Nov. 20, 1934. E. F. NORTHRUP 1,981,631

ELECTRIC INDUCTION FURNACE

Filed Jan. 5, 1931 2 Sheets-Sheet 1

Fig. 1.

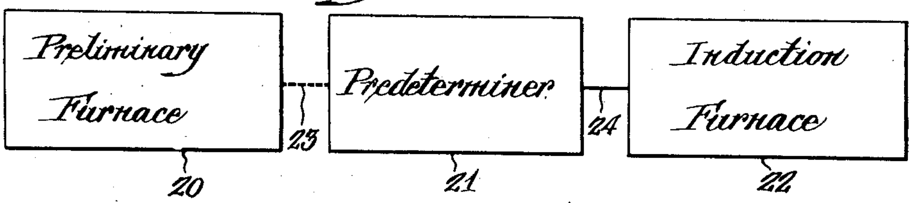
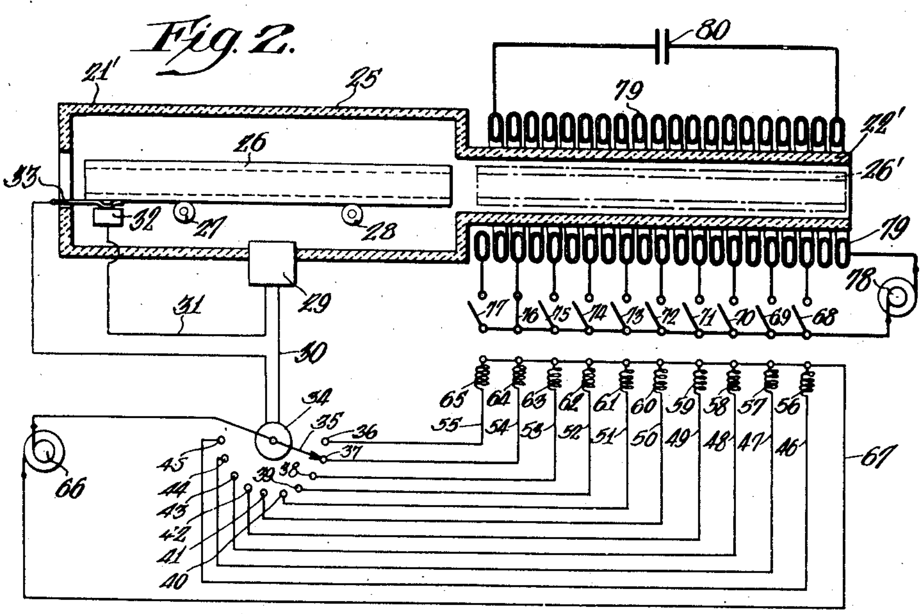


Fig. 2.



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Witnesses:

by

Attorney.

