Sept. 20, 1971 W. M. BLOOM 3,606,289

APPARATUS FOR ANNEALING STEEL COILS

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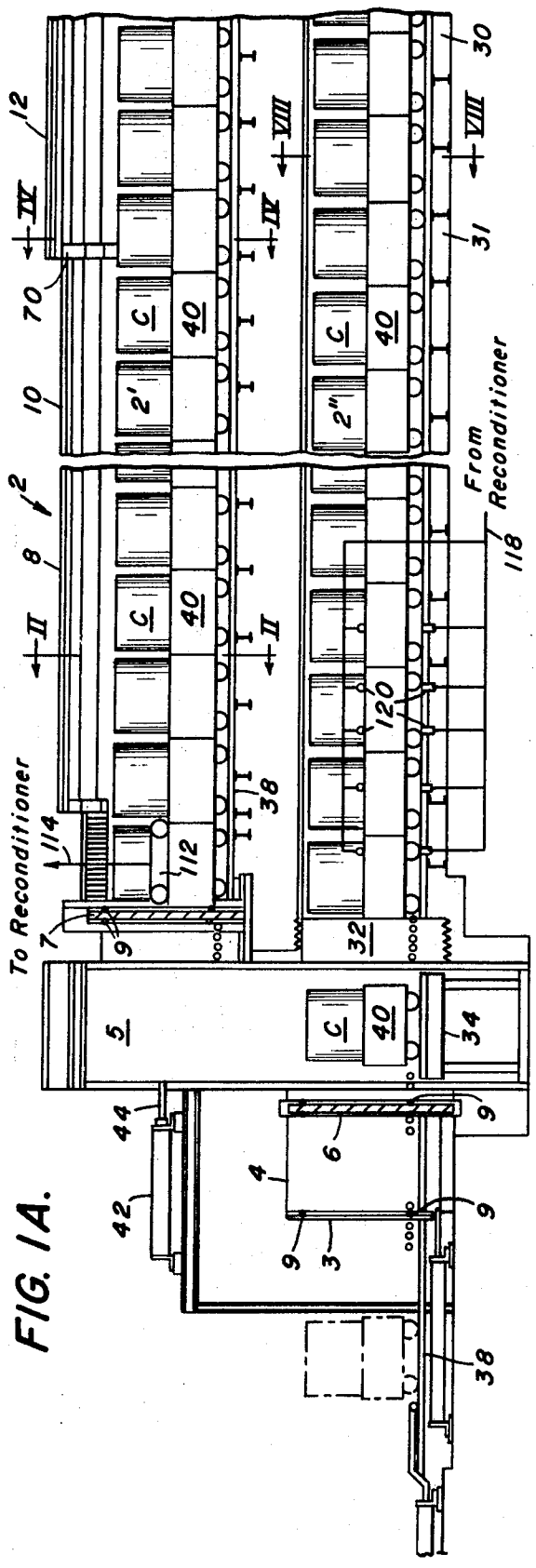


FIG. 1A.

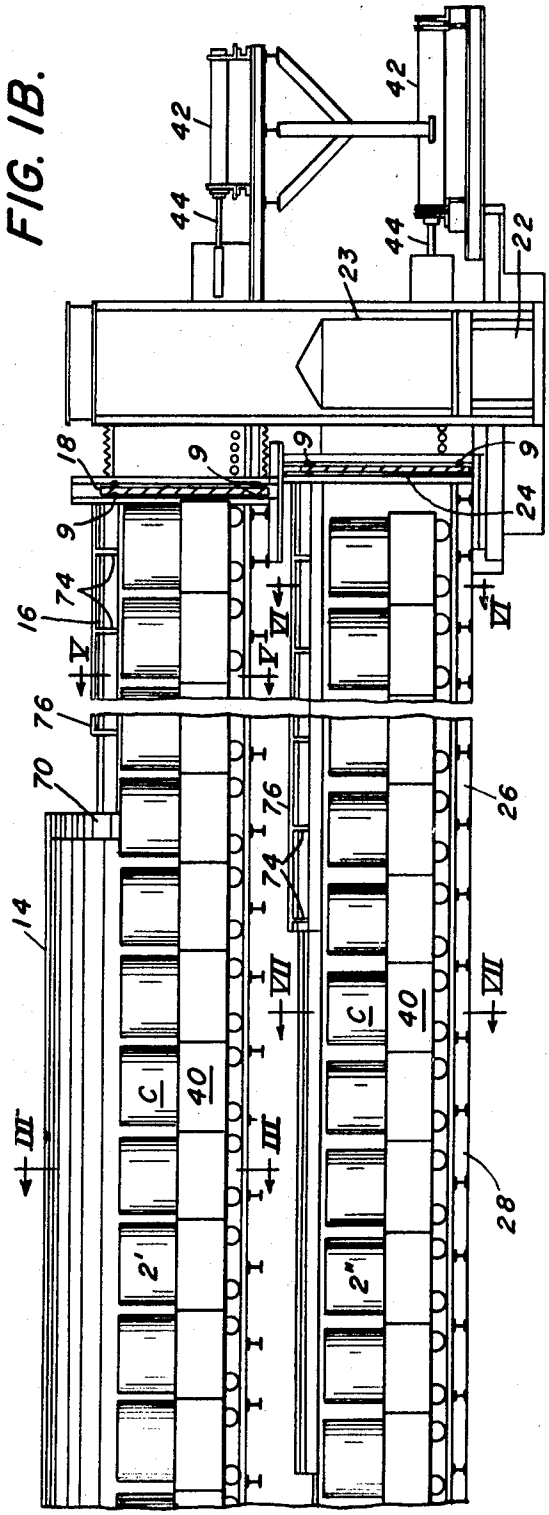


FIG. 1B.

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APPARATUS FOR ANNEALING STEEL COILS

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FIG. 2.

