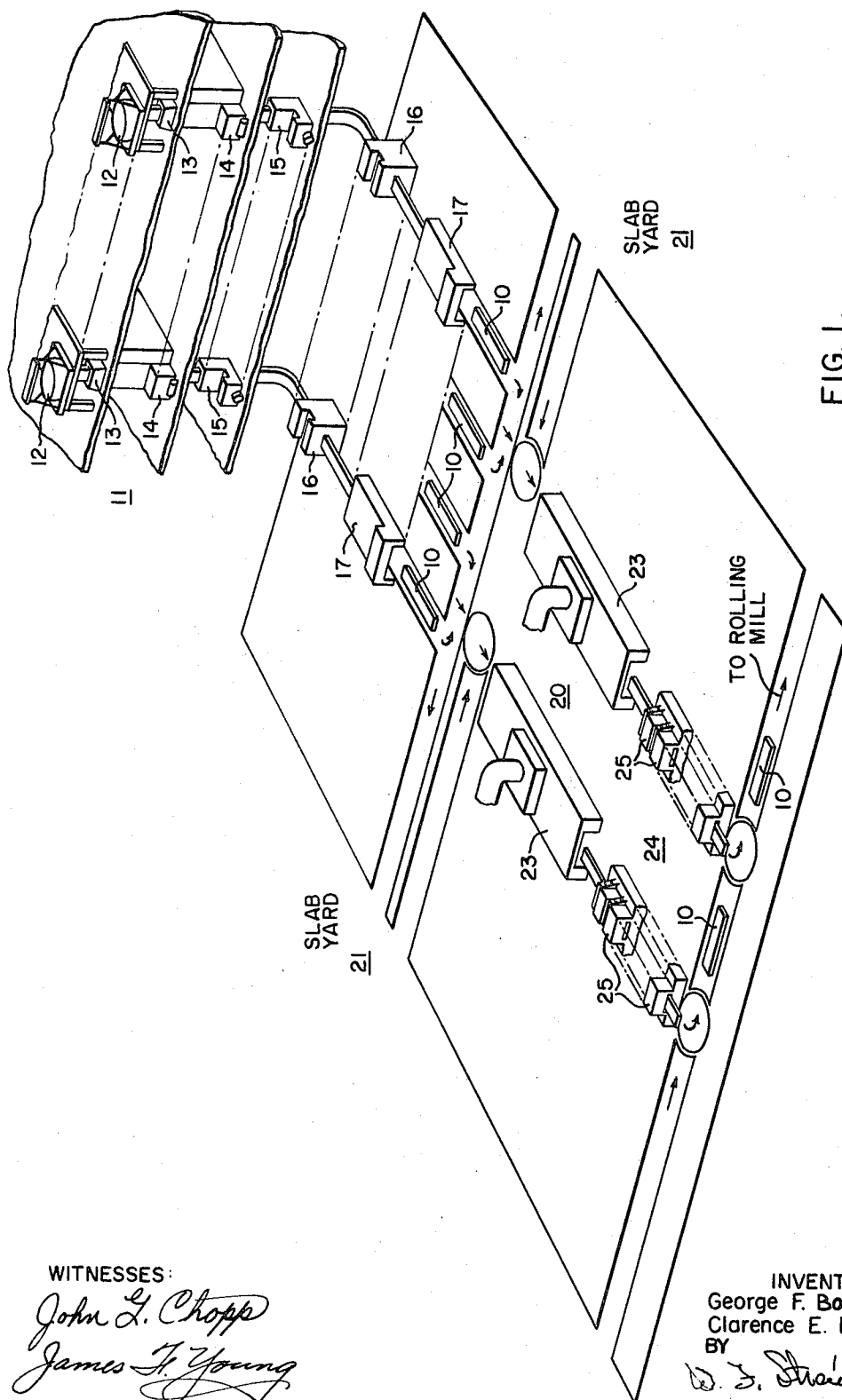
C. E. PECK ET AL

3,385,579

SLAB HEATING APPARATUS

Filed Dec. 8, 1965

4 Sheets-Sheet 1



WITNESSES:

John L. Chopp
James H. Young

INVENTORS
George F. Bobart and
Clarence E. Peck
BY

W. J. Strickland

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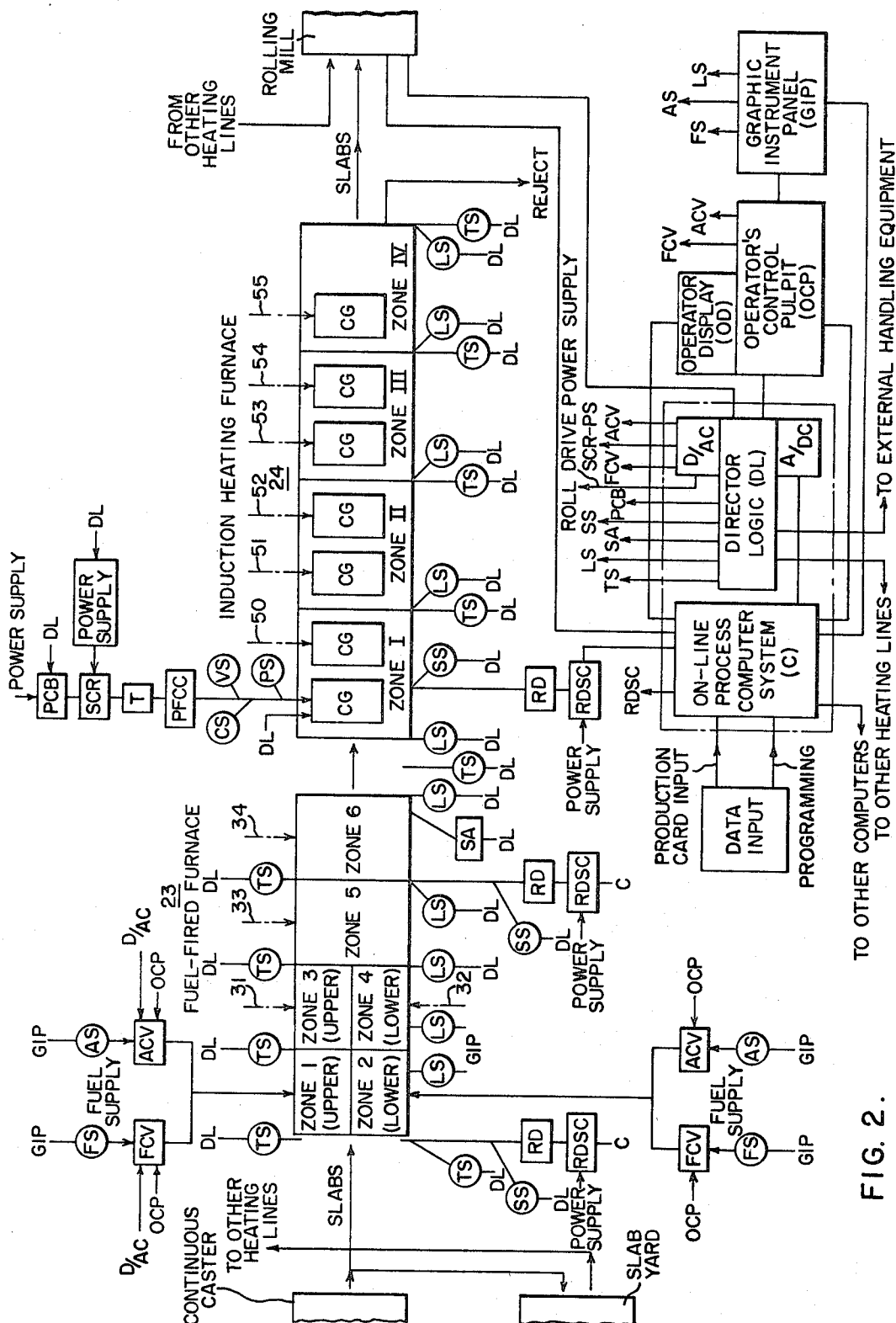


FIG. 2.