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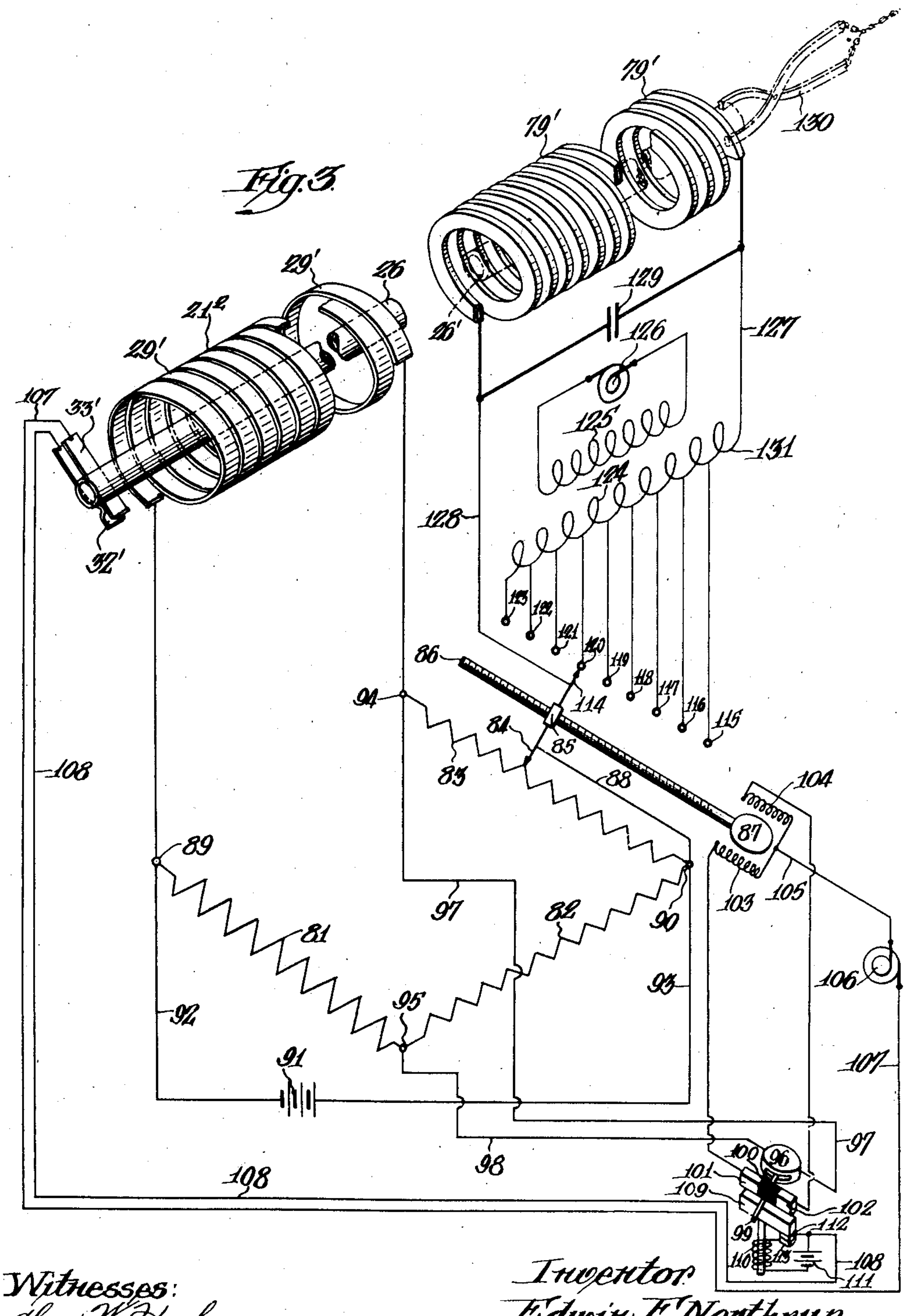

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UNITED STATES PATENT OFFICE

1,981,631

ELECTRIC INDUCTION FURNACE

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Application January 5, 1931, Serial No. 506,571

10 Claims. (Cl. 219—13)

My invention relates to electric induction furnaces and to methods of controlling their operation.

A purpose of my invention is to predetermine the rate of inductive heating of charges in accordance with their charging temperatures, preferably making the time of heating uniform.

A further purpose is to heat automatically, to an established uniform finishing temperature, charges placed in an electric induction furnace at variant initial temperatures.

A further purpose is to inductively heat charges supplied to a furnace at relatively low initial temperatures more rapidly than those coming at higher initial temperatures.

A further purpose is to inductively reheat stock, which has undergone uncontrolled cooling during mechanical working, automatically to a uniform forging temperature preliminary to further mechanical working.

A further purpose is to control automatically the inductive heating of charges supplied at variant initial temperatures to a uniform final temperature preliminary to heat treating the charges.

A further purpose is to vary the voltage impressed upon a furnace inductor coil by moving the balancing arm of an automatic self-balancing potentiometer.