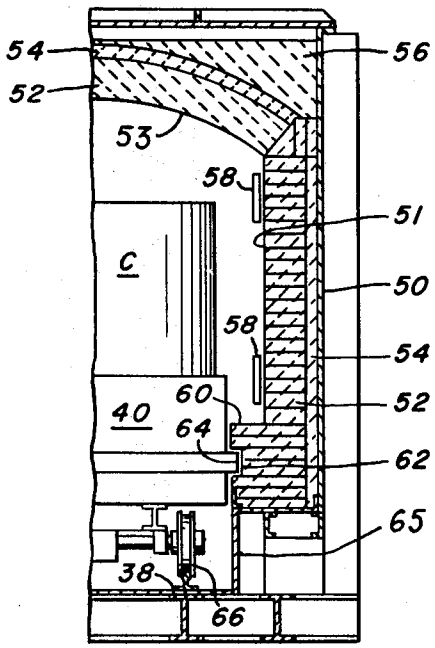


FIG. 4.

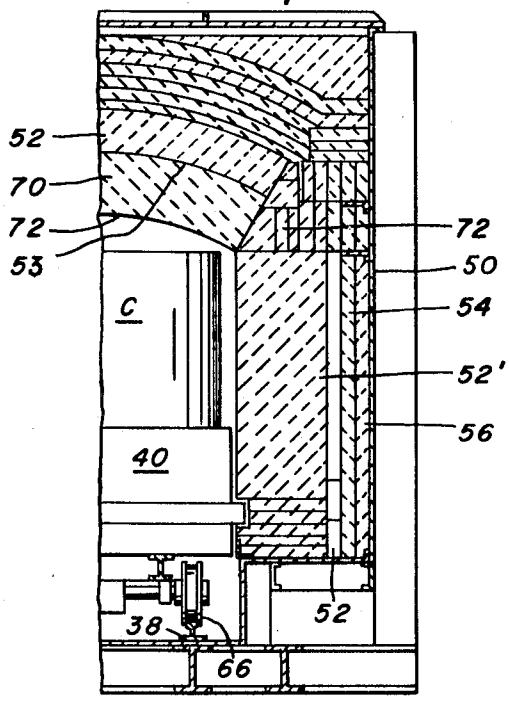


FIG. 5.

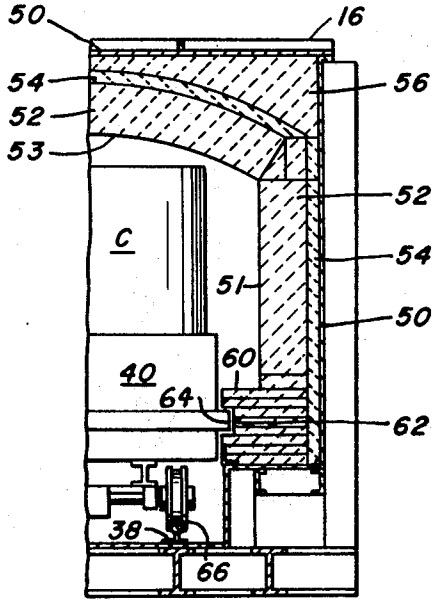
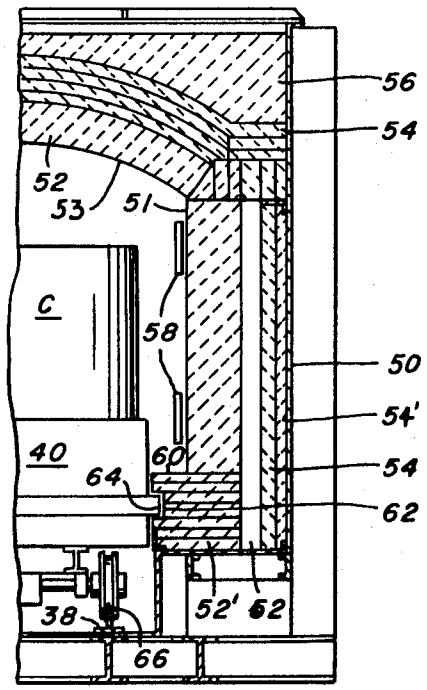


FIG. 3.



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FIG. 6.

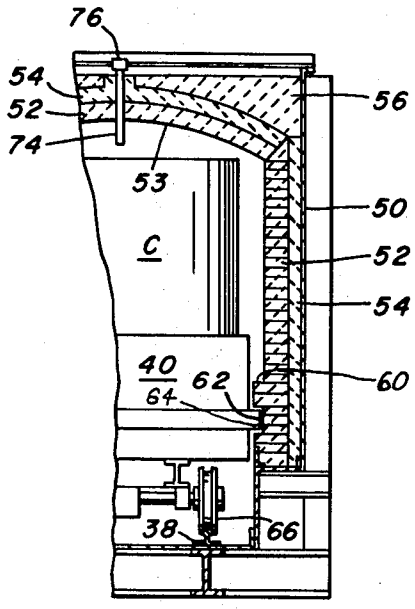


FIG. 7.

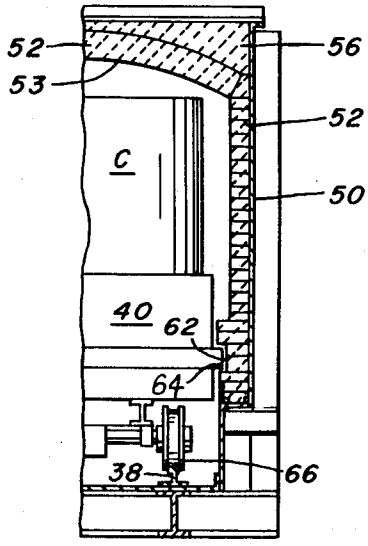


FIG. 8.

