Differential Temperature Measurement on Billets

Filed Oct. 29, 1956

Fig. 1

Fig. 2

INVENTOR.

Bruce E. McArthur
Vernon R. Pierson

BY John Hawaiian
THEIR ATTORNEY.
This invention relates to a method and apparatus for the induction heating of billets and the like and particularly to a new and improved method and apparatus for cyclically heating a billet by induction in a maximum time interval to a forging or extruding temperature which is uniform throughout the billet cross section.

The induction heating of a billet, it is well known that the heating effect is produced very rapidly in a relatively thin outer skin or surface stratum of the billet and the heat there produced must flow by conduction from this outer stratum to the center of the mass, which, in the conventional cylindrical billets used for extrusion, is at the longitudinal axis of the billet.

This flow of heat by conduction inherently is much slower than the production of heat in the surface stratum or skin and consequently the heat tends to concentrate in the outer skin or stratum. This concentration of heat raises the surface temperature to such a high degree that unless considerable care is exercised to permit the heat to flow from the surface to the center at a rate consistent with its production, the billet surface will become overheated and rendered semi-plastic and too soft. Furthermore, excessively high temperatures of the surface stratum can result in excessive oxidation, scaling, change in grain structure, or even a change in the chemical composition in the case of billets of alloyed metals. In the case of high strength aluminum alloys, for example, overheating of the surface completely ruins the metal billet so that the billet must be scrapped. Often these billets weigh as much as five thousand pounds and are worth over a thousand dollars each, so that the loss of a single billet is a serious matter economically.

A number of correlative problems, therefore, are encountered when it is attempted to heat a billet inductively in a limited time to an extruding or forging temperature which is uniform through the billet cross section.

One of the principal objects of the present invention is to provide a method and apparatus for heating a billet inductively to a uniform temperature in a maximum period of time by maintaining a maximum surface temperature at the optimum degree which is both consistent with the protection of the surface from excessive heating, and with the maximum rate of flow of heat by conduction from the billet surface to the center of the billet.

In accordance with the present invention the billet is heated by means of an induction coil which is arranged to be energized and deenergized cyclically during the heating operation. The temperature of the billet is raised materially, preferably to the peak allowable safe surface temperature which, in the illustrative example hereinafter, is a few hundred degrees, whereupon recycling is begun. In the recycling operation, the surface temperature of the billet is maintained as many degrees above the desired average temperature of the billet as possible without excessive heating of the surface or skin of the billet until the temperature differential between the outer surface stratum or skin of the billet and the center of the billet has been reduced to a predetermined number of degrees, at which time the temperature at the center of the billet is approaching more closely the average billet temperature desired. When this reduced temperature differential is reached the cycle is changed to provide a new preselected reduced maximum surface temperature which is at a lesser number of degrees above the desired average temperature of the billet than the original maximum. The cycling then is continued between the new reduced maximum temperature and a new minimum temperature until the temperature gradient or differential between the surface temperature and center temperature is substantially zero.

In practice, it is desired to measure the surface temperature by engaging the end of the billet with a thermocouple, and it is impractical to engage the billet end exactly at the surface with a thermocouple. On the other hand, although it can be shown that it is not desirable to engage the circumferential surface with the thermocouple. Accordingly, the surface temperature is measured a slight distance from the outer circumferential surface. The temperature thus measured a slight distance from the surface is included in the meaning of the words "surface temperature" as used herein. A correction factor can be used in the setting of the apparatus to allow for any slight differential in temperature between the actual surface temperature and the surface temperature measured by the outer thermocouple, but generally such is not required. Usually the surface temperature is measured within an inch of the peripheral surface.