A further purpose is automatically to alter the number of inductor coil turns connected to the source with change in the temperature differential between the initial and final charge temperatures.

Further purposes appear in the specification and in the claims.

My invention relates chiefly to the methods involved, but it also includes apparatus suitable to carry out the methods.

In the drawings I illustrate one general type of apparatus, of the many which might be employed, as well as one specific instance of the general type. I have chosen the apparatus largely from the standpoint of convenient illustration of the principles involved, and with the knowledge that many others might be devised.

Figure 1 is a chart indicating steps in my method.

Figure 2 is a diagrammatic section of a general form of apparatus which I may employ.

Figure 3 is a diagrammatic perspective view of a specific circuit which I may conveniently use.

In the drawings like numerals refer to like parts.

In metallurgy it is very common to heat metallic charges to relatively high temperatures, to subject them to operations during which they cool to an uncertain extent, and finally to reheat them to a desirably definite temperature, usually determined by one of the critical points of the particular metal.

The making of iron and steel is replete with cases in which the metal, at an uncertain relatively high temperature, must be heated to a definite temperature. I will refer briefly to a few instances.

Iron from the blast furnace is commonly tapped into ladles and carried directly to the steel-making furnace without intermediate solidification. Various charges enter the steel-making furnace, as for example an open hearth, at variant temperatures, depending among other things, upon the temperature at which the blast furnace is tapped, the size of the ladle and the length of time in which the steel is held in the ladle.

However, it is important to tap the steel-making furnace at a definite temperature without regard to the charging temperature of the metal. As a consequence, the cycle of operation of the steel-making furnace varies with the individual charge, in the effort of the operator to obtain a uniform finishing temperature.

Again, the product of the open hearth is frequently charged into an electric induction furnace and there further refined or mixed with alloying ingredients. The initial temperature of the induction furnace charge is again dependent upon a number of factors, such as the temperature of tapping of the open hearth, the size of the ladle, the time during which the steel is held in the ladle and the time during which the induction furnace has been idle prior to charging.

In order to obtain a uniform pouring temperature for the induction furnace, the time of the heating operation is varied to suit the needs of the particular charge.

After the ingots have been poured, have solidified and have been removed from the mold by stripping, they are ordinarily placed in a soaking pit, while they still retain some sensible heat from the steel-making furnace. The temperatures of the ingots entering the soaking pit vary considerably, and therefore ordinarily the ingots are allowed to remain in the soaking pit for such a long time that it is certain that even those charged at the minimum temperature have reached the selected finishing temperature.

After the ingots have been removed from the soaking pit and have been cropped, they may be mechanically worked, as for example by rolling, and, after several passes through the rolls, placed in a reheating furnace. Here also, the temperatures of the charges as they enter the reheating furnace vary widely, and the reheating operation must be lengthened considerably to make sure that even those charges supplied at minimum temperatures have reached the proper finishing temperature for further mechanical working.

After mechanical working has been finished, the charges are commonly heated to a carefully regulated temperature and heat treated, as by annealing or quenching. The temperature of charging into the heat treating furnace varies, and the cycle of operation of the heat treating furnace varies undesirably with individual charges.

Each of the instances cited, the open hearth, the induction furnace, the soaking pit, the reheating furnace and the heat treating furnace, presents the problem of regulating the operation to bring charges inserted at varying temperatures to a finishing temperature which is uniform from charge to charge and from cycle to cycle.

With a rate of power input varying about in proportion to the required increase in temperature it is possible to make the time of heating so nearly uniform for all charges (independently of the initial temperature) that workmen can proceed confidently upon a time basis or schedule without having to verify temperatures.

In as much as each of the types of furnaces named, and in fact all furnaces operating upon metallic charges and many handling nonmetallic charges, may now be or may be in the future an induction furnace, my invention is broadly applicable to all of them.