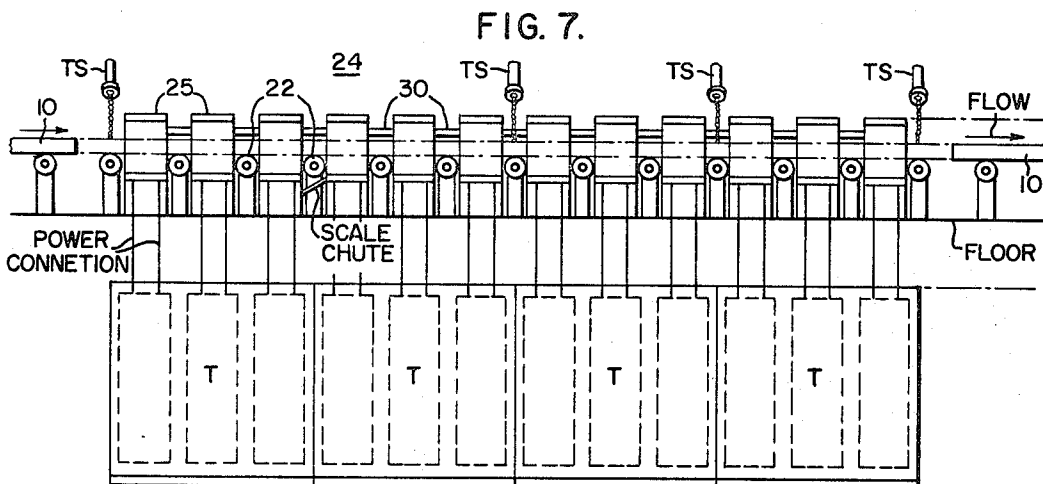
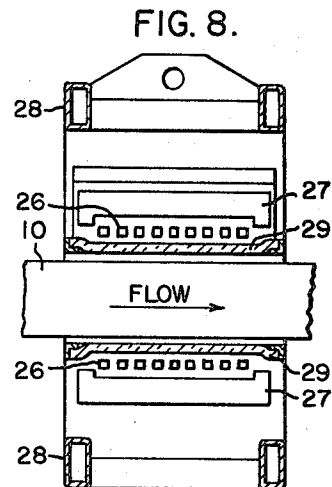
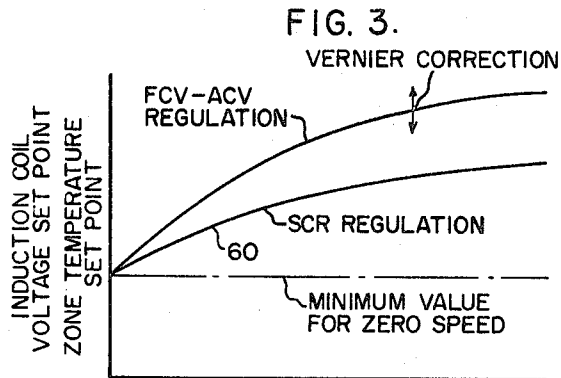
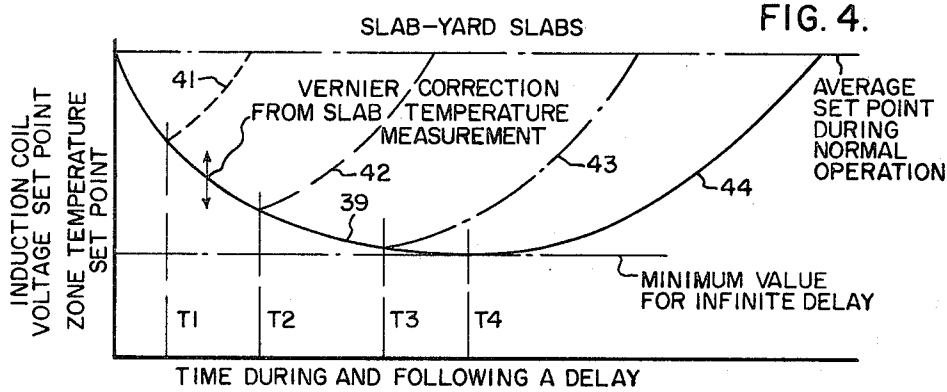
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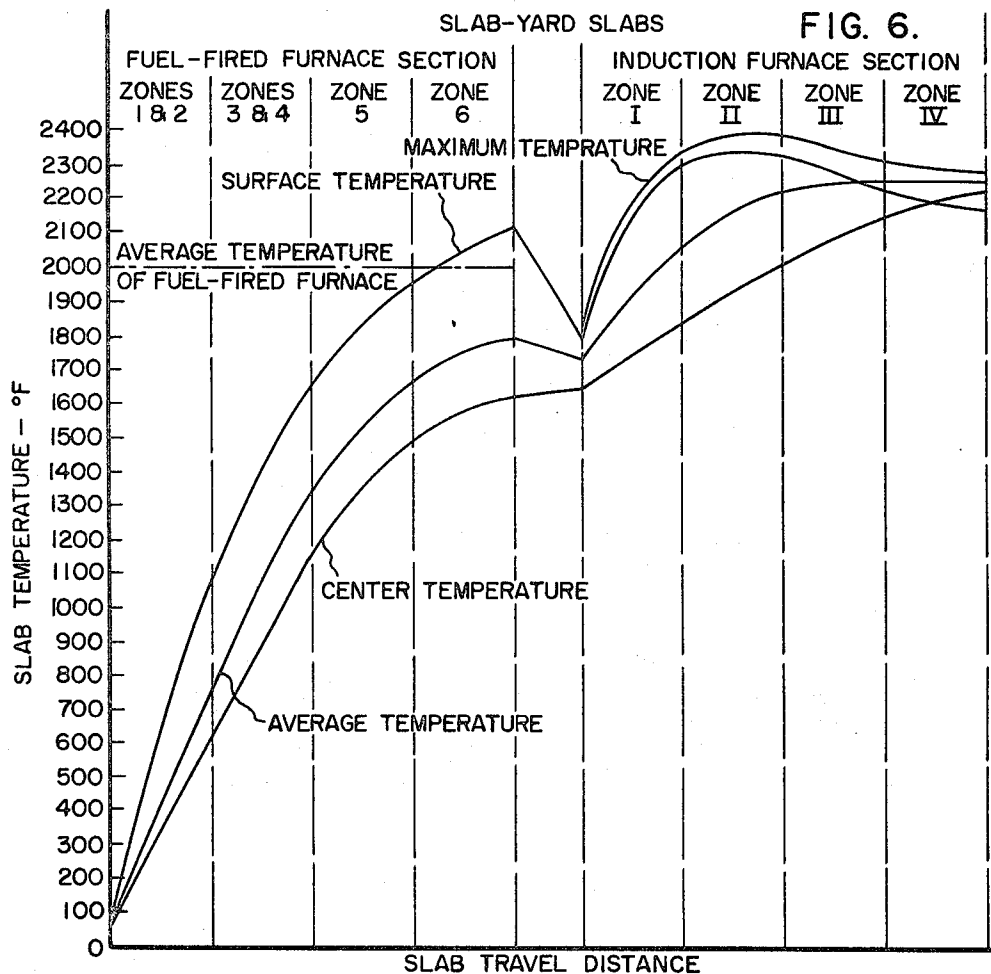
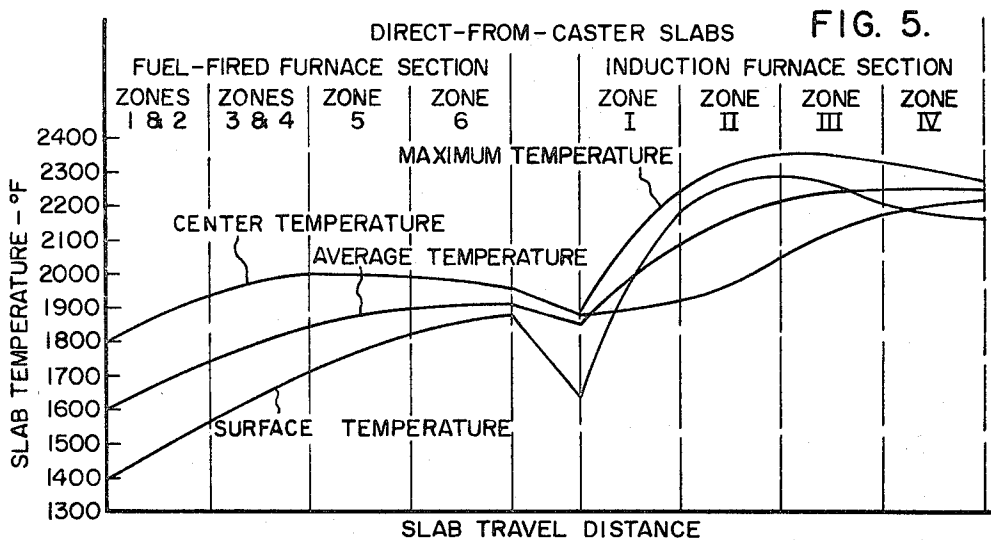
C. E. PECK ET AL

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SLAB HEATING APPARATUS

Filed Dec. 8, 1965

4 Sheets-Sheet 4



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3,385,579

SLAB HEATING APPARATUS

Clarence E. Peck, Williamsville, N.Y., and George F. Bobart, Ellicott City, Md., assignors to Westinghouse Electric Corporation, Pittsburgh, Pa., a corporation of Pennsylvania

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2 Claims. (Cl. 263—6)

ABSTRACT OF THE DISCLOSURE

A horizontal straight line rolling temperature heating apparatus aligned with the cutoff station of a continuous caster to receive hot slabs directly therefrom as well as cooled slabs from slab yard storage. Roller means convey all slabs longitudinally and consecutively through aligned multi-zoned radiant and induction coil furnaces under separate zone regulation by a stored-information computer grossly according to time of presence of the slabs in the furnaces and finely in accord with slab surface temperatures. Control of the furnaces is such that all slabs enter the induction heating coil furnace at substantially the same average temperature as direct-from-caster slabs and leave at a desired uniform temperature for presentation to a rolling mill.