As an example of the operation, in the case of an aluminum, or aluminum alloy, billet to be heated for extrusion, let it be assumed that the average desired temperature is about 855° F. and the maximum safe temperature of the surface stratum or skin of the billet is about 900° F. When the coil is first energized the billet is at room temperature. The coil is operated to bring the billet up to a temperature of about 900° F. at the surface quite rapidly. Due to the rapid heat conduction of the relatively cool billet metal, the temperature at the center of the billet rises in almost a linear relation, at about a 200° F. differential, relative to the temperature of the surface. Thus, when the center of the billet has reached approximately 700° F., the surface temperature is about 900° F. At this point accurately controlled cycling begins. When the surface reaches 900° F., the coil is deenergized until the surface temperature drops to about 885° F., whereupon the coil is again energized to build up the surface temperature to 900° F. This cycling is repeated until the differential in temperature between the surface of the billet and the center of the billet is about 50° F., for example, when the surface is at about 885° F. and the center at 835° F. At this point the cycling is changed, the coil remaining deenergized until the surface temperature drops to about 855° F., above the average billet temperature desired, which in the example would be about 860° F. Thereupon cycling continues between about 870° F. and 860° F. surface temperature until the temperature at the center is substantially 855° F. and the surface temperature 5° F. or less thereabove, the latter 5° F. excess being allowed to offset radiation losses during transfer of the billet from the induction heater to the press. If extremely accurate temperature control is required, a third stage of cycling can be added, the third stage using an excess surface temperature of 1° F. to 2° F., instead of 5° F. Ordinarily such accuracy is not required.

When the billet has reached the latter temperature, the cycling at the reduced maximum temperature may be continued sufficiently to maintain the billet as near as may be at the desired average temperature until the billet
is ready for use, only enough heat being supplied to offset that lost by radiation.

Cycling at the new reduced maximum eliminates the possibility of heating the entire cross section to a temperature greatly above the desired average temperature throughout.

The method and an apparatus for carrying it out are more fully described hereinafter by reference to the drawings, wherein:

Fig. 1 is a graph illustrating a heating cycle in accordance with the present invention; and

Fig. 2 is a diagrammatic side elevation of an apparatus suitable for performing the method and a wiring diagram for use in connection therewith, and embodying the principles of the present invention.

Referring first to the graph illustrated in Fig. 1, the ordinate indicates temperature in degrees F. and the abscissa indicates times in minutes. It is assumed that the particular billet is to have an average temperature of 855° F., as indicated by the graph line 1 and that the temperature attained by the surface of the billet is about 900° F. The temperature of the billet surface stratifies or graph indicated by the graph line 2, and the temperature at the center of mass of the billet is indicated by the graph line 3.

It is apparent by reference to the graph that the temperature of the billet surface stratifies or skin, indicated by line 2, rises quite rapidly, in almost a substantially linear relationship with respect to the time of heating during initial heating of the billet and, within a short time, would rise to a temperature considerably above that required if induction of heat at the billet surface were continued unabated. Within a very few minutes the temperature differential between the skin or outer stratifies of the billet and the center becomes about 200° F., after which this differential remains substantially constant until the surface temperature of the billet reaches about 900° F. and the center about 700° F.

At this point, on and off cycling of the induction coil is begun, the power to the coil being cut off and remaining off until the temperature at the surface drops to about 15° F. below the 900° F. whereupon the power is again applied and the surface temperature raised to 900° F. and then cut off and the surface temperature allowed to drop again about 15° F. therebelow. This cycling, as indicated by the line 2, continues until the temperature differential between the surface and the center of the billet has decreased several, for example, sufficiently so that a temperature differential of about 50° F. between the billet surface and the center of the billet results. Thereupon the temperature at the surface is allowed to drop to a new reduced maximum less than 900° F.; for example, to around 870° F. Cycling is continued, cut off occurring at this newly reduced maximum surface temperature and the power being turned on at about 860° F. until the gradient or differential between the desired average temperature and the center of the billet closely approaches zero. It is to be noted that during this latter cycling the temperature of the billet surface tends to drop more closely to the average desired temperature and the temperature at the center tends to rise more closely to the average desired temperature, so that, when the center temperature reaches the desired average temperature, there is no excess heat at the surface tending to cause the billet temperature to overshoot the average desired. In this manner, the cross section of the billet is brought to a temperature of substantially 855° F. throughout its entirety, the allowance of the slight excess temperature near the surface to offset radiation losses during transfer from the heater to the press being made, either in the two or three stage operation above described.