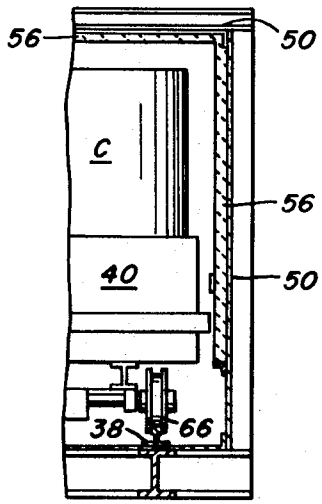
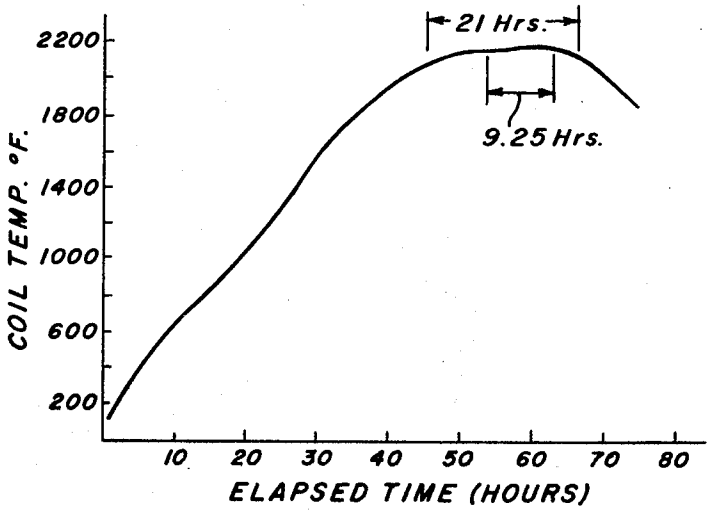


FIG. 12.



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FIG. 9.

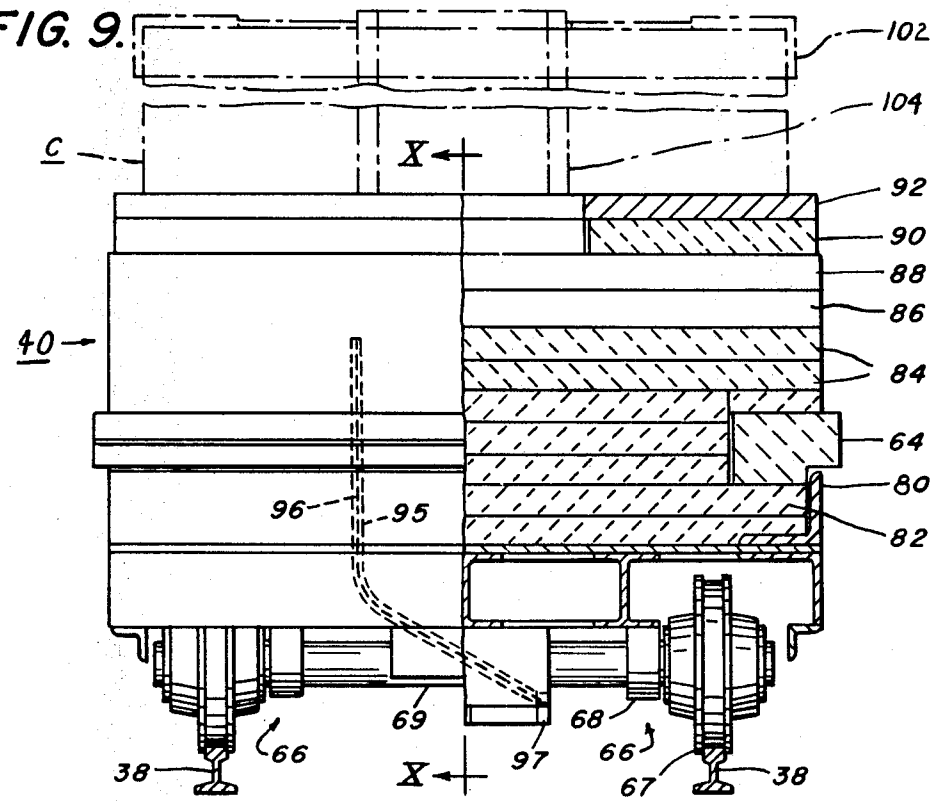
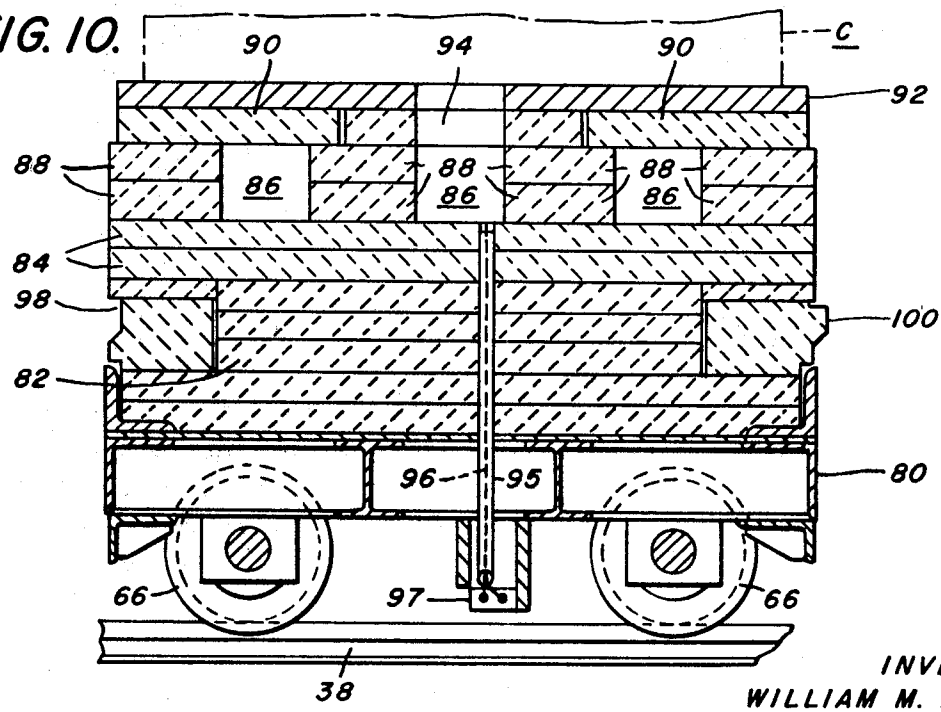


FIG. 10.

