A furnace, and method of furnace operation, for annealing whole coils of steel, particularly silicon steel. The furnace includes a welded gas-tight shell lined with varying thicknesses of refractory material defining a plurality of independently controllable heating and cooling zones and in which a vacuum is maintained at the entry section and a hydrogen atmosphere in all other sections. The furnace additionally includes vacuum-purged vestibules at both ends to accommodate the entrance and exit of coils from the interior atmosphere of the furnace.

14 Claims, 15 Drawing Figures
ANNEALING FURNACE AND METHOD FOR ITS OPERATION

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of copending application Ser. No. 802,548, filed Feb. 26, 1969 now U.S. Pat. No. 3,606,289.

BACKGROUND OF THE INVENTION

In copending application Ser. No. 802,548, filed Feb. 26, 1969, a coil annealing furnace is disclosed for annealing whole coils of steel on a continuous basis. The coils are individually placed on cars and moved into the furnace through a vestibule from which they are pushed into and through an elongated heating chamber comprising sections of increasingly higher temperature to produce a predetermined controlled heating rate for the coils. Following the heating chamber is a soaking chamber comprising sections of substantially the same controlled temperature. Finally, the coils pass through a cooling zone comprising sections of decreasingly lower temperature to provide a predetermined controlled cooling rate for the coils. With the furnace of the aforesaid copending application, any section in the heating and soaking chambers may be used for heating or soaking except the first section which is for heating only and the last section which is for soaking only. Thus, a multiplicity of heating and soaking cycles can be obtained to accommodate a variety of time and temperature cycles.

In the furnace disclosed in the aforesaid copending application Ser. No. 802,548, a coil is initially pushed into a vestibule at the entrance end of the furnace and doors on opposite sides of the vestibule closed; whereupon the vestibule is purged of air by forcing an inert gas such as nitrogen into the vestibule. Thereafter, the nitrogen gas is purged with hydrogen, which is the same atmosphere used within the furnace proper. Following this purge, the door between the vestibule and the furnace is opened and a coil to be heat treated is pushed into the furnace; following which the door between the vestibule and furnace is again closed. The operation at the exit end of the furnace is the same, requiring purging of a vestibule with nitrogen.

The use of nitrogen as a purging gas in the aforesaid copending application Ser. No. 802,548 was used to prevent admixing of the oxygen in the air with hydrogen, an obviously highly explosive mixture. The necessity for a nitrogen purge, however, increases the overall cost of the annealing operation.

Further, while the apparatus shown in the aforesaid copending application Ser. No. 802,548 is entirely satisfactory for its intended purpose, the coils, as they leave the aforesaid entrance vestibule, are immediately introduced into the hydrogen atmosphere of the furnace. The furnace of the invention is particularly adapted for use in annealing silicon steel strip coated with magnesium oxide which acts to protect the surface of the strip and also acts as an insulator between successive laminations of the silicon strip material when used, for example, in a transformer or other electrical device. The coating used on such strip material, because of its nature, forms a certain amount of water of hydration. Furthermore, when a silicon steel coil having a magnesium oxide coating of this type enters the initial heating section of the furnace, the water of hydration vaporizes and tends to form a discoloration and possible oxidation of the strip material. This discoloration and/or slight oxidation can be tolerated; however it is desirable to eliminate it.

SUMMARY OF THE INVENTION

In accordance with the present invention, an annealing furnace of the type described above is provided wherein the vestibule means which the coil enters at the entrance end of the furnace is evacuated to remove gaseous impurities within the coil wraps and furnace car prior to charging the coil into the furnace. At the exit end of the furnace, the vestibule means is again evacuated without the introduction of an inert gas to remove hydrogen from the vestibule prior to discharge of the coils into the atmosphere. This eliminates, but for the hydrogen flushing gas requirement, all vestibule purge gases such as inert gases and reduces the overall cost of the annealing operation. Furthermore, by initially evacuating the vestibule at the entrance to the furnace, then charging with hydrogen, and again evacuating, a more complete elimination of gaseous contaminants from between the coil wraps is achieved.

Further, in accordance with the invention, the initial heating section of the furnace, instead of containing hydrogen as in prior devices, is evacuated and separated from the remainder of the hydrogen-filled furnace by a transfer station having sealable doors on either side thereof. In this manner, the water of hydration formed in the initial heating section is carried away by the vacuum pumps connected to this section and does not form the undesirable discoloration and/or possible formation of oxide experienced in prior art furnaces.

Still another features of the invention resides in the provision of a back-up nitrogen purging system for the vestibule at the entrance and exit to the furnace in the event that the vacuum system normally used should fail.