As the billet has been brought to this uniform temperature, the cycling may continue so as to add just enough heat to the surface to offset that lost by radiation and maintain the billet at a substantially constant uniform temperature desired until it is ready for use.

Cycling in this manner permits the maintenance of the billet at an average temperature more nearly the peak temperature to which it is heated, affords much more precise control and permits heating safely within a much shorter time.

The times used as examples in the graph in Fig. 1 are for a billet of aluminum alloy having a diameter of about 20". For larger diameter billets, heating by cycling in this manner is even more important because of the much greater heating times required for large billets. The heating time increases approximately as the square of the diameter. The advantages of the present method over prior methods increases at an accelerated rate as the billet diameter increases. Billets not infrequently are from 20" to 80" in length, but except for the fact that the radiation loss at the ends is the same for long and short billets and thereby reduces the proportional overall surface radiation loss for a long billet as compared to a short billet, the length of the billet is immaterial and limited only by the length of the coil available.

In order to carry out the method above described, the apparatus shown in Fig. 2 may be employed. In general, the induction furnace employed may be such as described in United States Patent No. 2,676,234, issued April 20, 1954, to Robert V. Lackner et al.

The end 31 may be obtained at the end of the billet by means of prod thermocouples arranged on the billet stop at the end of the coil so that, when the coil is energized, the billet is thrust thereby against the prods. Since billets are cut to length by sawing and the sawed ends are bright and free from oxides, a good contact with the prods is assured.

In accordance with the present invention two temperature sensing devices are used. These may be thermocouples, one having its prod engageable with the leading end of the billet at or near the axis of the billet and the other having its prod engageable with the billet at or near the circumferential surface, and preferably at the leading end of the billet, which end is readily accessible. For example, the two thermocouples may be arranged on the billet stop in proper position to engage the end of the billet as above described. Thus the structure, illustrated in Fig. 2, comprises one or more induction coils 5 in which a billet 6 is suitably placed and a core stop 7, which may be similar to that described in the above patent, is provided and supports the two sensing devices or thermocouples 8 and 9, respectively. The thermocouple 8 is arranged for cooperation with the end of the billet at the axis or center and the thermocouple 9 is arranged for cooperation with the end of the billet near the circumferential surface of the billet. Each thermocouple is provided with a pair of prods, as indicated. The thermocouple 8 is connected by lead wires 14 to terminals 16 of an amplifier 17 forming part of a temperature differential controller, later to be described. The thermocouple 9 is connected by wires to terminals 20 of the amplifier 17. The thermocouple 9, as is also connected, through wires 22, with terminals 24 of an amplifier 25 forming part of a temperature controller which is thereby made responsive to the temperature at the outer surface of the billet 6.

The temperature differential controller includes, in addition to the amplifier 17, a pair of electromagnetic relays 28 and 29 having operating windings 28w and 29w, respectively, and contacts 28a and 29a, respectively. The relays 28 and 29 are supplied from the amplifier 17 as indicated, the output of the amplifier 17 being responsive to the difference in temperature between the thermocouples 8 and 9.

The temperature controller includes, in addition to the amplifier 25, a plurality of electromagnetic relays 31, 32, 33, and 34 having operating windings 31w, 32w, 33w, and 34w, respectively, and contacts 31a, 32a, 33a, and
The relay 34 also has contacts 34a. The relays 31, 32, 33, and 34 are supplied from the amplifier 25 as indicated, the output of the amplifier 25 being responsive to the temperature at the surface thermocouple 9.