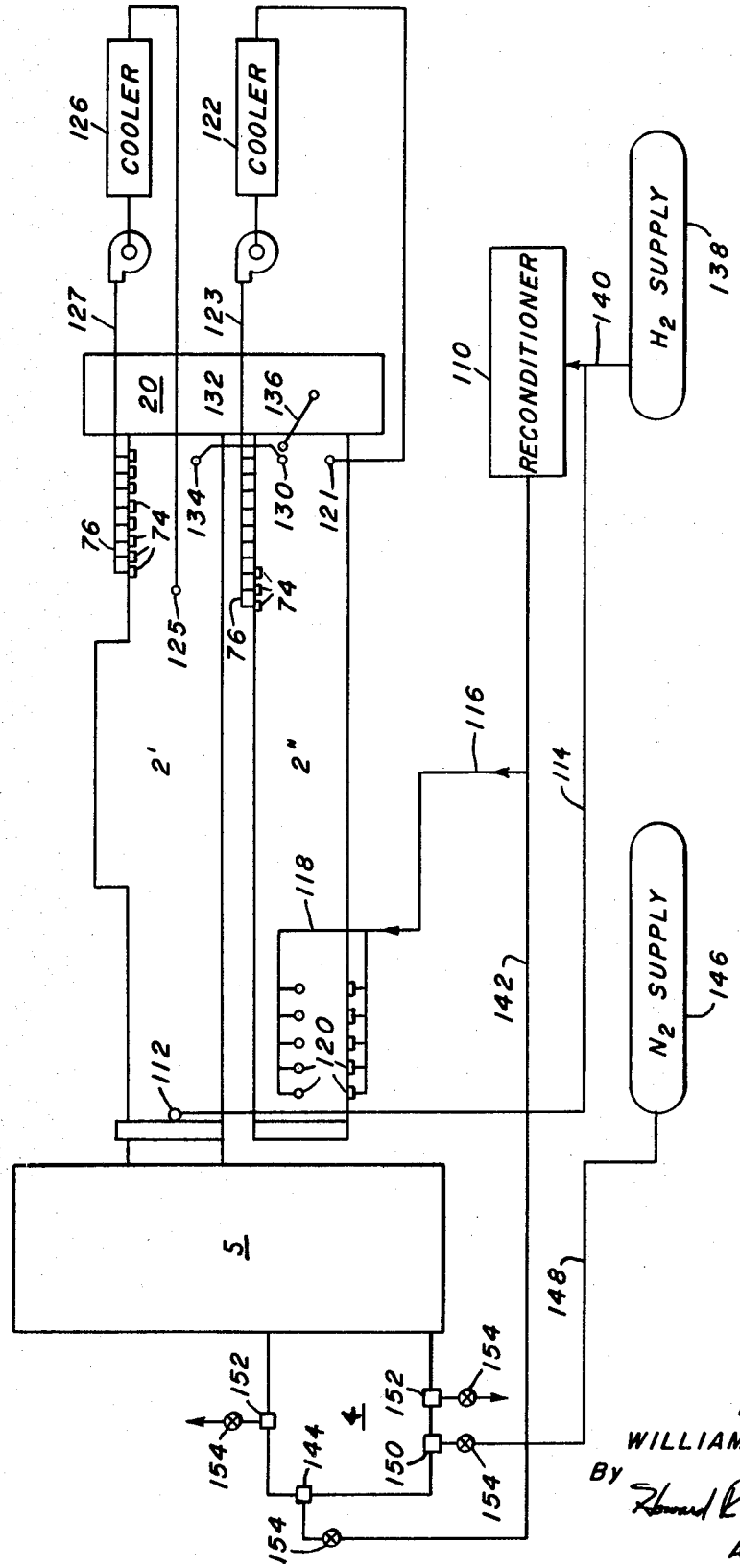


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APPARATUS FOR ANNEALING STEEL COILS

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FIG. 11.



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3,606,289

APPARATUS FOR ANNEALING STEEL COILS

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Int. Cl. C21d 1/00
U.S. Cl. 266—5R 15 Claims

ABSTRACT OF THE DISCLOSURE

A furnace for annealing whole coils of silicon steel which includes a welded gas tight shell lined with varying thickness refractory material defining a plurality of independently controllable heating and cooling zones and in which a hydrogen atmosphere is maintained; the furnace having cars of special design for transporting the coils therethrough, special heating elements extending along the furnace walls of the heating zone and a supplemental cooling arrangement for the coils to provide a controlled heat treatment.

BACKGROUND OF THE INVENTION

In the production of grain oriented magnetic alloys, such as silicon steel, a closely controlled processing anneal for grain orientation must be performed in order to provide a product of good magnetic and structural qualities. Annealing performed in a non-oxidizing atmosphere deters the magnetic alloy's absorption of undesirable elements. Further, heating, soaking and cooling by controlled rates is necessary to assure production of material having desirable properties. Conventional equipment used for producing grain oriented silicon steel include high temperature batch furnaces and continuous type strip furnaces; however, each of these has disadvantages which are overcome by a semi-continuous tunnel-type furnace in accordance with the invention having a controlled atmosphere and which is capable of economically processing whole coils.

Batch furnaces are typically wasteful of heat energy because since the coils are heated, soaked and cooled in the same furnace components, the heating elements must have sufficient input energy to heat the coils and the furnace components themselves. Moreover, the higher heat input results in localized over heating in the outside wraps and edges of the coils which may result in deformation of the coil known as "top edge flair" and "bottom edge oil canning." Additionally, all sections of the coils are not uniformly heated and variations in properties along the coil may occur. Because of the cyclic operation of batch furnaces, oxidants such as water droplets or carbon dioxide may appear on the metal surface and the resulting oxidation of the coiled strip surfaces increases surface emissivity which promotes differential heating of the coil. This also results in further coil deformation as well as an undesirable oxide anneal pattern on the surface of the strip. As with the heating cycle in the batch type processing, the cooling cycle also suffers from irregularities. The cooling of the furnace refractories during cooling of the coil in turn promotes differential cooling within, which may also cause coil deformation and loss of magnetic properties. Additional disadvantages are incurred in batch processing through the atmosphere purge requirements. Production time is lost through the multiple changes of gases that are required in establishing a reducing atmosphere. Material is lost through the contamination and discharge of the nitrogen and hydrogen gases in purging the furnace in order to open the furnace for loading and unloading.