With the advent of continuous casting of steel slabs of sizes larger than heretofore produced by previous techniques, problems involved in providing suitable apparatus for reheating of slabs in preparation for introduction into a rolling mill are compounded by the added sizes introduced by the continuous casting technique.

For example, the length of a fuel-fired furnace for reheating of the thicker continuous cast slabs without exceeding a certain maximum surface temperature must be increased to provide sufficient time for diffusion of the heat into the slab to obtain effective equalization of the temperature throughout its thickness, a twelve inch thick slab would need about twice the furnace length previously needed for the heating of an eight inch thick slab of the same width.

By way of further example, the formation of scale is a function of the duration of exposure of the slab surfaces to an oxidizing atmosphere, the amount of such atmosphere to which the surface is exposed, the composition of such atmosphere, and the temperature of the surfaces at time of such exposure. Accordingly, it will be apparent that the increased furnace length required to heat the thicker continuous cast steel slabs to rolling temperature has a pronounced tendency to increase formation of scale, in view of the increased volume of hot combustion gases introduced by forced convection onto the slab surfaces and the longer period of time to which the slab is subjected to such gases.

In accord with general features of the present invention, an objective of heating continuous cast slabs up to a rolling-mill-requirement temperature is minimal time, maximum temperature uniformity and without surface overheating, there is provided a heating system that comprises a computer-including control system that regulates the heating capability of the heating means according to heat transfer relationships that are caused to exist within such slab as a result of heating. Such system takes into account the temperature conditions existing in the slab prior to entry into the furnace, tracks the slab enroute through the furnace, computes the rate of heat input required at the successive positions of the slab in travel through the furnace, and regulates such heat input accordingly, on the basis of the amount of heat added to the slab at a particular rate of heat input over a particular period of time. The computer also calculates what

2

the surface temperature of the slab should be at successive stages of heating, which surface temperature of the slab is measured and compared by the computer with the calculated value and fed back to the heating control means to apply a vernier adjustment within a limited temperature range.

As to the increased length represented by a reheat line where heating is done exclusively by fuel-fired furnace means, the present invention proposes a heating apparatus which includes a fuel-fired furnace in series with an induction furnace. The fuel-fired furnace is arranged to function primarily during heating of cold slabs coming from the slab yard where it is necessary to add a considerable amount of heat in order to raise the slab up to its rolling temperature. The following induction furnace raises the preheated slab up to its final rolling mill temperature. By virtue of the fact that the induction heating stage can heat the slab internally as determined by depth of heating current penetration, while the fuel-fired furnace heating is limited to introduction of heat only by way of the surface, such final stage of heating by induction results in a reheat line which can be of significantly lesser length than were the slab heated exclusively by a fuel-fired furnace.

It is another feature of the present invention as embracing a fuel-fired furnace section followed by an induction furnace section that both heating sections be made in line and continuous, with roller conveying of the slabs therethrough, and that when the slabs to be reheated come directly from the continuous caster and therefore are relatively hot compared to slab-yard slabs, these direct-from-caster slabs are heated at least substantially exclusively by the induction furnace section. The fuel-fired furnace section is substantially ineffectuated by reduction of the heat input thereto and/or by increasing the rate of travel of the slabs therethrough. By virtue of this arrangement the roller conveying means within the fuel-fired heating section is always in use for conveying slabs through the heating line for reheating both the slab-yard slabs as well as the direct-from-caster slabs, while being immediately available for effecting the bulk of the heating of such slab-yard slabs when required.

In accord with yet another feature of the present invention, the computer-including heating control system embodied therein also provides for automatic adjustment of the rate of heat input to the slabs according to the duration of a delay in operation of the line, in a manner which aims at exiting of the slabs from the furnace line at slab temperature conditions as close as possible to those which would otherwise prevail had operation of the line been uninterrupted.

Other objects, features, and advantages of the invention will become apparent from the following more detailed description of the invention when taken in connection with the accompanying drawings, in which:

FIGURE 1 is an isometric view of the heating apparatus proposed by the present invention in association with continuous casting equipment for producing continuous cast slabs;

FIG. 2 is a schematic representation in block diagram form showing an illustrative embodiment of the invention;

FIG. 3 is a curve showing a typical correlation between heat input to the slab with respect to speed of travel of such slab;

FIG. 4 is a curve showing a typical relationship which is programmed into the computer to vary the heat input to the slab according to the duration of a delay in operation of the heating line;

FIG. 5 shows typical temperature conditions which are caused to exist during the heating of direct-from-caster slabs during transport through the heating apparatus under normal conditions;

FIG. 6 shows similar temperature curves for slab-yard slabs;

FIG. 7 is a side elevation view of induction heating equipment embodied in the present invention; and

FIG. 8 is a side elevation section view of an exemplified construction of an induction heating coil assemblage employed in plurality in the equipment of FIG. 7.

The heating apparatus of the present invention is particularly suitable for use in heating steel slabs 10 which are in excess of eight inches thick, vary in width between twenty and eighty inches, and are from one hundred fifty inches up to continuous form in length. The invention is particularly suited to heating such slabs as formed by the continuous cast process or by a continuous caster 11 such as shown schematically in FIG. 1 and essentially includes the ladle 12, tundish 13, oscillating mold 14, cooling chambers 15 and 16, and cutoff station 17, from which discrete lengths of slab up to one hundred feet long emerge and are either sent directly through the reheating furnace lines 20 or to slab-yards 21 for temporary storage pending need for such slabs at the rolling mill (not shown). At the exit from the continuous caster 11 the slabs 10 substantially consistently have a temperature profile such that the center is about 1800° F. and the outer surface is about 1400° F. The slabs usually repose in the slab-yard for a sufficient length of time such that their interior and exterior temperatures are equalized and near room temperature, prior to introduction to the reheating apparatus and subsequent introduction to the rolling mill. The present invention proposes provision of one or more reheating furnace lines 20, two of which are shown in FIG. 1, comprising conveyor roll means 22 for accepting slabs either directly from the continuous caster 11 or from the slab-yard 21 and advancing such slabs longitudinally through the heating lines in continuous fashion during normal operation of such lines. The apparatus embodies a computerized control system shown in FIG. 2, which tracks the slabs en route through the heating lines, takes into account the temperature profile of the slabs entering the heating lines and controls the application of heat through a plurality of zones along the length of such lines to maximize the heat input to the slabs at any given rate of travel of such slabs through the line without exceeding a certain maximum surface temperature of the slabs, such as 2550° F., above which such slabs cannot be heated, and with minimal surface-to-interior temperature difference at exit from the heating lines for introduction to the rolling mill. The computerized control means performs such function in the successive heat application zones of the furnace line by grossly adjusting the heat input to such respective zones on the basis of the time that the slab remains in such zone, calculates the desired temperature that the slab should have in such zone and applies a vernier correction to the heat input to the slab within the zone in the event that the calculated slab temperature deviates from the measured slab temperature.