The contacts 29a are closed when the differential temperature between the thermocouples 8 and 9 is below a predetermined low value and are open when the differential temperature is above that value, whereas the contacts 29b are open when the differential temperature between the thermocouples is below a predetermined low value and are closed when the differential temperature is above that value. The contacts 31a, 32a, 33a, and 34a are closed at low temperature at the surface of the billet 6 as measured by the thermocouple 9 and open at higher temperatures selectively. For example, contacts 31a are open above 900°F, contacts 32a are open above 855°F, contacts 33a are open above 870°F, and contacts 34a are open above 860°F. When the contacts 34a open, the contacts 34b close, and vice versa.

The two controllers are arranged in the manner of this invention to maintain different predetermined temperature ranges at the surface of the billet 6 selectively and sequentially, and to prevent the exceeding of a maximum safe temperature at the billet surface. The temperature ranges become lower sequentially to provide a minimum final differential temperature between the surface and the center of the billet 6. To this end, the relays 29 through 34 are arranged to control an electromagnetic contactor or relay 35 having an operating winding 35w, normally open main contacts 35n, and normally open auxiliary contacts 35b and 35c. The contacts 35a are interposed in one side of a supply circuit 36 leading from a suitable power source 38 to the coil 5. An electromagnetic relay 39 having an operating winding 39w, normally open contacts 39a, and normally closed contacts 39b also controls the relay 35 and is, in turn, controlled by the relay 29. The contacts 39a and 39b are made to overlap upon operation in any well known manner so that the contacts 39a always close before the contacts 39b open and vice versa.

The operation of the control system will now be explained. With the thermocouples 8 and 9 positioned as indicated, the billet 6 cold, and a control switch 40 open, all of the contacts in the respective positions shown in the drawing. Closure of the switch 40 completes a circuit from a suitable source, which may be the source 38 if that is of low frequency or which may be a separate A.C. or D.C. source, through a conductor 41, the contacts 34a, 33a, and 39b and the winding 35w to a supply conductor 42 leading to the other side of the source. Consequently operation of the relay 35 closes the contacts 35a to complete the supply circuit 36 to the coil 5, and closes the contacts 35b and 35c to complete respective by-pass circuits around the contacts 32a and 34a, respectively.

The billet 6, upon energization of the coil 5, starts to heat and a temperature gradient forms between the center and surface of the billet. When the differential temperature between the thermocouples 8 and 9 reaches a predetermined low value, the contacts 29a open but nothing happens since the contacts 34b are now open. When the differential temperature reaches a higher value, the relay 29 closes its contacts 29a completing an energizing circuit from the conductor 41 through the winding 39w to the conductor 42. The contacts 39a thereupon close followed by opening of the contacts 39b. Opening of the contacts 39b does not cause deenergization of the winding 35w because the prior closure of the contacts 39a completes a second energizing circuit for the winding 35w through the contacts 32a in parallel with the contacts 35b and the contacts 31b.

When the temperature at the surface of the billet 6 as measured by the thermocouple 9 reaches a predetermined high temperature, such as 885°F, in the example herein used, the contacts 32a open. This is indicated at point 44 in the graph of Fig. 1. Opening of the contacts 32a is of no effect at this time because the contacts 35b are closed. When the surface temperature reaches a maximum safe temperature such as 900°F, for example, the contacts 31a open and cause deenergization of the winding 35w. The contacts 35a thereupon open to interrupt the circuit to the coil 5 and heating ceases. The operation of the relay 31 is indicated by point 45 in Fig. 1.

The temperature at the surface of the billet 6 now starts to fall, but the temperature at the center of the billet continues to rise, as shown in Fig. 1. Within a short time, the contacts 31a reclose but the relay 35 does not operate because the contacts 35b are open. When the surface temperature is reduced to 885°F, the contacts 32a reclose. Since the contacts 31a are now closed, the winding 35w is again energized and the relay 35 closes, its contacts 35a causing heat to be applied again to the billet 6. This operation is indicated at point 46 in Fig. 1. The relay 35 thereupon opens and closes in like manner by cyclic operation of the relays 31 and 32 until the differential temperature, between the billet surface and billet center, is reduced to 50°F.