Some of the above disadvantages are overcome in a continuous process strip furnace. Separate zones may

be established in such a furnace to regulate heating and cooling of the material as it proceeds through the furnace. Since each of the separate zones perform a continuous function, and are not temperature cyclic, the heat energy requirements are much lower. The continuous process also offers the advantages in that a continuous atmosphere may be maintained within the furnace. Time and gaseous matter are not lost in changing atmospheres. Heretofore, the continuous type annealing process has been applied only to strip processing wherein a coil of strip material was located at one end of the continuous furnace and the strip paid off of the coil and run through the furnace with the material recoiled after completion of the anneal. However, the nature of the heat treatment limits the efficiencies and economies possible by continuous strip processing. The present invention provides a furnace for effective coil annealing minimizing heat energy requirements and material deterioration during heat treatment while being capable of producing oriented silicon steel of uniformly high quality.

SUMMARY OF THE INVENTION

The invention disclosed herein is a coil annealing furnace for annealing whole coils of steel on a continuous basis. To process whole coils, they are individually placed on cars and moved into the furnace through a vestibule from which they are pushed into and through a heating chamber comprising sections of increasingly higher temperatures to produce a predetermined controlled heating rate in the coils within a particular section of the furnace. A soaking chamber is provided which comprises sections of substantially the same controlled temperature. Also included is a cooling zone comprising sections of decreasingly lower temperatures to produce a predetermined controlled cooling rate for coils within a particular section. Within the furnace 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 within the furnace to accommodate a variety of time and temperature cycles.

An integral part of the invention is the provision for a recirculated atmosphere system designed to maintain a clean, purified reducing furnace atmosphere relatively free of contaminants such as air, moisture, oxygen, carbon monoxide, carbon dioxide, hydrogen sulfide and nitrogen surrounding or in contact with the coil during the heating, soaking and cooling cycles. The recirculated gas is introduced into the furnace at the coil exit end of the cooling chamber and is caused to flow opposite to the direction of coil travel through the furnace sections and through the heating chamber and the coil entry end where the atmosphere is removed, reconditioned, and recirculated. The cars upon which coils travel through the furnace sections are specially adapted for use within the furnace and have radiation tunnels located below the coil supporting surfaces which themselves are of special high conductivity material.

It is therefore an object of my invention to provide a heat treating furnace for processing whole coils on a continuous basis.

It is another object of the invention to provide a furnace suitable for annealing oriented silicon steel in coil form on a continuous basis.

A further object of my invention is to provide a coil annealing furnace which reduces coil damage which normally occurs during coil annealing due to non-uniform heating and cooling.

A still further object of my invention is to provide a coil annealing furnace which is of the recuperative type

whereby a substantial portion of the heat applied to the coils to anneal same is recuperated or recovered and utilized to assist the uniform heating of coils not yet brought up to the annealing temperature.

Another object of my invention is to provide a coil annealing furnace which has a closed recirculating atmosphere which can provide coils with a reducing atmosphere immediately upon their entry into the furnace.

Still another object of my invention is to provide a coil annealing furnace which provides a closed recirculating atmosphere of a very low dew point to facilitate the removal of moisture from the coil strip surfaces immediately upon entry into the furnace.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1*a* and FIG. 1*b* are broken sections showing the profile of the furnace including the heating, soaking and cooling chambers.

FIG. 2 is a partial sectional view of the initial heating and soaking sections taken at line II—II of FIG. 1*a* and 1*b*.

FIG. 3 is a partial sectional view of the final heat and final soak sections taken along line III—III.

FIG. 4 is a partial sectional view taken at line IV—IV showing the jack arch dividing the various heating, soaking sections.

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

FIG. 6 is a partial sectional view of the second cooling section taken along line VI—VI.

FIG. 7 is a sectional view taken along line VII—VII of the third cooling section.

FIG. 8 is a partial sectional view of the fourth cooling section taken along line VIII—VIII.

FIG. 9 is an end view of coil supporting car including a partial section through the center of said car.

FIG. 10 is a sectional view of coil supporting car **40** taken along line *x*–*x*′.

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

FIG. 12 is a chart of the internal coil temperature of the coil over the elapsed time within the heating, soaking and first cooling section of the furnace.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings in general and FIG. 1 in particular reference numeral **2** indicates a semi-continuous coil annealing furnace having an entry door **3** serving vestibule **4** located adjacent elevator shaft **5**. Elevator shaft door **6** isolates vestibule **4** from shaft **5**. Furnace entry door leads into furnace initial heating section **8**. All doors art sealed with suitable gaskets **9**. Continuing through furnace **2** on upper lever **2′** are initial soak section **10**, final heat section **12**, final soak section **14** and first cooling section **16** which terminates at door **18**. Door **18**, also sealed with gaskets **9**, leads into elevator shaft **20** containing elevator **22**, providing access to door **24** and second cooling section **26** on lower furnace level **2″**. Also in annealing furnace **2** are third cooling section **28**, fourth cooling section **30** and fifth cooling section **31** which terminates at opening **32** providing access to elevator shaft **5**. Shaft **5** contains an elevator **34** serving opening **32** and door **6** and door **7** providing access and exit from the furnace **2**. Extending to and throughout furnace **2** are tracks **38** on which cars **40** carrying coils C traverse the furnace **2**. Located adjacent elevator shaft **5** and aligned with heating section **8** is a hydraulic cylinder **42**, such as Anker-Holth Hydraulic Cylinder Series 100 Model 12C, having a rod **44** extending into shaft **5**. Located adjacent shaft **20** and aligned with cooling sections **16** and cooling section **26** are similar hydraulic cylinders **42** having rams **44** extending into shaft **20**. Within shafts **5** and **20**, elevators **34** may be actuated by conventional systems such as a Vickers CHJO Custom Power Package.