The above and other objects and features of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings which form a part of this specification, and in which:

FIGS. 1A, 1B and 1C are broken sections showing the profile of one embodiment of the furnace of the invention including the heating, soaking and cooling chambers;

FIG. 2 is a partial sectional view of the initial heating and soaking sections taken along line II—II of FIG. 1A;

FIG. 3 is a partial sectional view of the final heating and final soaking sections of the furnace of the invention taken substantially along line III—III of FIG. 1B;

FIG. 4 is a partial sectional view taken along line IV—IV of FIG. 1A showing the jack arch dividing the various heating and soaking sections of the invention;

FIG. 5 is a partial sectional view showing the initial cooling section taken along line V—V of FIG. 1B;

FIG. 6 is a partial sectional view of the second cooling section of the furnace of the invention taken substantially along line VI—VI of FIG. 1B;

FIG. 7 is a sectional view taken along line VII—VII of FIG. 1B showing the third cooling section of the furnace of the invention;

FIG. 8 is a partial sectional view of the fourth cooling section of the furnace of the invention taken along line VIII—VIII of FIG. 1C;
FIG. 9 is an end view of the coil supporting car of the invention including a partial section through the center of said car.

FIG. 9A is a cross-sectional view taken along line IX-A—IXA of FIG. 9 showing the radiation tunnels of the coil supporting car of the invention;

FIG. 10 is a sectional view of the coil supporting car of the invention taken substantially along line X—X of FIG. 9;

FIG. 11 is a schematic diagram showing the vacuum system, reconditioning system, and nitrogen and hydrogen supply for the atmosphere of the furnace of the invention; and

FIG. 12 is a plot of internal coil temperature of a coil processed in the furnace of the invention versus time within the heating, soaking and first cooling sections of the furnace.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings in general and FIGS. 1A–1C in particular, reference numeral 2 indicates a semicontinuous coil annealing furnace having an entry door 3 serving vestibule 4 providing access to door 6. Furnace door 6 isolates vestibule 4 from the furnace initial heating section 8. The initial heating section 8 terminates at door 167 which leads into transfer station 180 located between the initial heating section 8 and initial soak section 10. Transfer station door 168 isolates the initial soak section 10 from the transfer station 180, and door 167 isolates the initial heating section 8 from transfer station 180. All doors are sealed with suitable gaskets 9.

Continuing through furnace 2 are initial soak section 10, final heat section 12, final soak section 14, first cooling section 16, second cooling section 26, third cooling section 28, fourth cooling section 30 and fifth cooling section 31 which terminates at exit vestibule 20. Extending to and throughout furnace 2 are tracks 38 on which cars 40 travel carrying coils C. Located adjacent vestibule 4 and aligned with the heating section 8 is a hydraulic cylinder 42, such as Anker-Holth Hydraulic Cylinder Series 100 Model 12C, having a piston rod 44 adapted to extend into vestibule 4. Located adjacent transfer station 180 are similar hydraulic cylinders 42' having rams 44' adapted to engage cars 40 in section 8 to push them one-by-one into transfer station 180, and to engage cars 40 in station 180 to push them into the remainder of the furnace.

Referring now to FIG. 2 which is a cross section of the initial heating section 8 and the initial soaking section 10, reference numeral 50 indicates the gas-tight welded steel tunnel shell through which cars 40 and coil C transit furnace 2. The tunnel has internal walls 51 and roof 53 lined with refractory brick 52 to a predetermined thickness (e.g., about 9 inches) on both sides and overhead and backed up further by insulation such as a second refractory 54, also of predetermined thickness (e.g., about 3 inches) and a third refractory 56 such as vermiculite. Heating elements 58 which are preferably ¾ inch diameter molybdenum rods available from General Electric Company, Cleveland, Ohio, are mounted on the walls 51 of tunnel 50. In the vicinity of car 40, the walls 51 have a protruding portion 60 approaching car 40 and contain slots 62 which cooperate with a protrusion 64 on car 40 to form a radiation shield between the coil area of tunnel shell 50 and the car understructure 66. Below the protruding portion 60, the tunnel shell 50 is cut back at 65 to the vicinity of the car understructure 66 and is unlined.

FIG. 3 represents a cross section of the final heat section 12 and the final soaking section 14 of tunnel furnace 2 showing the additional layers of refractory that are contained within this section. The section structure is basically the same as that of the initial heating and soaking sections 8 and 10, respectively, shown in FIG. 2. Reference numeral 50 indicates the welded steel tunnel shell having tunnel walls 51 with first refractory 52 and second refractory 54 and third refractory 56 of materials specified in the paragraph relating to FIG. 2. In addition to the foregoing structure, a face refractory brick 52', e.g., about 11 inches in front of the first refractory brick 52 and a backup refractory brick 54' such as 3 inches of thermobestos, is placed along the interior of tunnel shell 50 between the shell and the previously-mentioned second refractory 54.

Referring now to FIG. 4, reference numeral 70 indicates a modified jack arch lowering the roof 53 and separating furnace sections 10 and 12 and sections 14 and 16 to provide isolation between the initial soaking section 10 and the final heating and soaking sections 12 and 14 and the first cooling section 16. The jack arch 70 is also used in conjunction with doors 6, 167 and 168 (FIG. 1) to isolate vestibule 4, furnace section 8 and transfer station 180 from the initial heat section 8 and the initial soak section 10 when the doors are open. The jack arch 70 is formed by laying additional courses 72 of refractory brick below the tunnel roof 53. The additional courses 72 are built down to limit tunnel area 50 so that it will just pass coil C as the coil transits the furnace 2. Similarly, walls 51 are extended outward to further isolate the adjacent sections by additional refractory brick 72.