Inherently my invention is not limited to use upon molten or upon solid charges, although I anticipate that its widest application will be in heating solid charges for the purpose of mechanical working or heat treating.

I have discovered that the operation of an induction electric furnace may be very desirably improved by employing a cycle of constant length and automatically varying the power input of the furnace inversely with respect to the initial temperature of the individual charge. If an individual charge be at a relatively low initial temperature, I will apply a higher power input, so that it will reach the required temperature by the end of the predetermined time, while if it be at a relatively high initial temperature, I will use a comparatively low power input, and still finish heating in the same time.

Thus with a charge of low initial temperature the power input is relatively high, while with one of high initial temperature the power input is relatively low. Although no proportionality exists between the initial temperature of the charge and the power input, the power input varies inversely with respect to the initial temperature.

Essentially my invention comprises an inductor coil connected to a power source, suitable power switches and connections for changing the power input to the inductor coil, a temperature measurer for determining the initial charge temperature and a power switch control responsive to the temperature measurement for varying the power input inversely with respect to the temperature measurement. The location of the temperature measurer, whether in the induction furnace or in a separate place, is relatively immaterial to my invention.

In Figure 1 I illustrate three steps proceeding in time sequence from left to right. The charge is first heated in a preliminary furnace 20, is subsequently exposed to the predeterminer 21, and finally passes to the induction furnace 22.

The preliminary furnace may be any furnace whatever in which heat is added to the charge, as for example a blast furnace, open hearth, induction furnace, soaking pit or reheating furnace. The function of the preliminary furnace from the standpoint of my invention is solely to add heat to the charge, without regard to whether the charge be melted or subjected to any other operation. Ordinarily heating in the preliminary furnace is incidental to some other purpose there being served.

Between the preliminary furnace and the predeterminer there may be any number of steps, as indicated by the dotted flow line 23, during which an uncertain change in temperature occurs. For example, the charge may initially require superheating above the temperature to which the preliminary furnace raises it; be transferred to a ladle; cast into an ingot, cooled and stripped; allowed to stand and partially cool; mechanically worked; heat treated; or subjected to any operation whatsoever which results in a variable charge temperature.

I then place the charge in the predeterminer, where its temperature is gaged and the power input of the induction furnace is regulated according to the gaged temperature. Between the predeterminer and the induction furnace there is no temperature change or a definite temperature change of the charge, as indicated by the solid flow line 24.

I refer to the operation as "gaging" rather than "measuring", notwithstanding that all of the physical steps of measuring are performed, because the knowledge of the temperature of the charge need not be brought home to the operator, since the variation in the power input is automatic.

The predeterminer may be in the induction furnace itself, in which case the temperature which it gages is the temperature at which the inductive heating starts. In this event the predeterminer must be disconnected after the furnace starts to heat the charge. On the other hand, the predeterminer may be located at some distance from the induction furnace, and all charges passing from the predeterminer to the induction furnace will in that case undergo the same conditions so that the temperature gaged in the predeterminer will have a definite relation to the initial temperature of the charges in the induction furnace.

The particular mechanism for carrying out my invention is of relatively secondary importance, as many different forms of apparatus could be devised.

In Figure 2 I show operation upon metallic pipe. The predeterminer 21′ having a wall 25 is located at a point earlier in the direction of charge travel than the induction furnace 22′, and is connected to the power variation switches of the induction furnace so that the power input is regulated inversely with respect to the temperature determination of the predeterminer.

A charge 26 is shown in the predeterminer resting upon suitable supports, desirably consisting of rollers 27 and 28. A temperature gage 29 of any suitable character is exposed to the heat of the charge so that it gives a relative determination if not an actual measurement of the temperature of the charge. The temperature gage may be of any character whatsoever which is automatic, and the particular form used will depend of course upon the temperature which is to be gaged and the conditions in the predeterminer.