Referring now to FIG. 2 which is a cross section of the initial heating section **8** and 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″ and a third refractory **56** such as vermiculite. Heating elements **58** which are preferably ¼″ diameter molybdenum rods available from Sylvania, Inc., are mounted on the walls **51** of tunnel **50**. In the vicinity of car **40** the walls **51** have a built out portion **60** approaching car **40** and contain a slot **62** which cooperates with the 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 built out 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 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** 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″ in front of first refractory brick **52** and a backup refractory brick **54′** such as 3″ 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 modified jack arch lowering roof **53** and separating furnace sections **10** and **12** and sections **14** and **16** which provides an isolation between initial heating and soaking sections **8** and **10** and final heating and soaking sections **12** and **14** and first cooling section **16**. 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 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 a slot **62** accommodating car protrusion **64** establishing the radiation shield and the shell **50** cut back **65** in the vicinity of the understructure **66** at FIG. 2. It is to be further noted that 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 being reference numeral **26** shown on 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″ thick, a second refractory material which may be about 3″, and third refractory material **56** such as 3″ 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 thick, and a refractory **56** such as 3" 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 having a welded steel shell **50** lined with refractory material **56** such as about 3" 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 coil supporting car having understructure **66** including wheels **67**, bearings **68** and axles **69** which support car upperstructure **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 the additional protection against the higher temperatures as necessary. On the top of the refractory material are radiation tunnels **86** formed by walls of a first quality fire brick, such as "UFALA" brick. These tunnels are located to cooperate in part with heating elements **58** 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 hearth plate **92** of a low carbon steel having, for example, a 1/16" 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 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**.

Detail of the atmosphere recirculation system is shown in the schematic of FIG. 11 wherein a reconditioner **110** receives the contaminated atmosphere from furnace **2** entry end 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 LBS–4–10–304, a spiral heat exchanger type I–V by the American Heat Reclaiming Corporation, an adjustable Roots-Connersville Rotary Gas Blower Type XA and an Engelhard Oeoxo Tower Model O–3000–1 by the Engelhard Industries, Incorporated and a B–1500–SP Lectrodryer by the McGraw Edison Company. The reconditioner may also include a carbon monoxide to carbon dioxide conversion tower such as Engelhard Industries "Selectoxo." The reconditioned atmosphere is returned to furnace **2** from reconditioner **110** through a conduit **116** to 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 elevator shaft **5** and ten on the sides of 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 addition gas for cooling in the second cooling section **26** is collected at header **121** located in the lower side walls **51** above the level of the car hearth **90** in the furnace tunnel area **2"** adjacent elevator shaft **20** and recirculated 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 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 is turn supplies a manifold **76** from conduit **127** supplying gas jets **74** also located on the external centerline of the roof **53** of first cooling section **16**. The cooling jet **74** is located along the center line of the tunnel roof immediately above the center of the last group of coil stations on the upper furnace level **2'** and above the first group of stations in the second cooling section **26** coil centerline **2"**. The atmosphere flowing through second cooling section **26** is conveyed to the first cooling section **16** by means of a collecting header **130** which is connected to a conduit **132** and to a discharge manifold **134**. Header **130** is located adjacent the warmest or first coil in the second cooling section such that it will collect the atmosphere at a level above the car hearth **90** as it passes that coil and convey it to the first cooling section **16** discharging the gas through discharge manifold **134** located adjacent the side of the coolest or last coil in section **16**.

Reconditioner **110** is also connected to a hydrogen supply **138** through conduit **140** in order to provide make-up hydrogen for that lost through operational leakage of the system. A conduit **142** extends from recirculator **110** to a discharge manifold **144** located in vestibule **3** to provide hydrogen atmosphere to the vestibule prior to opening doors **6** to **7** to maintain the atmosphere within furnace **2**. A nitrogen supply **146** is also connected to vestibule **4** through conduit **148** and discharge manifold **150** to provide a nitrogen purge of the vestibulte to clear the hydrogen atmosphere from it prior to opening door **3** which allows air to enter vestibule **3**. Headers **152** located high and low in vestibule **3** are vented to the outside to facilitate purging the existing atmosphere of vestibule **3** by a lighter (hydrogen) or heavier (nitrogen) gas to prepare the vestibule for opening to the furnace **2** or to the air 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 vestibule internal pressure.