FIG. 5 shows a cross section of the first cooling section 16 of the furnace 2 having a gas-tight tunnel shell 50, walls 51 and roof 53 of which are formed with a first refractory brick 52 similar to preceding sections, a second refractory 54 and a third refractory 56 also similar to preceding sections. It is to be noted that the tunnel walls 51 in section 16 also include slots 62 accommodating car protrusion 64 establishing the radiation shield and the shell 50 is cut back at 65 in the vicinity of the understructure 66 at FIG. 2. It is to be further noted that the refractory thickness of walls 52 varies from section-to-section, the reasons for which will be described below in conjunction with furnace operation. Located on the center line of furnace 2 and at the center of the coil positions are cooling jets 74 connected to piping 76.

FIG. 6 is a cross section of the second cooling section identified by reference numeral 26 in FIG. 1. The overall construction of the second cooling section 26 is similar to the first cooling section 16 described in FIG. 5 wherein a welded steel shell 50 surrounds and defines the furnace cavity which is lined with three refractory materials, a first refractory 52 which may be about 4 inches thick, a second refractory material which may be about 3 inches, and a third refractory material 56 such as 3 inches or more of vermiculite. Within the furnace roof 53 are cooling jets 74 connected to pipe 76 which directs the cooling gases into the center hole of coil C. The figure also shows a built-out portion 60 in tunnel wall 51 including a slot 62 which cooperates with a protrusion 64 on car 40.
Referring now to FIG. 7 which shows a cross-sectional view of third cooling section 28, reference numeral 50 indicates the welded steel wall of the furnace tunnel which is lined with a first refractory brick 52 (e.g., about 4½ inches thick) and a refractory material 56 such as 3 inches or more of vermiculite forming roof 53. As in previous figures showing sections of the furnace, there is a built-out portion 60 having a slot 62 which cooperates with a similarly-shaped structure 64 of car 40.

Fourth cooling section 30 is shown in FIG. 8 and has a welded steel shell 50 lined with refractory material 56 such as about 3 inches of suitable refractory on both side walls 52 and roof 53. A fifth cooling section 32 comprises an unlined steel shell 50.

Referring now to FIG. 9, reference numeral 40 indicates a coil supporting car having an understructure 66 including wheels 67, bearings 68 and axles 69 which support the car upper-structure 78. Car upperstructure 78 includes a frame 80 supporting refractory material 82 to insulate the frame and the understructure 66. A second refractory material may be used for additional protection against higher temperatures as necessary. On the top of the refractory material are radiation tunnels 86 (FIG. 9A) formed by walls of a first quality firebrick 87, such as UFALA brick. These tunnels are located to cooperate in part with heating elements 88 located on tunnel walls 51. This is done so that a portion of the heat developed in the heating element 58 may be radiated into the tunnel to facilitate coil heating. Forming the top of the radiation tunnels are heating tiles 90 formed of a high conductivity, yet strong material such as Oxynitride-bonded silicon carbide plate as available from the Norton Company, Worcester, Mass. Providing a resting pad for coil C on the car structure 78 is a hearth plate 92 of low carbon steel having, for example, a 1/16 inch coating of alumina. Hearth plate 92 contains a center hole 94 communicating with the center radiation tunnel 86. Also communicating with the center radiation tunnel 86 is a tube 95 carrying a thermocouple conductor 96 which extends to a plug-in receptacle 97 in an area adjacent the car understructure 66.

Within the refractory portion 82 of car 40 is a protrusion 64 which cooperates with slot 62 within the furnace tunnel wall 51 forming a radiation shield between the portion of the tunnel containing the coil and the car understructure 66 area as previously described. This protrusion may be formed by stepping a course of the utilized refractory or a specially formed brick as shown in FIG. 9.

FIG. 10 shows a side view of coil car 40, the trailing edge of which includes a slot 98 in the refractory portion. The leading edge of car 40 includes a protrusion 100 in the refractory portion 82. The slot 98 and the protrusion 100 are adapted to cooperate with similarly shaped protrusions and slots in adjacent cars. The cooperating slots and protrusions form radiation shields between the cars, further isolating car understructure 66.