When the differential temperature reaches 50°F, the relay 29 opens its contacts 29a, causing the relay 39 to open its contacts 39a and to close its contacts 39b. Opening of the contacts 39a prevents further control of the relay 35 by the relays 31 and 32 and transfers the control thereof to the relays 33 and 34. This change in operation is indicated by the portion 48 of the curve in Figure 1.

Since the relays 34 and 33 opened their respective contacts 34a and 33a when the surface temperature reached 860°F and 870°F, respectively, no circuit to the winding 35w is now completed, the coil 5 is deenergized, and the surface temperature continues to fall as indicated at 48. If the relay 39 should reclose while the contacts 39a are closed, the relay 35 is deenergized and heating ceases whereas if the relay 39 operates while the contacts 32a are open, the relay 35 remains open.

When the surface temperature reaches 870°F, the contacts 33a close and when the surface temperature reaches 860°F, the contacts 34a close. As soon as the contacts 34a close with the contacts 33a closed, the circuit to the winding 35w through the contacts 39b is completed and the relay 35 operates again to cause energization of the coil 5. This closure of the contacts 34a is indicated at 49 in Fig. 1.

The surface temperature of the billet 6 now rises until it reaches 870°F whereupon the contacts 33a open to cause opening of the relay 35. Operation is now at point 50. The surface temperature starts to fall again. The relay 35 continues to open and close to maintain the surface temperature between 860°F and 870°F. The temperature at the center of the billet continues to rise, however, to further reduce the differential temperature. When a predetermined minimum differential temperature is reached, the relay 28 operates to close its contacts 28a. If the contacts 34b are closed at this time a circuit is completed from the conductor 41 to the conductor 42 through the contacts 28a and 34b of an eject mechanism 51 which operates to eject the billet from the coil 5 in a well known manner. If the contacts 34b should be open when the contacts 28a close, opera-
tion of the mechanism 51 is delayed until the contacts 34b do close. If there is any delay in the readiness of the press to receive the billet after heating, the circuit to the eject mechanism may be manually opened so as to shut off the eject mechanism until such time as the billet is required. No matter how long the delay, the billet can be kept in readiness at the proper temperature throughout its cross section until such time as it is needed, this holding the billet at the required temperature being accomplished by the recirculating at the low differential.

As an extra precaution, a maximum temperature differential control means responsive to both thermocouples may be provided. Such a maximum temperature differential control means may include a relay 52 having normally closed contacts 52a in series with the coil 35w of the main control relay 35. The coil 35w of the relay 52 is connected through the amplifier 17 to the thermocouples and is operative at a preselected maximum temperature differential which, when reached, causes the contact 52a to open, thus deenergizing the winding 35w and causing the main control contact 35w to drop out and disconnect the coil from the source of power. The present apparatus can be set to control the peaks and valleys in the graph of the temperature cycle so as to provide an unlimited number of combinations, these depending on the type, size, cross sectional shape, and composition of the billet.

The method and apparatus are effective for heating not only aluminum and aluminum alloy billets but also billets of ferrous metal and its alloys, billets of titanium, cupro-nickel, brass and, in fact, billets of substantially any metal composition. The benefits of the method and apparatus are particularly pronounced in the case of metal billets of low thermal conductivity.

Furthermore, the method and apparatus are suitable for heating billets of other than circular cross section; for example, billets of elliptical, hexagonal, rectangular, or square cross section. In the case of billets of non-circular cross section the outer thermocouple, when engaged with the end of the billet, is placed in engagement with the end of the billet near the outer surface in a position, peripherally of the billet, which is near the end of the major axis of the cross section. For example, in the case of a rectangular billet, the outer thermocouple 9 is placed near that face of the billet farthest from the longitudinal axis of the billet, this being, of course, the short side of the rectangle.

Herefore, in the heating of billets by induction, one method was to use a lower power input than that herein contemplated and to maintain a lower differential between the billet surface and the billet center during the heating cycle. In this method, the power cut-off was provided which cut off the power to the coil once the temperature of the surface reached a predetermined maximum temperature. The billet temperature was then permitted to equalize throughout the cross section without any further control or further heating but, instead, merely by thermal conduction. The lower power input, of course, the greater is the heating rate required under this method. For example, for a given billet, if the differential were reduced to one half the differential maintained in the present invention, then heating time would be approximately doubled, thus requiring, to maintain equal production, twice as many heating coils as are required in the present invention.