For example, the temperature gage 29 may operate by variation of electrical resistance, by change in thermal electromotive force, by alteration in photoelectric current, by thermal expansion, or in any other manner. Of course, with each of these forms the usual circuit will be used, with suitable resistances, reactances, power sources, relays or meters as required. I do not refer to the gage as a "pyrometer" because I do not wish to limit myself to high temperatures within the pyrometer range, although the gage will ordinarily be required to operate on high temperatures.

In Figure 2 I show conventional connections 30 and 31 through contacts 32 and 33 to a relay switch 34 responsive to variation in the electrical characteristics of the circuit from the temperature gage 29. The contacts 32 and 33 are closed when the charge 26 is in the predeterminer and open, as for example by upward spring of the contact 33, when the charge is withdrawn from the predeterminer. The predetermined is disconnected so that it cannot function to vary the induction furnace power input when no charge is in the predeterminer.

The current or voltage variation produced by change in temperature in the temperature gage 29 is ordinarily so small that I will use a relay switch circuit to vary the induction furnace power input.

In response to variation in the current and/or the voltage from the temperature gage 29, the relay switch arm 35 moves over the contacts 36, 37, 38, 39, 40, 41, 42, 43, 44 and 45, which are connected by leads 46, 47, 48, 49, 50, 51, 52, 53, 54 and 55 to remote control coils 56, 57, 58, 59, 60, 61, 62, 63, 64 and 65. The circuit through the remote control coils from a source 66 is completed by a connection 67 which is common to each of the remote control coils.

Each of the individual remote control coils closes one of the switches 68, 69, 70, 71, 72, 73, 74, 75, 76 and 77, which impress the voltage of an alternating power source 78 across varying numbers of turns of the inductor coil 79 through suitable taps. The power factor of the inductor coil is corrected by capacity 80 shunted across the entire coil. The inductor coil is indicated as hollow flattened edgewound water cooled tubing, but of course it may be of any suitable type.

In operation, when the charge 26 is inserted in the predeterminer 21', the switch contacts 32 and 33 are closed so that the temperature gage 29 is operative to control the relay switch 34. If the individual charge 26 in the predeterminer be at an abnormally low temperature, a relatively small current flows through the connections 30 and 31 or a relatively low voltage is impressed across them and the relay switch arm 35 finds a position near the end 45 of the switch arm movement.

Assume that contact is made at 45. Then the remote control coil 56 is excited, closing the switch 68, and impressing the voltage of the power source across only a small part of the inductor coil.

The inductor coil 79 acts as an autotransformer of which the turns connected across the power source are the primary and the entire coil, connected across the capacity 80, is the secondary. With the power source 78 connected across only a small part of the inductor, the ratio of transformation is high and the voltage impressed across the capacity is correspondingly high, so that the oscillation circuit carries a large current.

When the charge 26 moves to the position 26' indicated in dot and dash, it is subjected to a high power input which heats it relatively rapidly. Since, however, its initial temperature was low, it requires a relatively large amount of heat, and is brought to finishing temperature in exactly the time chosen for completion of the cycle.

If, on the other hand, the charge 26 be at a relatively high temperature when placed in the predeterminer, a high current flows in the connections 30 and 31 or a large voltage is impressed across them, moving the relay switch arm 35 to a position near the end 36 of the contacts. Assume that contact is made at 36. Then the remote control coil 65 is excited, closing the switch 77 and connecting the power source 78 across the entire inductor coil. The ratio of transformation of the inductor coil is low, producing a correspondingly low oscillation circuit current and low power input. This is desirable because the charge came to the induction furnace at an abnormally high temperature. The charge is brought to the uniform finishing temperature in the same time as was required for the charge of abnormally low initial temperature.

Charges entering the predeterminer at intermediate temperatures are correspondingly subjected to intermediate power inputs, so that all charges are finished in the same time.

In Figure 2 the charge 26 is evidently at a relatively high initial temperature, since the switch arm 35 at the point 37 has actuated the remote control coil 64 to close the switch 76, placing the inductor coil on relatively low power input.