The details of the atmosphere recirculation system are shown in the schematic of FIG. 11 wherein a reconditioner 110 receives the contaminated atmosphere from the entry end of initial soak section 10 as collected by a header 112 located on tunnel walls 51 above the level of the car hearth 90 and transported through conduit 114. The reconditioner preferably includes several purifying and cooling devices to recondition the atmosphere for recirculation through the furnace. Useful devices for the foregoing are V.D. Anderson Hi-EF Purifier, Model IBS-4-10-304, a spiral heat exchanger type I-V by the American Heat Reclaiming Corporation, an adjustable Roots-Compressors Rotary Gas Blower Type XA and an Engelhard Deoxo Tower Model D–3000–1 by the Engelhard Industries, Incorporated and a B–1500–SP Lectrodrayer by The McGraw Edison Company. The reconditioner 110 may also include a carbon monoxide to carbon dioxide conversion tower such as Engelhard Industries “Selectox”. The reconditioned atmosphere is returned to furnace 2 from reconditioner 110 through a conduit 116 to a manifold 118 containing cooling jets 120. In the example disclosed there are five jets 120 located on the bottom of the tunnel at the coil exit end of furnace 2 adjacent vestibule 20 and ten on the sides of the tunnel 50 at the coil exit end, five of these jets being disposed on each of the two sides of the furnace. First cooling section 16 and second cooling section 26 are supplied additional hydrogen gas for cooling. The additional gas for cooling in the second cooling section 26 is injected at header 121 located in the lower side walls 51 above the level of the car hearth 90 in the furnace tunnel area 2, circulated through a cooler 122 such as a fin tube cooler available from Brown Fin Tube Company, and then supplied through conduit 123 to manifold 76 which supplies cooling jets 74 located in the roof 53 of the cooling section 26. The additional cooling gas for the first cooling section 16 is collected in a similar header 125 and supplied to a cooler 126 which, in turn, supplies a manifold 76 from conduit 127 supplying gas jets 74 also located on the external center line of the roof 53 of the first cooling section 16. The cooling jet 74 is located along the center line of the tunnel roof immediately above the center of the coils in the coil stations of cooling sections 16 and 26. The atmosphere flowing through the initial soak section 10 can be bypassed around the transfer station 180 to the initial heat section 8 in event of vacuum system failure by opening valve 181 in conduit 132 and by-pass valve 182 and closing valve 183 in conduit 114 and valve 162 in conduit 188 to vacuum pumps 160. In a similar manner, the furnace atmosphere can be altered to provide a vacuum-hydrogen combination, all hydrogen, or all vacuum.

Reconditioner 110 is also connected to a hydrogen supply 138 through conduit 140 in order to provide make-up hydrogen for that lost through leakage from the system. A Stokes vacuum pumping system 190 is connected to the vestibule 4 by suction conduit 161 and control valve 186 to evacuate all gaseous impurities from the vestibule after a coil and car are placed therein and doors 3 and 6 are closed. In normal operation, the vestibule is evacuated to less than 1,000 microns pressure, then backfilled with pure dry hydrogen from conduit 142 and discharge manifold 144 which refills the evacuated voids between the wraps of the strip in the coil and voids in the car refractories. The vestibule is again evacuated by pumps 190 to less than 1,000 microns to flush out residual gases from the car and coil prior to opening door 6 and entry to the initial heating section 8. A standby gaseous purge system described hereinafter is provided to backup the vacuum purge system in event of failure of the vacuum pumps. Although the entry purge utilizes a hydrogen flush of
residual impurities for best results, this step could be eliminated without serious detriment to coil quality.

The exit vestibule 20 is similarly evacuated to remove a car and coil from the furnace, except that the vestibule 20 is evacuated only once, then backfilled with nitrogen or air prior to opening of exit door 18. A conduit 142 extends from reconditioner 110 to a discharge manifold 144 located in vestibules 4 and 20 to provide hydrogen atmosphere to the vestibules for use as a backflushing gas during the vacuum purge and as a purge gas for use with the standy gaseous purge system prior to opening door 6. A nitrogen supply 146, used with the standy gaseous vestibule purge system, is also connected to vestibules 4 and 20 through conduit 148 and discharge manifolds 150 to provide a nitrogen purge of the vestibule 4 to clear the air from it prior to hydrogen purge and opening door 6, to clear the hydrogen atmosphere from vestibules 4 and 20 prior to opening doors 3 and 18 which allows air to enter the vestibules, and as a backfill gas after a vacuum purge of vestibule 20. Headers 152, also used with the back-up purge system, located high and low in vestibules 4 and 20 are vented to the outside to facilitate purging the existing atmosphere of vestibules 4 and 20 by a lighter (hydrogen) or heavier (nitrogen) gas to prepare the vestibule for opening to the furnace 2 or to the vacuum environment outside the furnace 2. In the illustrated example, the hydrogen and nitrogen discharge manifolds are equipped with suitable laminar flow nozzles to minimize mixing of the gases during purging. The nitrogen supply line 148 and the hydrogen supply line 144 include pressure regulators 154 which receive their pressure impulse from the vestibule internal pressure. The vestibule outlet lines have outlet flow pressure regulators 154 with their pressure impulse from the vestibule internal pressure.