Another prior method was to heat the outside surface of the billet to the desired average billet temperature or a few degrees thereabove and then cycle the heating by means of a standard temperature controller from a single thermocouple at the outer surface of the billet, as is frequently done at present with billets of small diameter. This manner of heating causes the center of the billet cross section to come up to temperature at a slower rate than in the case of the present invention so that the time required to obtain a uniform temperature throughout the cross section of the billet is considerably greater than in the case of the present invention.

The first of the foregoing prior methods also was subject to another disadvantage. Generally, the heating cycle of a billet is correlated with the readiness of the press to receive the billet, the optimum timing being such that the billet reaches the right temperature just as the press is ready to receive it. So long as the press operation continues as scheduled, this system works reasonably well. However, when a press breaks down, or other interruptions along the production line interrupt the schedule, a time delay occurs between the time the billet is at the proper temperature and the time the press becomes ready to receive it.

Under these prior methods, a billet cannot be held at the proper temperature for sufficiently long intervals as to be in readiness for the press after such a delay in press readiness. Instead, if the power application to the heating coil is continued after the billet is fully heated, overheating of the billet results. If the power application to the heating coil is interrupted after the billet is fully heated, undue cooling results.

With the present method and apparatus the time required to bring a billet to substantially uniform temperature throughout its cross section is much less than is required by the prior methods and apparatus, a saving of 25% in time being quite common. The greater, the diameter or major axis of the cross section of the billet, the greater is the saving in time. Consequently, by using the present method and apparatus, production can be increased accordingly.

Further, once the billet is brought to the proper temperature by the present method and apparatus, it can be held at that temperature for an indefinitely long period without overheating and without undue cooling. As a result, a billet once heated can be maintained in readiness for the press regardless of the delays in press operation. Hence delays in operations of the press are not critical.

The present method and apparatus, therefore, permit rapid initial heating, cycling at a relatively high temperature differential until the billet is at approximately the desired temperature, and then cycling continuously at a much reduced differential until the billet is used.

In accordance with the present invention, which is particularly applicable for billets of large diameter or cross section, the billet is initially heated continuously and rapidly with a differential as high as may safely be employed without overheating the surface of the billet, then is cycled so as to maintain the surface as near as practical at a maximum safe temperature above the uniform billet temperature required until the temperature of the center of the billet approaches near to the uniform temperature required, then is cycled at a lesser differential in temperature until the temperature at the center of the billet is substantially equalized with that at the surface, this last cycling being continued during the temperature equalizing period, and, if the billet is not used promptly upon equalization, until such time as it is used.

The present method and apparatus is particularly well adapted for induction heating of large diameter billets with low frequency current of which 60 cycle current is one illustrative example.

It is apparent that a billet can be heated to a uniform temperature throughout its cross section in a minimum of time by means of the foregoing method and apparatus.

Having thus described our invention, we claim:

1. The method of heating a billet by induction to substantially uniform temperature throughout its cross section, said method comprising, by induction, intermittently creating and controlling successive increments of
heat in the surface stratum of the billet so as to maintain the surface stratum within a safe surface temperature range above the desired average temperature of the billet until the temperature of the billet has increased to a predetermined temperature below the desired average temperature, and then, by induction, intermittently creating and differently controlling successive increments of heat in the surface stratum so as to maintain the surface at a lower temperature than said average temperature but above said desired average temperature at least until the temperature at the center is substantially the desired average temperature, whereby the billet is heated to the average temperature required uniformly throughout its cross section.