In accord with the preferred construction of the heating line, it is proposed that each line includes a fuel-fired furnace section 23 for heating slab-yard slabs up to about the same average temperature as that of direct-from-caster slabs, and an induction furnace section 24 to apply final heating of the slabs up to their desired rolling mill temperature, as well as to apply at least preponderant heating of the slabs which reach the furnace line direct from the continuous caster. By virtue of such dual furnace arrangement, advantage may be taken of the relatively economical fuel costs of a fuel-fired furnace for preheating the cold, slab-yard slabs, while affording opportunity for reducing the overall length of the combined furnaces versus the equivalent length of a single fuel-fired furnace. Also, at least with respect to the induction furnace 24, it is preferred that such furnace take an open-end form through which the slabs are advanced longitudinally by

the conveyor rolls 23 located at intervals therealong, with the advantage that the slab travel can be continuous.

Although other modes of actuating the slabs through the radiant furnace 23 of the heating line may be accomplished, by use of such as walking beams, for example, the roller type hearth furnace is well suited for the continuous in-line operation in conjunction with the induction furnace 24 as exemplified herein. With this arrangement it is proposed that even the direct-from-caster slabs pass through the fuel-fired furnace 23 enroute to the induction furnace 24, even though little if any preheat may be performed by the radiant furnace on such slabs. Under direct-from-caster heating operation of the lines, the fuel-fired furnace 23 will be substantially ineffectuated with respect to significant application of heat to the slabs passing enroute therethrough. Where the direct-from-caster run is of slight duration, this ineffectuation can be accomplished by reducing the steady state fuel input to the fuel-fired furnace section. If the operation of a particular furnace line demands intermixing of the direct-from-caster slabs with slab-yard slabs, the relative ineffectuation of the fuel-fired furnace 23 with respect to direct-from-caster slabs can be accomplished by providing suitable spacing between direct-from-caster slabs and slab-yard slabs and speeding up the travel of the direct-from-caster slabs through the fuel-fired furnace, relative to their subsequent speed of travel through the induction furnace 24 and to the speed of travel of the cold slab-yard slabs through the line. Under these latter circumstances the rate of heat input to the fuel-fired furnace section can be maintained at a sufficiently high level as to be immediately available for preheating of the slab-yard slabs intermixed with the direct-from-caster slabs.

Referring to FIGS. 1 and 7, the induction heating furnace 24 comprises a plurality of spaced-apart heating coil assemblies 25 between which are disposed the conveyor rolls 23. As is shown in FIG. 8, each of the coil assemblies 25 includes a water-cooled induction coil 26 having a number of turns wound helically to form a rectangular-shaped tunnel through which the slab will pass. The coil can be affiliated with a plurality of iron laminations 27 around its exterior, supported by a frame construction 28, and provided with a liner 29 of heat resistant material at its interior. The construction of the coil together with the liner is such as to provide close electromagnetic coupling with a particular-sized workpiece slab, or workpiece sizes within a narrow limited range. The clearance-way between the inside of the coil liner 29 and the exterior of the slab to be heated is extremely narrow, in the order of three inches, to provide, in addition to such close coupling, little opportunity for entrance of air into the surface of the slab portion which lies within the domain of the heating coil, thus tending to minimize rate of scaling of the surface of the slab within such region. In addition, the space between the coils occupied by the rollers is provided with a shield or hood 30 which serves the dual function of acting to reduce radiation of heat from the slab while in transit between coil sections as well as to discourage entrance of air to the slabs at the roller locations.

Referring to FIG. 2, where the heating system is shown in block diagram form, a fuel-fired furnace having six independently-controllable heating zones, labelled Zone 1 to Zone 6 is exemplified and arranged in alignment with an induction heating furnace having four independently controllable heating zones, labelled Zone I to Zone IV. In the fuel-fired furnace, Zone 1 lies above Zone 2, and Zone 3 lies above Zone 4, such separately controllable upper end lower zones being located at the input end of the furnace to provide for compensation for differences in temperature between the upper and lower parts of the slabs upon entering such furnace, which temperature difference may be accounted for by different cooling effects to which the slab may have been subjected enroute to the furnace line; the lower surface of the slab being in con-

tact with the water cooled conveyor rolls, for example, while the upper surface radiates heat to the atmosphere, or the slab having been stacked in the slab-yard as the uppermost slab, for example, which could introduce differences in heat transfer characteristics from the upper and lower surfaces of the slab.

During normal operation of the fuel-fired furnace 23, in accord with well-known practice, all zones of the furnace will be operated at substantially the same temperature, within the variance necessary to accommodate adjustment between the upper and lower zones, Zones 1 and 3, and Zones 2 and 4, respectively, during normal operation of the furnace to a preheat slab-yard slabs. The furnace normally will be at a value of such as 2000° F. and the slab will become progressively heated enroute through the furnace at a rate which varies inversely in proportion to its degree of advancement through the furnace. This is so by virtue of the fact that the length of the heating zones are substantially equal and the flow of heat into the slab by radiation is substantially proportional to the fourth power of the temperature difference between the surface of the slab and the furnace temperature, which difference becomes progressively less as the slab approaches the exit end of the furnace.