FURNACE OPERATION

In the description which follows, it will be assumed that the initial heating section 8 is evacuated to remove the water of hydration as explained above. The furnace 2 of this invention is constructed with a welded, gas-tight shell designed to maintain a clean, purified reducing atmosphere, such as hydrogen or a vacuum, within the furnace. A vacuum gas-tight gasket 9 at doors 3, 6, 167, 168, 7 and 18, and purgible vestibules 4 and 20 allow charge and discharge of coils into the vestibules 4 and 20 and then into and out of the furnace 2 without any contamination of the furnace atmosphere. Coil C to be annealed is placed on a coil-supporting car 40 with the coil C resting on one of its ends. The cars 40 have refractory portions 82 and 84 and a steel frame 80 supported on wheels 67, bearings 68, and axle 69 and are moved along rails 38 into and through the furnace 2. The coil C in the example is silicon steel to be annealed for grain orientation and is set on the hearth plate 92 which is supported by the hearth tiles 90 set over tunnels 86 which run radially outward from the center hole 94 of car 40. The car 40 carrying coil C is pushed into the entry vestibule 4 through door 3 by any suitable means, such as a hydraulic cylinder ram. The outer door 3 is closed and the air in the vestibule 4 is purged out of the vestibule through conduit 161 by the vacuum pumping system 190 until vestibule internal pressure drops to the 50 to 100 microns range. Hydrogen is backfilled into vestibule 4 through manifold 144 to refill the evacuated space between the individual lay-
tion to reach the receptacle 97 to attach leads by which external recording equipment (not shown) may read the temperatures.

RECRYCULATION ATMOSPHERE SYSTEM

The atmosphere system includes circulation through the final heating and entire soaking and cooling sections of the furnace. Its purpose is to serve as a heat and contaminant transport to protect the steel coil as it is heated and cooled. As the atmosphere is circulated through the furnace it picks up heat and contaminants from the coil surfaces and coil coatings and is withdrawn and cleaned. The flow of the atmosphere acts to flush back toward the more contaminated coils, the off gases extracted by the dry, reducing atmosphere. In the flush back operation, the atmosphere containing some contaminants extracted from the hotter coils washes the relatively more contaminated, cooler coils enhancing the atmosphere’s ability as a transport of the off gases and minimizing its potential as a carrier of pollutants. During the cleaning process, the atmosphere is cooled and then is reintroduced into the furnace so that the only makeup gas required is for that which leaks out on the various seals on the furnace and that which is vacuum purged in the transfer station. The atmosphere is introduced into the furnace 2 at the discharge end through manifold 118 and jets 120 which are located on the bottom and the side walls 51 of the furnace. The atmosphere is circulated against the coil travel and toward transfer station 180 at predetermined rate such as about 30,000 SCFH. Since a portion of the cool hydrogen is injected in the car understructure 66 area, it travels toward transfer station 180 below the radiation shields 62–64 and 98–100 serving to cool that area.

This flow rate of the atmosphere provides adequate dryness in the atmosphere throughout the circulation and constant rate heating and cooling for the temperatures involved in the system in conjunction with heat input from the elements 58 and the heat dissipated through cooling jets 74 and through the cooling section walls. Changing the parameters of the system, such as the coil charge interval, rate of coil heating or cooling, temperatures, etc. could call for a change in rate of atmosphere flow. At the entry end of the initial soak section 10, the gas (atmosphere) is picked up by header 112 and returned to the reconditioner 110 through conduit 114. As the relatively cooler hydrogen atmosphere is flushed back through the cooling sections, it settles around the successive coils above the hearth plate 92. The gradual heating of the hydrogen and cooling of the coils produces a smooth transfer of heat and the flow of atmosphere cools the coils at a constant rate. At the second cooling section 26 of the furnace, a collecting header 121 collects a portion of the atmosphere circulating it through cooler 122 which reduces the temperature of the atmosphere from about 1,700°F to about 150°F, forwards it to manifold 123 and distributes it through to jets 74 located on the roof portion 53 of tunnel 50. These jets 74 are located above the center of the coil openings for a first group of coil stations along second cooling section 26 and direct a cooling jet down into the center of these cooling openings to provide additional cooling over that passed through the furnace refractories 52, 54 and 56 and by flow of the atmosphere to maintain the cooling rate set in the other cooling sections. The last group of coil stations of first cooling section 16 also are fitted with cooling jets 74 in the roof 53 of the tunneled portion 50. A portion of the atmosphere passing coil station 44 is collected in headers 125 and directed to a cooler 126 and further to a manifold 127 distributing the atmosphere to jets 74. The atmosphere being introduced into the furnace system at jets 120 is high purity hydrogen, e.g., 99.995 percent pure, at a temperature between 80° and 100°F with a dew point of drier than −100°F. As the atmosphere transits the furnace 2 and reaches the entry portion of the second cooling section 26, its temperature has been elevated to approximately 1,800°F by carrying heat away from the coils C as it circulates past them. As the atmosphere flows through the first cooling section 16 of the furnace, the temperature is raised to 2,150°F at the soak section 14 and is retained at that temperature through this section. The heat gained by the atmosphere system flowing through cooling sections 30, 28, 26 and 16 is gained from the coils as the gas circulated around the coils. Heat is added to the system from the molybdenum heating elements 58 located along the walls 52 of the tunnel selected sections. The heat is added to the furnace to make up heat losses through the refractories of that section, all the while maintaining the temperature constant. In a constant temperature section, the atmosphere stabilizes the coil temperatures by transporting heat from any coil above the soak temperature to any coil below that soak temperature (2,150°F for example). Similarly, heat may be supplied to the atmosphere sections 12 and 10 by similar molybdenum heating elements 58 located along the tunnel walls 51 to supplement the heat given up to the coils. As the atmosphere transits to the first soak section 10, its temperature is reduced from 2,150°F to approximately 1,200°F at header 112. This reduction in temperature of the atmosphere reflects the heat given up to the coils C within the heating sections 12 and 10. Additionally, heat is supplied to the atmosphere individually in sections 12, 10 and 8 through molybdenum heating elements 58 located along the walls 52 of the tunnel 50 in such a manner to maintain the heat transfer rate to the coils throughout.