2. The method of heating a billet by induction to substantially uniform temperature of about 855°F. throughout its cross section, said method comprising, by induction, intermittently creating and controlling successive increments of heat in the surface stratum of the billet to maintain said surface stratum about 900°F. and 885°F. until a billet center temperature above 835°F. and below the desired average temperature results, and then, by induction, intermittently creating and differently controlling successive increments of heat in the surface stratum to maintain said surface stratum between the limits of 870°F. and 860°F. until the temperature at the center temperature is substantially 855°F., whereby the billet is heated to the average temperature required uniformly throughout its cross section.

3. The method of heating a billet by induction to substantially uniform temperature throughout its cross section, said method comprising heating, by induction, the surface stratum of the billet until a predetermined temperature below a safe maximum and above the average temperature required in the heated billet, is obtained, then, by induction, intermittently creating successive increments of heat in the surface stratum and thereby maintaining said stratum between a predetermined maximum temperature and a predetermined minimum temperature which are within a range materially above said desired average temperature and below the temperature at which the surface of the billet would be overheated until the center temperature has risen more nearly to the desired average temperature, then, by induction, intermittently creating successive increments of heat in the surface stratum and thereby maintaining said surface temperature between a lower maximum temperature and a minimum temperature which are within a range slightly above said average temperature until the differential between the desired average temperature and the center temperature is reduced to substantially zero, whereby the billet is heated to the average temperature required uniformly throughout its cross section.

4. In an induction heating apparatus including an induction coil adapted to accommodate a billet to be heated, a center temperature sensing device and a surface temperature sensing device, said devices being operative for sensing the temperature of the billet in the center and near the surface, respectively, when a billet is accommodated in the coil, a temperature controller means responsive to the surface temperature sensing device for controlling the surface temperature of the billet by controlling the energization of the coil at lower and upper limits, respectively, of a predetermined temperature range, said temperature controller means including differential controller means responsive to both temperature sensing devices and operative to modify the action of the first mentioned controller means in response to a predetermined difference in temperature between the center and outer surface of the billet.

5. In an induction heating apparatus including an induction coil adapted to accommodate a billet to be heated, a center temperature sensing device and a surface temperature sensing device, said sensing devices being operative for sensing the temperature of the billet near the center and near the surface, respectively, when a billet is accommodated in the coil, a temperature controller means responsive to the surface temperature sensing device for controlling the surface temperature of the billet by controlling the energization of the coil at lower and upper limits, respectively, of a predetermined temperature range, a temperature differential controller means responsive to both temperature sensing devices and operative to control the coil in response to a predetermined difference in the temperatures between the center and outer surface, and means coordinating the control actions of the said temperature controller means and said temperature differential controller means.

6. In an induction heating apparatus according to claim 5 ejecting means responsive to said controls for ejecting the billet from the coil when the billet is heated to said average temperature uniformly throughout.

7. In an induction heating apparatus including an induction coil adapted to accommodate a billet to be heated, a center temperature sensing device, a surface temperature sensing device, said sensing devices being operative for sensing the temperature of the billet, when a billet is accommodated in the coil, near the center and near the surface, respectively, of the billet, a temperature controller responsive to the surface temperature sensing device for controlling the surface temperature of the billet by controlling energization of the coil at lower and upper limits, respectively, of a predetermined second temperature range, a temperature controller responsive to the center temperature sensing device and operative to modify the action of the first controller in response to predetermined temperature of the center of the billet.

8. A method according to claim 1 characterized in that said outer surface temperature is maintained at said safe maximum temperature for a preselected time until the temperature at the center has reached substantially the uniform billet temperature required.

9. An apparatus according to claim 4 characterized in that a maximum temperature differential control means responsive to both temperature sensing devices is provided and is operatively connected to the coil and is adapted to operate, in response to the combined effect of the temperature sensing devices and independently of the demands of said first mentioned controller means and first mentioned differential controller means, to limit said temperature differential created by the coil to a predetermined maximum.

References Cited in the file of this patent

UNITED STATES PATENTS
2,400,472 Strickland May 14, 1946
2,676,232 Dreyfus Apr. 20, 1954
2,787,692 Braeuninger et al. Apr. 2, 1957