The steps from tap to tap need not represent equal temperature differences and the coils thrown in by reason of their successive engagement need not be equal in their additions to the heat input.

The number of taps from the inductor coil depends of course upon the number of turns in the inductor coil and upon the closeness of regulation which is desired. For moderate size furnaces I find that 20 taps are sufficient, although any number could be used.

It will be evident that my invention could be carried out by placing the temperature gage in the induction furnace itself. However, I do not consider this as desirable as the form of Figure 2, because it would then be necessary to operate the power switches when the furnace was under load, whereas now the switches are operated while the charge is in the predeterminer and before the furnace comes under load. The oscillation circuit through the condenser 80 does not include the taps or switches 68 to 77, so that this equipment does not carry the heavy oscillation currents.

The switch between the contacts 32 and 33 prevents change in the power switch setting for the induction furnace after the individual charge leaves the predeterminer and enters the induction furnace and before the next charge is inserted in the predeterminer. The predeterminer of course cools after the charge is removed, and, if the switch 32, 33 did not open to disconnect the relay switch 34, the predeterminer would increase the power input of the induction furnace as it cooled.

The circuit of Figure 2 is of course entirely diagrammatic since the details of the temperature gage, the relay switch and the remote control switches are not shown. In Figure 3 I indicate in more detail one desirable form of my invention.

The charge 26 is shown in the predeterminer 21^2, which consists of a temperature gage 29′ formed of a continuous coil of flat wound nickel strip. To illustrate that the predeterminer will normally be of the approximate length of the charge, where the entire charge is to be heated, or of the portion of the charge to be heated, where only part of the charge is to be heated, the coil is conventionally broken in Figure 3.

The ends of the temperature gage 29′ form one leg of an automatic self-balancing potentiometer system having fixed resistances 81 and 82 and a resistance 83 varied by a movable contact 84 on an advancing nut 85 carried by a threaded shaft 86 of a motor 87. Connection is made to the sliding contact 84 by a movable lead 88. Opposite points 89 and 90 of the bridge are connected to a suitable power source 91 through leads 92 and 93.

As in the conventional Wheatstone bridge, when the resistances are balanced there is no potential difference between opposite points 94 and 95. This condition is maintained automatically by means of a double deflecting galvanometer 96 connected to the point 94 by a lead 97 and to the point 95 by a lead 98. The galvanometer 96 has a suitable electrically conducting pointer 99, which, when the bridge is balanced, lies immediately below the block 100 of insulating material. The pointer 99 is in reality a switch arm.

When the bridge is out of balance, current flows through the galvanometer 96, and the pointer 99 swings either to the left or to the right, depending upon the direction of current flow. If it swing to the left, it lies immediately below the contact 101, while if it swing to the right it lies immediately below the contact 102. The contact 101 is connected to a field winding 103 of the motor 87, while the contact 102 is connected to an opposite field winding 104 of the same motor. The opposite ends of the field windings are joined to a lead 105 from a suitable power source 106.

The opposite side of the power source 106 is connected at 107 to one contact 33′ of a switch closed by the charge when it is in the predeterminer. The other contact 32′ of the switch is connected at 108 to an armature 109. The armature 109 constantly moves up and down under the influence of a solenoid 110 connected to a power source 111. When the armature is in upper position, the solenoid circuit is broken by separation of the contact 112 on the armature from the stationary contact 113, and the armature then drops until the solenoid circuit is completed once more, when the armature receives a new impulse upward.

If the pointer 99 is below the block of insulation 100, the motor field circuit is not completed by upward movement of the armature 109. If the pointer is below the contact 101, due to unbalance of the bridge in one direction, the circuit through the field coil 103 is completed, and the motor is driven in the direction to cause the sliding contact 84 to balance the bridge. On the other hand, if the pointer is below the contact 102, due to unbalance of the bridge in the opposite direction, the circuit through the opposite field coil 104 is completed, and the motor turns in the reverse direction to balance the bridge.