In addition to the above-recited means for adding to or removing heat from the atmosphere and coils within the atmosphere, temperature control is achieved by varying the amount of refractory material within the various furnace sections. It should be noted in FIGS. 2, 3, 5, 6, 7 and 8 that the across sections of various sections of the furnace are varied. In FIG. 2, for example, the initial heating and soaking sections 8 and 10 of the furnace utilize relatively thick refractory materials making up the side walls 51. Comparing those heating sections with the final heating and soaking sections shown in FIG. 3 via sections 12 and 14, wherein a great deal more heat is contained within the system, it can be seen that the refractory walls in these sections are a great deal thicker. The total amount of refractory material in the sections 12 and 14 amounts to approximately 25 inches thick in an effort to retain as much heat as possible within the system and thus reduce the input requirements of the heating element 58. Beginning with cooling section 16 wherein it is desirable to dissipate some of the heat of the system and thus bring the temperature of the coils down to a convenient temperature for removal from the furnace, the thickness of the refractory walls decreases. In section 16 shown in FIG. 4, the total thickness is down to 15 inches and this
area is provided with additional cooling from above by cooling jet 74. Proceeding to the second cooling section, section 20, and the Lectrodryer 6, it can be seen that the refractory wall thickness is about 10 inches and subsequent FIGS. 7 and 8 show that in successive sections 28 and 30, the refractory thickness decreases to about 7 inches and 3 inches, respectively. In section 31, the heat is permitted to conduct directly through the tunnel shell 50. By varying the overall thickness of the furnace walls from section-to-section, particularly in the cooling areas of the furnace, the dissipation of heat from the interior of the furnace through the furnace refractory material to the surrounding atmosphere is controlled to assist in maintaining a constant cooling rate throughout the cooling sections 16, 26, 28, 30 and 31. In the example described, the heat loss in the cooling sections is maintained at an average of 400 BTU's per square foot per hour which produces a 40°F/hr. cooling rate in the steel coils. Throughout the initial heating and soaking sections, and in the final heating and soaking sections 8, 10, 12 and 14, the average heat loss is maintained at approximately 170 BTU's per square foot per hour and the average coil heating rate of 43°F/hr. is provided. The atmosphere exits the furnace at header 112 and is returned to the reconditioner 110 laden with the contaminants from the coil surfaces such as hydrogen sulfide, water vapor, carbon monoxide, carbon monoxide, oxygen and nitrogen removed in the coils.

Within reconditioner 110, the atmosphere passes through the spin-type drying filter previously mentioned where all the dust particles larger than 10 microns fall out by impingement and centrifugal action. Also within the reconditioner 110, the gas enters the spiral-type water-cooled heat exchanger at 600°F. to be cooled to 89° to 100°F, the temperature at which it is returned to the furnace system. Within the preferred embodiment disclosed herein, the gas is then circulated through a series of bag-type dry filters within the reconditioner 110 which remove all dust particles one-half micron and larger from the atmosphere system. The oxygen, hydrogen sulfide, air, carbon dioxide, carbon monoxide and water vapor are then removed in the Lectrodryer 6 restoring the gas to its purity of 99.5 percent and the dew point of below about -100°F. The gas is then returned to the furnace system through jets 120.

In the operation of the standby purging system, used only on failure of the vacuum system, the natural density of the various gases within purging vestibule 4 is utilized to reduce the quantity of the purge gas required. Gases of lighter weight, such as hydrogen, are put into the top of vestibule 4 to purge heavier gases out the bottom such as air or nitrogen, which exit through headers 152 to the bottom of vestibule 4. Conversely, heavier gas, such as nitrogen, is put into the bottom of the vestibule through manifold 150 to purge lighter gas out of the top of the vestibule through a second header 152' located at the top of vestibule 4. As in the example, the gases may be injected into vestibule 4 through a distribution manifold having laminar flow nozzles to minimize mixing of the purging gas with the purged gas. Further, as in the example, the supply flow rates are equated to the exhaust flow rates. A purging chamber such as the vestibule 4 having laminar flow nozzles and flow rate control of supply and exhaust provides a complete purge with a volume purging gas equal to twice the volume of the chamber. Convenational systems require five to eight chamber volumes of purging gas. The exit vestibule 20 is similarly equipped and operated.