In accord with a feature of the illustrative embodiment of the present invention as employing an induction heating furnace 24 for effecting the second stage of heating of the slab, the heating imparted by the fuel-fired furnace 23 to the slab-yard slabs for preheating same provides for exiting the preheated slabs from the fuel-fired furnace with a considerable temperature differential between the surface of such slabs and the interior thereof, such for example from 500° F. to 800° F. surface-to-center differential, and the usual "soaking" zone of the furnace to provide for equalizing-temperature flow of heat from the surface to the interior is dispensed with. At the same time, the fuel-fired furnace, in operating at a nominal value of 2000° F. is operated for relatively efficient transfer of radiant heat to the slab even in the final zone of such furnace by permitting a temperature difference between the furnace and the exiting slab of at least 200° F. Referring also to FIG. 6, typical temperatures resultant from heating slab-yard slabs enroute through the fuel-fired furnace 23 are shown, as well as a typical average furnace temperature.

In each of the zones of the furnace there is associated a respective fuel control valve means, FCV, for regulating flow of combustible gas from a fuel supply source to the particular furnace zone as well as an air control valve means, ACV, for regulating the amount of air supplied to each particular furnace zone either for supporting combustion of the gas supply to such zone and/or for effecting rapid cooling of the particular zone according to needs. Operation of such fuel and air control valve means may be based at least in part upon thermocouple-sensed information obtained from the walls of the furnace in the several zones to provide temperature set points for such controls, but, in accord with a feature of the present invention, adjustment of the temperature set points of these controls also is controlled, at least in part, by an on-line process computer C which compares information on slab location within the furnace, the slab surface temperature in the different zones of the furnace, and the speed of travel of the slab enroute through the furnace with a mathematical model of the heating to be imparted by a particular furnace zone according to such information to obtain a calculated set point temperature for the fuel and air control valve means. Such a mathematical model can be based on well-known heat transfer equation, and/or on empiric information gained from model test procedures or full scale operation of the heating line. A typical program in the form of a curve showing slab surface temperature as effected by the travel speed of the slab through a furnace zone is shown in FIG. 3. In this regard the slab

surface temperature can be picked up at various locations in the several zones of the furnace by temperature sensors, TS, in form of radiation pyrometers, the slab position within the furnace can be picked up by a plurality of location sensors, LS's, in the form of photocells situated at the front and rear of each of the longitudinal zones of the furnace, and the line speed information can be picked up by speed sensors, SS, in the form of such as tachometer generators.

The temperature information from the radiation pyrometers will be in analog form as well as may be the speed information, and such information will be transmitted to the computer, C, by way of such as a director logic means, DL, and analog-to-digital converter means, A/D C. The temperature set point value arrived at by the computer for a particular zone will be fed back to the respective fuel and air control valve means, FCV and ACV, by way of such as a digital-to-analog converter, D/A C, to apply at least a vernier adjustment in the temperature set point of such control valve means.

The system may also include a graphic instrumentation panel, GIP, on which information may be displayed and recorded, for example, as to the rate of fuel and air supplied to the separate sections of the furnace based on information afforded by a fuel sensor, FS, and an air sensor, AS, capable of reading the air and fuel flow rates, respectively.

While in FIG. 2, a fuel control valve means FCV, and an air control valve means, ACV, has been shown affiliated with each of Zone 1 and Zone 2 of the fuel-fired furnace, arrows 31, 32, 33 and 34 directed respectively to the other zones of the furnace are intended to indicate provision of a similar arrangement for these zones also.

The process computer C may be of the type and capacity presently sold by Westinghouse Electric Corporation under the trade name Prodac 500, for example. It is provided with a plurality of curves to suit different operating parameters of the heating line. For example, information is fed into the computer in the form of such as a card or cards which set forth such parameters as the dimensions of the slab, its point or origin, such as direct from the caster or from the slab-yard, as well as the desired speed of operation of the line in order to be compatible with the demands of the rolling mill. The computer will then select the suitable set of temperature speed curves on which the several furnace zones are to operate to give the desired slab heating at a maximum rate of heat input commensurate with a particular line speed and limitation as to maximum allowable slab surface temperature. Where a relatively long run of direct-from-caster slabs are to pass through the fuel-fired furnace 23 enroute to the induction heating furnace 24, the computer C will call for reduction in furnace temperature to a value in the neighborhood of 2000° F. and the rate of operation of the conveyor rolls 22 will be such that the speed of travel of the slabs 10 through the fuel-fired furnace 23 will agree with the rate of travel through the induction heating furnace 24. Control of speed of the roll drive, RD's in FIG. 2, for the conveyor rolls 22 in the heating line will be controlled by the computer C in accord with the desired production rate data fed to the computer. Roll drive speed control units, indicated by the RDSC's in FIG. 2, translate computer commands for response by the rolls drives, RD's. The roll drive system for the radiant furnace 23 of the line has at least a separate drive for the final zone, Zone 6 in FIG. 2, to suit an input condition where an occasional direct-from-caster slab is fed through the line and intermixed with a normal production run of slab-yard slabs. Under this operating demand condition the computer C will call for the furnace to remain up-to-temperature for preheating of the slab-yard slabs, and the arrival of the occasional direct-from-caster slab appearing at the input to the radiant furnace of which the computer is apprized by the operator or by