It will be recognized of course that the automatic self-balancing potentiometer has in practice many refinements not shown in my diagrammatic view. These are well known to electrical engineers, and may be seen on the Leeds and Northrup instrument of this type, or in a Leeds and Northrup catalogue forming part of the literature of this subject.

The nut 85 moves along the resistance 83 as the shaft 86 rotates, taking a direction depending upon the direction of rotation of the shaft. As it moves to balance the bridge, the nut 85 also carries a power-switch arm 114, which travels over tap contacts 115, 116, 117, 118, 119, 120, 121, 122 and 123 of a secondary winding 124 of a transformer having a primary 125 connected to an alternating current power source 126.

One end of the secondary 124 is desirably connected at 127 to one end of the inductor coil 79′ which desirably consists of hollow flattened edgewound water cooled tubing. The inductor coil is conventionally broken to indicate increased length to correspond roughly with the length of the charge 26′, or of the portion of the charge to be heated, where less than the entire charge is to be operated upon. The other end of the inductor coil is connected at 128 to the power switch arm 114. The power factor is desirably corrected by capacity 129 shunted across the inductor coil so that the oscillation circuit does not include the power switch arm 114 and the taps.

At the end of the uniform heating cycle, the charge is withdrawn from the inductor by any suitable means, such as the automatically operated tongs 130, which may be controlled by suitable timing mechanism, or manually.

When the predetermined winding 29′ is cool, it is of relatively low resistance, but, as soon as a charge is placed in the predeterminer, the winding becomes heated, and as it does so its resistance increases. The charge closes the switch between the contacts 32′ and 33′, so that the power source 106 may be connected with the field of the motor 87 when the bridge is out of balance. Initially, since the resistance of the temperature gage 29′ is low at first, the bridge is balanced with the switch arm 84 near the point 94.

As the resistance of the predeterminer winding 29′ increases with increase in temperature, the switch arm 84 moves nearer to the point 90 in order to maintain the balance of the bridge. When the temperature gage 29′ reaches an equilibrium temperature for the individual charge, the switch arm 84 will be close to or far from the point 90, depending upon whether the temperature of the individual charge be abnormally high or low.

The power switch arm 114 will correspond in position to the position of final balance of the switch arm 84. If the charge be at an abnormally high initial temperature, the temperature gage 29′ will have a high resistance, the bridge will be finally balanced with the switch arm 84 near the end 90, the power switch arm 114 will come to rest in contact with one of the points 115, 116 or 117, a low voltage will be impressed across the inductor coil, and the furnace will operate on low power, as it should because of the abnormally high temperature of the charge.

If the charge be at a relatively low initial temperature, the temperature gage 29′ will have a low resistance, the bridge will be balanced with the switch arm 84 near the end 94, the power switch arm 114 will then be in contact with one of the points 121, 122 or 123, a high voltage will be impressed upon the inductor coil and the furnace will be on high power. This is proper because the initial temperature of the charge was low.

It will be evident of course that the number of turns included between each tap, the number of taps, and the number of turns of the transformer secondary invariably left in the circuit because of location at the untapped end 131 of the transformer secondary are details of design merely.

The frequency which I will use depends of course upon the size of the furnace, the magnetic or nonmagnetic character of the charge, the temperature of heating if the charge be normally magnetic, the dimensions of the charge if it be solid and many other factors. I consider, however, that my invention is especially applicable to high frequency furnaces used to heat solid stock.

It will of course be understood that my broad invention may be applied to heating stock which is in motion, in which case the switch 32, 33 or 32', 33' can be removed from the predeterminer circuit and the predeterminer can operate continuously upon a portion of the stock at the point where heating commences.

I believe that I am the first to heat charges of varying initial temperatures automatically to a uniform final temperature in an induction electric furnace.