The material heat treated in the example disclosed is silicon steel strip in coil form which has been cold rolled and normalized and is 10 to 14 gauge. Prior to being rolled into coils, the material is normalized with a bright shiny surface and electrolytically or slurry coated with a magnesium hydroxide coating and dried. The refractory coating and air gaps between wraps of the coil combine to form an insulant against radiant heat flow through the coil from the outer wrap to the inner center section. The furnace atmosphere is maintained reducing to the oxides on the wrapped surfaces of the coils to keep surface emissivity low and minimize the heat transfer radially through the coil wraps. The dew point is maintained low, e.g., below -20°F, in the initial soak section of the furnace and below -45°F in the final heating section to promote the removal of water vapor from within the wraps due to the difference in partial pressures between the furnace atmosphere and gases within the wraps. A -45°F dew point hydrogen gas is equivalent to a 100-micron vacuum in its potential to remove moisture from the coil wraps. However, silicon steel has been heat treated in the furnace with minimal oxidation due to the water vapor with dew points up to +10°F. Water of hydration released from the strip coating is removed by the vacuum in the initial heating section of the furnace. Heat flow to and from the coils is promoted through the coil ends by high conductivity heat plates supporting the coils and a flare cap on the exposed top edges of the coil. Heating of the coil wraps through the ends utilizing the high conductivity of the coil itself promotes the uniform heating of the coil by providing heat input to each wrap. By way of example, the vertical coil is supported by the high conductivity heat plate and encapped with the flare cap and is heated at a rate of about 50° per hour. A lower heating rate could be chosen, however, this would lengthen the time required to raise the coil to the heat treating temperature. The overall heating time would require either a longer heating chamber or a longer interval prior to the introduction of the additional coils into the furnace. The ability to promote the flow of heat into the coil limits the practical maximum heating rate allowable without coil deformation to about 100°F per hour. The heating rate can be increased by laying the coil on the side and heating the ends of the coil by means of the heating elements 58 radiating directly on the ends of the coil. Such a method may produce a heating rate of as high as 150°F per hour, however, some coil deformation may also be experienced. Further, it would be necessary to provide adequate support in the center of the coil to prevent the coil from collapsing as well as banding the outside diameter of the coil to prevent unraveling.

In the furnace described, good grain growth and grain orientation is achieved by annealing at 2,150°F for a period of 21 hours in a dry atmosphere having a dew point of -15°F or below and in an atmosphere flow rate of 30,000 s.c.f. per hour. The heat treatment may be accomplished at lower temperatures such as 2,000°F over a longer period of time or the annealing temperatures may be increased to as high as 2,250°F for shorter periods of time. Operation with the parameters selected in the example minimizes coil deformation and maximizes coil yield by minimizing radiant heat input.
to the coils from the heating elements and by removing contaminants from the coil surfaces while the coils are still relatively cool and the strip material is less likely to react with the contaminants. The effectiveness of the reducing atmosphere maintained within the furnace as a means of suppressing radiant heat transfer to the coils is attested to by the bright shiny surface of the coil wraps exiting the furnace. The suppression of radiant heat transfer to the coil and the effectiveness of the conductive heating through the hearth plate is further confirmed by the minimum amount of coil deterioration through deformation as well as the uniform heating and cooling rate demonstrated in Fig. 12 showing the average coil temperature through the heating, soaking and first cooling sections of the furnace. Cooling of the coils is continued to a convenient temperature for removal from the furnace, such as 100°F in the example. Coils may be removed from the furnace at a higher temperature, up to approximately 800°F, however, removal at a temperature any higher than this could result in substantial oxidation of the surface of the coil and in deterioration of properties. The coils from the furnace herein disclosed are cooled at a continuous rate of approximately 40°F per hour. So long as the coil is continually cooled, however, any rate conveniently obtainable within the cooling sections may be used. The cooling effect of the argon atmosphere of the invention is a furnace capable of grain growth and grain orientation annealing of full coils of silicon steel wherein the coils are heated at a more constant rate than previously known, maintains the coils at a constant temperature during soaking and then cools the coils at a rate better controlled than any previously known.

Although the invention has been shown in connection with a certain specific embodiment, it will be readily apparent to those skilled in the art that various changes in form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention. In this respect, it will be apparent that while the embodiment of the invention shown herein comprises a straight-through furnace with one long chamber having vestibules at either end thereof, it could also be constructed on two levels with a single inlet and outlet vestibule as shown, for example, in the aforesaid copending application Ser. No. 802,548. In this latter case, the coil passes through upper and lower reaches of the furnace in a generally U-shaped pattern. The coil enters the vestibule, is elevated to the upper reach of the furnace, passes through the upper reach, is then lowered downwardly to the bottom reach of the furnace which is directly below the upper reach, and then traverses the lower reach back to the single vestibule.