FURNACE OPERATION

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, within the furnace. A hydrogen gas-tight gasket **9** at doors **3**, **6** and **7** and a purgible vestibule **4** allow charge and discharge of coils into the vestibule **4** and then into the elevator shaft **5** 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 a refractory 82 and 84 and 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 laterally across the width of car 40. The car 40 containing coils 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 top of the vestibule through header 152 by nitrogen gas which enters the vestibule 4 through manifold 150 from the bottom of the vestibule 4. Upon completion of the air purge, hydrogen gas is then introduced into the top of the vestibule 40 to purge out the nitrogen gas through the vestibule bottom after which door 6 will be open into elevator shaft 5, the atmosphere of which is open to the furnace through opening 32. When the furnace door 6 is opened the car 40 and coil C may be pushed into the elevator shaft onto elevator 34 and raised to furnace level 2' by the elevator. When the car has reached the top furnace level 2', a hydraulic ram 44 powered by cylinder 42 pushes the car 40 and coil C into the furnace after door 7 has been opened, locating it at coil station 1 within the first heating section 8 of furnace 2. The door 7 is then closed and sealed against gasket 9 isolating the first heating section atmosphere from the elevator shaft. The cars proceed through the furnace 2 by being pushed to the new coil stations by subsequent cars being introduced into the furnace and assuming coil station 1. When there are cars in the furnace filling all of the coil stations on the upper furnace level 2', the introduction of subsequent cars into the furnace will require that cars be exited through door 18 into elevator shaft 20 onto elevator 22 after which door 18 is closed and sealed against its gasket 9. In the disclosed example elevator car 22 has an insulated hood 23 to surround the coil and car on three sides and the top so that the interior of the elevator shaft 20 is shielded from heat radiation from the coil. This shield further assists in maintaining constant cooling rates for the coils. When the car 40 is positioned within hood 23, the elevator 22 is lowered to furnace level 2''. A hydraulic ram 44 and cylinder 42 push the car 40 and coil into second cooling section 26 through the opening at door 24 into the last coil position on that level. When the coil and car 40 are in position the ram 44 is retracted and door 24 is closed against gasket 9 isolating the atmosphere of the second cooling section 26 from the elevator shaft 20. The coils C are advanced through furnace level 2'' as they were on furnace level 2' by being pushed into subsequent coil positions by additional cars being introduced into the second cooling section 26. When all of the coil stations in furnace 2'' are filled, the introduction of an additional car 40 and coil C into that deck will cause a car and coil to be exited through a doorless opening 32 into elevator shaft 5. That coil will be removed from the shaft 5 through vestibule 4 via doors 6 and 3 after a purge of the vestibule 4 of hydrogen by nitrogen. To ensure a proper temperature history on the coils, each coil may have a thermocouple embedded in it which by leads 96 in tube 95 terminate in a plug-in receptacle 97 in the car understructure. The furnace 2 has access doors (not shown) at each coil station to reach the receptacle 97 to attach leads by which external recording equipment (not shown) may read the temperatures.

RECIRCULATION ATMOSPHERE SYSTEM

The atmosphere system includes circulation through the entire heating, soaking and cooling and 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 polutants. During the cleaning process, the atmosphere is cooled and then is reintroduced into the furnace so that the only make-up gas required is for that which leaks out on the various seals on the furnace. The atmosphere is introduced into the furnace 2 on lower furnace level 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 elevator shaft 20 at a predetermined rate such as about 30,000 s.c.f.h. Since a portion of the cool hydrogen is injected in the car understructure 66 area, it travels toward shaft 20 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 lower furnace level, the gas (atmosphere) is collected with headers 130. It is transferred to the upper furnace level 2' and discharged into the first cooling section 16 at manifold 134. The gas continues through upper furnace level 2' against travel of the coils until reaching the entry end of furnace 2 where it is picked up by header 112 and returned to the recirculator 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 cross over point of lower level 2'' 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 1700° 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 lower level 2'' and direct a cooling jet down into the center of these cooling openings to provide additional cooling over that passed through the furnace refractory 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 of upper level 2'. 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% pure, at a temperature between 80 and 100° F. with a dew point of less than —100° F. As the atmosphere transits the lower level 2'' of the furnace and reaches the entry portion of the second cooling section 26 its temperature has been elevated to approximately 1800° F. by carrying heat away from the coils C as it circulates past them. As the atmosphere flows through the upper level 21 of the furnace, the temperature is raised to 2150° 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 tunnel selected sections. The heat is added to the furnace system 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 (2150° F. for example). Similarly, heat may be supplied to the atmosphere sections **12**, **10** and **8** 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 heat section **8** of the top level **2''**, its temperature is reduced from 2150° F. to approximately 1000° 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**, **10** and **8**. 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 equal throughout the sections.

In addition to the above recited means for adding to or removing heat from the atmosphere and coils within the atmosphere, temperature control in accordance with the invention 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 cross 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 (i.e., 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 refracotry material in the section **12** and **14** walls amounts to approximately 25'' thick in an effort to retain as much heat as possible within the system and thus reduce the input requirements of 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'' and this area is provided with additional cooling from above by cooling jet **74**. Proceeding to the second cooling section, section **26** on lower furnace level **2''** shown in FIG. 6, it can be seen that the refractory wall thickness is about 10'' and subsequent FIGS. 7 and 8 show that in successive sections **28** and **30** the refractory thickness decreases to about 7'' and 3'' respectively. In section **32** 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** and **30** and **32**. In the example described the heat loss in the cooling sections is maintained at an average of 400 B.t.u.'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. In final heating and soaking sections **8**, **10**, **12** and **14** the average heat loss is maintained at approximately 170 B.t.u.'s per square foot per hour and the average coil heating rate of 43° F./hour is provided. The atmosphere exits the furnace at header **112** and is returned to the recirculator **110** laden with the contaminants from the coil surfaces such as hydrogen sulfide, water, carbon dioxide, carbon monoxide, oxygen and nitrogen removed in the coils. Within recirculator **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 recirculator **110** the gas enters the spiral type water-cooled heat exchanger at 600° F. to be cooled to 80 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 recirculator **110** which remove all dust particles ½ micron and larger from the atmosphere system. The oxygen, hydrogen, sulfide, air, carbon dioxide, carbon monoxide and water vapor are then removed in the Deoxo Tower and the Lectrodryer restoring the gas to its purity of 99.5% and dew point of below about −100° F. The gas is then returned to the furnace system through jets **120**.

In the operation of the purging systems within purging vestibule **4** the natural density of the various gases is utilized to reduce the quantity of the purged 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 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, if as in the example, the supply flow rates are equated to the exhaust flow rates, excessively high or low pressures within the vestibule **4** are eliminated during the purge and leakage past the gaskets **9** is minimized. 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. Conventional systems require five to eight chamber volumes of purging gas.

Uniform heat input to the top edge of coil is promoted through the use of a flare cap **102**. This flare cap covers the corner of the coil around the outer wrap to suppress radiation heat transferred to the outer top corner of the coil. A center mandrel **104** inserted in the center of the coil C juxtaposed with the inner wrap and suppresses radiation transfer to this portion of the coil and provides structural support. This protection against radiant heat transfer suppresses deformation of those exposed areas of the coil and prevents unraveling of the coil wraps.