temperature information sensed at the furnace entrance, results in the computer C effecting a rapid movement of the direct-from-caster slab through the first five zones of the fuel-fired furnace, followed by normal-run-rate movement through the remaining Zone 6, thence into the induction heating furnace 24. The computer C also is programmed for a "hold" condition, which can be effectuated manually under a suitable operator-dictated command signal, at which time the computer C automatically calls for cutback in rate of heat input to the several zones of the furnace for reduction in set point temperature in such zones according to the duration of the delay, such as exemplified in FIG. 4 which includes a curve 39 showing variation in set point temperature as automatically adjusted over a period of time by the computer C according to the duration of a delay in operation of the line. The computer also has built-in curves for effecting a gradual increase in set point temperature within the several zones of the furnace following a delay according to the duration of the delay, such as the restart curves 41, 42, 43 and 44 corresponding to line delays of time durations T1, T2, T3 and T4, respectively. The computer-controlled cutback in furnace temperature aims at maintaining the slab temperature conditions in the several zones of the furnace at relative degrees of value as close as possible to those relative degrees that exist during a normal production run. This reduces the degree of compensation capability which need be designed into the subsequent induction heating furnace control functions performed by the computer C, as well as affords better compatibility between the two modes of heating. However, an alternate mode of operation of the fuel-fired furnace 23 during a delay can be to allow the furnace to remain at its normal-line-speed operating temperature while the computer determines the slab temperature conditions which result from the slabs remaining within such a furnace for the duration of such delay, and then apply correction in subsequent input of heat to the slabs by the induction heating furnace section. Even though the furnace temperature may be held substantially constant in the latter case, however, it will be appreciated that the fuel and air control valves, adjusted to maintain the furnace temperature constant, will effect cutback in supply of fuel to the furnace as the heat demand to the slabs reduces with the prolonged presence of the slabs in the furnace. The philosophy upon which the variable-zone-temperature-set-point-cutback-according-to-time-of-delay is based, however, is in behalf of maintaining, insofar as possible, a favorable temperature profile in the slabs which is compatible with the slab temperature profile tending to be created by heating in the induction furnace 24. In this regard the fuel-fired furnace 23 produces a slab which is hotter on the outside than on the inside, while the induction furnace 24 tends to heat the slab internally to a greater degree.

The above refers to reduction in temperature set points of the fuel-fired furnace 23 when preheating slab-yard slabs during a delay in operation of the line. When the line is shut down while heating direct-from-caster slabs, the computer C will initiate a furnace operating program which follows the same slab-yard slab heating philosophy and attempts to maintain such slabs at the same average temperature that they would have in the different furnace zones during a normal run of direct-from-caster slabs.

The induction heating furnace 24, in accord with the embodiment exemplified herein, comprises the plurality of axially-aligned mutually spaced-apart induction heating coil assemblies 25 such as shown in various details in FIGS. 1, 7 and 8. Each coil assembly 25 is energized by single-phase alternating current power. A total of such, for example, as twenty-one coil assemblies 25 may be employed, fore and aft of each of which are arranged the conveyor rolls 22. Referring to FIG. 2, the energization of the coils 26 of such assemblies are controlled in groups

of three, CG in FIG. 2, Zones I, II and III each contains two such three-coil groups CG and Zone IV contains one of such three-coil groups CG. Each group of three coils is served by a transformer means, T in FIG. 2, each transformer means T includes three single-phase transformer units in a common tank, with power factor corrector capacitors, PFCC in FIG. 2, interposed between the transformer means T and the respective group CG of coils; the PFCC will include three single phase units respective to the three transformer units. To control energization of the coils in groups of three, each three-coil group CG is provided with a saturable core reactor means, SCR in FIG. 2, which will include three single phase units in a common housing. Each of the three single phase units of an SCR will respond to a common control signal to vary the three single phase inputs to the transformer means T and thereby regulate the voltage applied to the three induction heating coils 26 affiliated with the respective three-coil group CG comprising such coils. In addition, the input circuit for each group of coils will include a power circuit breaker, in FIG. 2 PCB, interposed between a power supply and the saturable core reactor means SCR. Only one such energization control arrangement for a three-coil group CG has been shown in FIG. 2 and other such arrangements for the other three-coil groups CG of the induction heating furnace 24 are indicated by the arrows 50, 51, 52, 53, 54 and 55 in FIG. 2.

The conveyor rolls 22, which may be approximately twelve inches in diameter, seven feet long, and spaced on five foot centers, are all driven from a motor-operated roll drive means, RD in FIG. 2. Such motor means is arranged to be controlled by a roll drive speed control means, RDSC in FIG. 2. Such roll drive means may include a plurality of reducers and motors (not shown) distributed at different longitudinal locations along the furnace, which motors may be of a squirrel cage type whose speed can be controlled accurately according to the frequency of the power supplied thereto. The roll drive speed control means RDSC, therefore can take the form of adjustable frequency inverters responsive to a set point demand from the computer C to adjust the frequency of the power supplied to the roll drive motor means RDM and thereby accurately regulate its speed.

It is proposed in the illustrative embodiment set forth herein that the two three-coil groups of Zone I may have a kilowatt rating of approximately 9000 for each group, each of the three coil groups in Zone II will have a kilowatt rating of approximately 5000 for each group, each of the three coil groups in Zone III may have a kilowatt rating of approximately 3000 for each group, and the single three coil group of Zone IV may have a total kilowatt rating of 4000. These might be typical values for a heating line demand to heat twelve-inch-thick slabs up to the desired rolling mill temperature of 2250° F. (from the caster or furnace) at a heating load of 225 tons per hour.

To inform the computer as to the position of each slab 10 while enroute through the induction heating furnace 24, a plurality of location sensors, LS's in FIG. 2, which may take the form of photocells, are located fore and aft at suitable longitudinal locations along the furnace line to indicate slab positions with respect to each of the four zones.

To serve as indication of the speed of travel of the slabs through the induction heating furnace a speed sensor means, SS in FIG. 2, is affiliated with the roll drive means RD to furnish information to the computer for determining the time that the slabs remain in the respective zones.

In addition, information with respect to the voltage supplied to each three-coil group CG, the power supplied to each three-coil group, and the current supplied to each three-coil group, may be picked up by suitable sensors labeled VS, PS and CS, respectively, in FIG. 2.

In operation of the induction heating furnace 24 in the line 20, slabs 10 leaving the fuel-fired furnace 23 arrive at such induction heating furnace 24 at temperature conditions which will vary only slightly, according to the history of the heat transfer conditions experienced by the slab prior to entry to such induction heating furnace; the fuel-fired furnace 23 having heated all slabs up to an average temperature of 1800° F., for example, irrespective of initial temperature conditions of such slabs upon entering such radiant furnace. The computer C, having selected the program of heating each of the slabs 10 enroute through the fuel-fired furnace 23 in accord with the slab speed, accordingly will select the suitable heating program for the subsequent heating in the induction heating furnace 24. The computer C will automatically select the proper heating program for heating the slab to its final average temperature of 2250° F., for example, in a minimal amount of time in accord with the speed of operation of the line and without heating the surface of the slab to above the previously-mentioned value such as 2550° F. In accord with the multiple-zone philosophy of heating in minimal time, Zone I of the induction furnace section may apply approximately 60% of the heating energy employed for raising the temperature of the slab, Zone II may apply approximately 30%, and Zone III approximately 10%. The fourth zone, Zone IV, is employed not so much for adding temperature-raising amounts of heat to the slab as for holding the front end of the slab at the desired temperature while the trailing end is leaving Zone III.