Furthermore, the furnace can be constructed on a single level with the reaches of the furnace side-by-side again using a single vestibule, but replacing the elevators at opposite ends of the two reaches of the furnace with sideward transfer devices. Since the furnace has a plurality of chambers for heating and also for cooling, heat treatments other than the grain growth and grain orienting anneal of silicon steels may be performed therein. Heating and cooling rates can be readily controlled to establish predetermined desired values by controlling the input of heat by element 58 and the cooling of the charge by the atmosphere, rate and flow and by the input of cool atmosphere through jets 74 as well as controlled heat loss or dissipation through the walls. The vacuum chamber 10, in addition to facilitating removal of water of hydration, facilitates a single coil position after the moisture removal and initial heating where coils can be impregnated with special gases such as hydrogen sulfide, nitrogen, argon and the like to aid in the development of magnetic properties of silicon strip material.

I claim as my invention:

1. In the method for heat treating strip material in coil form by the steps of positioning a coil in vestibule means at the entrance end of a furnace having successive heating and cooling zones between entrance and exit ends, sealing said vestibule means and purging the same of gaseous contaminants, thereafter transferring the coil from the vestibule means to the furnace and moving said coil from the entrance end of the furnace through successive heating and cooling zones of the furnace while circulating through said furnace a non-oxidizing gas, and finally removing the coil from the exit end of said furnace; the improvement in said method which comprises:

   a. initially evacuating said vestibule means to purge it of gaseous contaminants,

   b. then filling said vestibule means with a non-oxidizing gas, and

   c. again evacuating said vestibule means to purge it of said gas before the coil is transferred from said vestibule means to said furnace.

2. The method of claim 1 wherein said non-oxidizing gas and the non-oxidizing gas with which said vestibule means is filled comprises hydrogen.

3. The method of claim 1 including the step of transferring the coil from the exit end of said furnace to second vestibule means and purging the last-mentioned vestibule means of said non-oxidizing gas prior to discharge of the coil from the last-mentioned vestibule means into the atmosphere.

4. The method of claim 1 including the step of initially heating said coil within said furnace while evacuating the space around it before said coil is subjected to said non-oxidizing gas within the furnace, whereby water of hydration will be removed from the surfaces of said strip material.

5. The method of claim 4 including the step of closing door means at both ends of said vestibule means during evacuation of the vestibule means, opening door means between the vestibule means and an initial furnace section while closing door means at the other end of said initial furnace section and moving a coil from said vestibule means to said initial furnace section, and then closing the first-mentioned door means while evacuating said initial furnace section.

6. The method for heat treating strip material in coil form by the steps of moving said coil through successive heating and cooling zones of a furnace while circulating through said furnace a non-oxidizing gas, the improvement which comprises:

   a. initially heating said coil in an evacuated chamber prior to its passage through said furnace containing a non-oxidizing atmosphere to remove from the surfaces of said coil any water vapor.

7. The method of claim 6 which includes placing said coil in a vestibule chamber at the entry end of said evacuated chamber, then creating a sub-atmospheric pressure in said vestibule chamber, and then moving said coil into said evacuated chamber.
8. The method of claim 6 in which said evacuated chamber includes a heating section, a transfer section at the exit end of the heating section and a sealing door at each end of the transfer section, said initial heating being done in said heating section, said method including moving said coil into said transfer section while the exit door is closed, and then introducing non-oxidizing gas into said transfer section.

9. Apparatus for heat treating strip material in coil form comprising a furnace structure, means for dividing said furnace structure into a plurality of independently controllable heating zones and a plurality of independently controllable cooling zones, means for supporting and advancing coils through said furnace structure, door means sealing the heating zone at the entrance end of said furnace structure from the rest of the furnace structure to provide a sealable chamber, means for generating heat within said sealable chamber, means for creating a sub-atmospheric pressure in said sealable chamber while a coil of heated strip material is present therein, and means for circulating a non-oxidizing gas through the rest of said heating and cooling zones.

10. Apparatus according to claim 9 in which said sealable chamber includes a heating section, a transfer section at the exit end of the heating section, and said door means including a sealing door at each end of the heating section.

11. Apparatus according to claim 10 including means for creating sub-atmospheric pressure in said transfer section while said doors are closed and means for filling said transfer section with non-oxidizing gas while said doors are closed.

12. Apparatus according to claim 10 including a sealable vestibule for receiving coils of strip material to be heat treated in said furnace structure, door means between said vestibule and said heating section, means providing a sub-atmospheric pressure in said vestibule after a coil to be heat treated in placed therein and while said vestibule door means is closed, and means for thereafter introducing said non-oxidizing gas into said vestibule while said vestibule door means is still closed.

13. The apparatus of claim 10 including back-up purging means for purging said vestibule with nitrogen gas.

14. The apparatus of claim 10 including a second sealable vestibule at the exit end of said furnace structure, door means between said second vestibule and the interior of the furnace structure, door means between said second vestibule and the atmosphere, means for evacuating said second vestibule, and back-up means for purging said second vestibule with nitrogen.

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