I further believe that I am the first to inductively heat charges of uncertain initial temperatures to a uniform finishing temperature in a definite time.

I also believe that it is new to adjust the power in a high frequency furnace automatically.

In view of my invention and disclosure variations and modifications to meet individual whim or particular need will doubtless become evident to others skilled in the art, to obtain part or all of the benefits of my invention without copying the structure shown, and I, therefore, claim all such in so far as they fall within the reasonable spirit and scope of my invention.

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

1. In the inductive heating of charges, means for determining the temperature range through which to raise a charge to be heated, an induction electric furnace and means for automatically varying the rate of inductive heating of a charge in response to variation in the determined temperature range.

2. In the heating of charges, a preliminary heating furnace, means in which uncontrolled change in temperature of the charge takes place, means for comparing the charge temperature after change in temperature with the desired ultimate temperature, an induction electric furnace and means for regulating the induction furnace input automatically in response to variation in the difference between the compared temperatures.

3. In an electric induction furnace, an alternating current source, an inductor coil, power switching connections between the source and the inductor coil for varying the power input to the inductor coil, a temperature gage for determining the relation of the temperature of an individual charge to an intended final temperature and a control for the power switching connections responsive to change in the temperature relation.

4. In an electric induction furnace, a source of alternating current, an inductor coil, connections from the inductor coil to the source, switches in the connections for varying the power input to the inductor coil, a temperature gage for determining the relation of the temperature of an individual charge to an intended final temperature and a control for the switches adapted to operate a switch decreasing the power input to the charge with decrease in the temperature difference.

5. In an electric induction furnace, an inductor coil, a source of alternating current, connections between the inductor coil and the source, power switches in the connections for varying the power input to the inductor coil, a temperature responsive device for determining the relation of the charge temperature to an intended final temperature, a relay switch controlled by the temperature responsive device, a relay circuit having individual branches corresponding to contacts upon the relay switch, a source of current for the relay circuit and remote controls in the relay circuit, operating the respective power switches when energized by the relay circuit current.

6. In an induction electric furnace, an inductor coil, an alternating current source, connections between the inductor coil and the source, power switches in the connections adapted to open and close to vary the rate of inductive heating of a charge, a temperature responsive device for determining the relation between the charge temperature and an intended final temperature, a control closing individual power circuit switches in response to variation in the temperature relation and a switch rendering the control inoperative to vary the power input to the charge when a charge is not in position for determination of the temperature relation.

7. In an induction electric furnace, an inductor coil, an alternating current source, connections between the inductor coil and the source, power switches in the connections for varying the rate of inductive heating of a charge, a temperature responsive device for determining the relation between the charge temperature and an intended final temperature, a control operating individual power switches in response to the temperature relation and capacitative reactance across the entire inductor coil free from connection through the power switches.

8. In an electric induction furnace, an inductor coil, a source of alternating current, connections between the source and the inductor coil, power switches in the connections for varying the power input to the inductor coil, a temperature responsive device for determining the relation between the charge temperature and an intended final temperature, an automatic self-balancing potentiometer having a bridge, connections for the temperature responsive device in series with one resistance branch of the potentiometer bridge and a movable balancing arm for the bridge changing the power switch settings during its movement.

9. In an electric induction furnace, an inductor coil, a source of alternating current, a transformer comprising a primary and a secondary having taps, connections from the source to the primary, connections from the secondary to the inductor coil, a power switch in the connections, making contact in its various positions with individual taps, a temperature responsive device for determining the relation between the charge

temperature and an intended final temperature and a control for varying the power switch setting responsive to change in the temperature relation.

10. In an electric induction furnace, an inductor coil, a source of alternating current for the inductor coil, means for varying the power input to the inductor coil, a temperature responsive device for determining the relation between the charge temperature and an intended final temperature, a control for changing the power input variation means in response to alteration in the temperature relation and means for automatically withdrawing the charge from the inductor coil at the end of an established period of heating.

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