Regulation of the amount of heat energy imparted to the slab is done by control of the voltage of the 60-cycle energizing current supplied to the coils 26 of the various three-coil groups of the induction furnace. The voltage of the separate groups of controls respective to the three-coil groups CG is determined primarily by the speed information fed to the computer C, and the computer will effect regulation of the voltage applied to the three-coil groups CG in accord with automatic selection of a suitable set of operation curves to grossly adjust the energy input to the slab according to its speed of travel through the furnace and to apply vernier correction of such energy input according to the measured surface temperature of such slab in the several zones of the furnace. A typical one of such curves for a particular coil group or heating zone may appear as represented by curve 60 in FIG. 3 of the drawings. As in the case of the heating program effected by the radiant furnace 23 in the heating line 20 during "hold" conditions of such line, i.e. temporary stopping of the line, a similar program is initiated for the induction furnace section. Such a delay-heating program is initiated by the computer when informed of such delay, as by an operator-controlled condition signifying existence of such delay or by such as automatic signal from roller drive operation information. Under such delay conditions the computer C automatically selects an energy cutback program for the heating coils of the furnace which will adjust the temperature set points of the several voltage controlling means in the form of the saturable core reactor means SCR's to call for a reduction in heat input to the slabs in a manner which minimizes differences in the relative temperature conditions in the slabs with respect to one zone and another, as between delay and normal running operation of the line. At the same time, the computer C automatically progressively effects adjustment of the energization of the heating coils 26 according to the duration of the delay; subsequent corrections being progressively less in extent than the initial correction until a minimum value is reached corresponding to what may be referred to as "infinite" delay. For sake of illustration, the curve 39 shown in FIG. 4 previously referred to in connection with programming of the heating applied by the fuel-fired furnace 23 also can be presumed to apply to the delay heating program to be imposed by the induction heating

furnace 24. Correspondingly, upon assuming normal running operation of the furnace 24, following a delay, the various energy control means, SCR's for the heating coils of the three-coil groups, CG's in the several zones are increased gradually up to the average set point employed during normal running operation according to the duration of such delay, as indicated in FIG. 4 by curves 41, 42, 43 and 44 following delay times of T1, T2, T3 and T4, respectively. During existence of such delay program, the gross adjustment of heating of the slab by the coils is in accord with time of such heating, and vernier adjustment is applied in accord with surface temperature of the slabs. Upon exit from the induction heating furnace 24, the slabs will have been heated to a temperature of about 2250° F. and may have an allowable temperature difference between surface and its interior within a range of 100° F. Upon exiting from the induction furnace 24 the heated slabs 10 will be transferred by a suitable means to the rolling mill (not shown).

It will be appreciated that the response of the induction heating furnace 24 to dictates of the computer, as during a delay, for example, will be substantially instantaneous with respect to input of heat to the slabs, and no possibility exists for overheating of the slab above the maximum allowable surface temperature of the slabs, 2550° F., for example.

To assure even distribution of heat along the length of the slabs 10 while in the induction heating furnace 24 during a delay, the computer automatically initiates a program of periodic reversal in operation of the roll drive means, RD, affiliated with such furnace to introduce an oscillatory movement of the slabs within a limited distance necessary to subject such slabs uniformly to the fields of the heating coils.

Also, by virtue of the exemplified embodiment of the induction heating furnace 24, as described herein, wherein the slabs pass through the heating coils, as well as by virtue of the multiplicity of separately-controllable heating zones, Zone I to Zone IV, located along such furnace, it is possible to so program the computer C as to obtain a temperature gradient from one end of the slab to the other when desired to suit rolling mill operating conditions.

While a particular embodiment of the invention is disclosed herein for illustrative purposes, it is intended that the invention not necessarily be limited to such particular embodiment, and that reference should be had to the appended claims which are intended to cover the true spirit and scope of the invention.

We claim as our invention:

1. In combination with a continuous caster producing relatively thick elongated metal slabs discharged longitudinally and horizontally therefrom at a cutoff station; heating apparatus for heating such slabs up to a rolling temperature, comprising
 - a horizontal array of motor-operated conveyor rolls aligned for conveying slabs longitudinally along a straight linear path of travel extending from said cutoff station and being adjustable in speed to correspond with different rates of slab production by said continuous caster,
 - a plurality of tunnel-shaped induction heating coils disposed horizontally between a number of such conveyor rolls and constructed and arranged for consecutive passage therethrough by slabs during their transport by such rolls,
 - said coils being arranged electrically in at least three separately-energizable groups,
 - control means including an information-storing computer controlling energizations of the groups of induction heating coils grossly in accord with stored information relative to the time of presence of the slabs therein and finely in accord with slab surface temperature while within such groups, and

11

sensor means furnishing to said computer information as to slab presence time and temperature respective to the separately-energizable groups of coils.

2. The combination of claim 1, further including a slab yard in which slabs from such continuous caster are stored and subject to cooling, and wherein said heating apparatus further comprises,

means for conveying slabs from said slab yard also to the aforesaid conveyor rolls,

a fuel-fired radiant furnace having at least three separately-regulatable heating zones through which longitudinally pass both direct-from-caster slabs and slab-yard slabs enroute to said induction heating coils, said control means also controlling regulations of the separately-regulatable heating zones to heat slab-yard-

12

slabs up to substantially the same average temperature as direct-from-caster slabs prior to entry into the induction heating coils while at least substantially ineffectuating said radiant furnace with respect to travel of such direct-from-caster slabs therethrough.

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FREDERICK L. MATTESON, Jr., *Primary Examiner*.

15 E. G. FAVORS, *Assistant Examiner*.