The car understructure **66** displayed in FIGS. 5 and 6 is kept at a relatively low temperature through various means. The low temperature in this car understructure area is very important in that the lubricants used normally have a very high carbon content and the tendency at high temperatures would be for the carbon to be volatilized into the atmosphere and could be absorbed by the coils. Absorption of carbon by the silicon steel should be suppressed because of both the aging which occurs from the inclusion of the additional carbon, and also because of the effect on the magnetic properties of the material by virtue of the carbon occpying interstitial spaces in the crystal structure of the steel. Means to keep the car understructure **66** cool include refractory shielding accomplished by refractory materials **82** and **84** as well as radiation shielding accomplished by the protrusions and slots in the car structure **98** and **100** and protrusion **64** in the car side structure cooperating with slots **62** in the tunnel walls **51**. Further promoting the lower temperatures in the car understructure region is the fact that the atmosphere in the furnace **2** is always collected in the coil or upper tunnel area as opposed to the car understructure

area. Some of the main atmosphere supply jets **120** are located below the cars **40** thereby also promoting cooling in this area. The utilization of hydrogen as the atmosphere in the annealing furnace further promotes a cool understructure **66** in that the natural buoyance of the hydrogen concentrates the heat in the coil area of the tunnel as opposed to the area or the car understructure **66**. Further, the cutback, unlined furnace structure dissipates much of the heat which does reach this area. Doors **7**, **18** and **24** isolate upper furnace level **2'** from lower furnace level **2''** preventing a flow of heat from the coil area of level **2''** to under car area of level **2'**. The exchange of atmosphere from one level to the upper **2'** is accomplished above the critical lower area by locating collecting header **130** and discharge manifold **134** adjacent the coils in the respective sections **26** and **16**.

The material heat treated in the example disclosed in 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 dryed. The refractory coating and air gaps between wraps of the coil combine to form an insulation against radial 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 −15° F., in the hot section of the furnace to promote the removal of water vapor from within the 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. Heat flow to and from the coils is promoted through the coil ends by high conductivity hearth 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 conducivity 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 hearth 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. Lengthening 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 produced 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 2150° F. for a period of 21 hours in a dry atmosphere having a dew point of −15° F. or below and in atmosphere flow rate of 30,000 s.c.f. per hour. The heat treatment may be accomplished at lower temperatures such as 2000° F. over a longer period of time or the annealing temperatures may be increased to as high as 2250° F. for shorter periods of time. Operation with the parameters selected in the example minimize coil deformation and maximize 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 tranfer 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 minimium 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 approximatly 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 combined effect of the various aspects 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 furnace in the embodiment disclosed includes two levels, **2'** and **2''**, one above the other, it could be constructed in one long chamber with an inlet and an outlet end and cooperating vestibules **4**. The furnace could be constructed on a single level with the lines side by side utilizing a single vestibule **4** however eliminating the need for elevators such as **22** and **34**. 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 also be performed. Heating and cooling rates can readily be 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 of flow and by the input of cool atmosphere through jet **74** as well as controlled heat loss or dissipation through the walls.

While one embodiment of my invention has been shown and described, it will be apparent that other adaptations and modifications may be made without departing from the scope thereof.

I claim:

1. Apparatus for heat treating strip material in coil form comprising an elongated furnace structure, means dividing said furnace structure into a plurality of independently controllable heating zones and a plurality of independently controllable cooling zones, radiant heating means for heating said heating zones, means for supporting and advancing said coils through said furnace structure, means for providing a reducing atmosphere within said furnace structure and means for substantially preventing the introduction of air thereinto, means for circulating said reducing atmosphere in a closed path through essentially the entire length of said furnace and counter to the direction of travel of said coils, means for purifying and adding additional reducing gas as necessary to said atmosphere upon completion of circulation thereof and prior to recirculation, whereby said coils are controllably heated and cooled by said heating and cooling means and said recirculating atmosphere, a sealable vestibule for receiving coils of strip material to be heat treated in said furnace structure, door means between said vestibule and the entrance end of said furnace structure, and means for purging said vestibule after a coil to be heat treated is placed therein and while said door means is closed.

2. Apparatus according to claim **1** wherein said coils to be heat treated are silicon steel and the atmosphere is dry hydrogen.

3. Apparatus according to claim 1 wherein said heating zones have individually controllable molybdenum electrical heating elements disposed over at least a portion of the length thereof.

4. Apparatus according to claim 1 wherein said heating zones are lined with refractory of varying insulating capacity adjusted to provide a controlled predetermined heat loss from said heating zones.

5. Apparatus according to claim 1 wherein said plurality of cooling zones are line with refractory of variable heat insulating capacity to provide a controlled predetermined heat loss from said cooling zones.

6. Apparatus according to claim 5 wherein the heat insulating capacity of said refractory lining is adjusted to provide a predetermined equivalent heat loss in each successive cooling zone to produce a constant cooling rate for the coils traveling therethrough.

7. Apparatus according to claim 6 wherein at least one of said cooling zones includes means for injecting additional recirculated hydrogen atmosphere into said zone for supplemental cooling of said coils.

8. Apparatus according to claim 1 wherein laminar flow nozzles introduce the non-oxidizing purging gas into said vestibule to minimize mixing of the purging gas with the purged gas.

9. Apparatus according to claim 8 wherein the denser of the purging gas and the purged gas is introduced and exhausted at the bottom of said vestibule and the less dense gas is introduced or exhausted at the top of said vestibule.

10. Apparatus according to claim 1 including rail means extending longitudinally through said furnace structure and coil-supporting cars, adapted to travel on said rails.

11. Apparatus according to claim 10 including refractory material disposed between the coil and said car shielding said car from the heat of said coil, a rigid high conductivity hearth plate disposed on top of said refractory to support said coil, said refractory structure having at least one channel below said hearth plate disposed transversely in communication with said hearth plate to promote heat transfer to and from said hearth plate and said coil.

12. Apparatus according to claim 11 wherein said coil supporting cars have a longitudinal projection of refractory material extending therefrom on the sides of said cars adjacent said furnace structure and said furnace structure has a cooperating groove in the furnace refractory to receive said projection to form a refractory shield between the coil area of said furnace and the track area of said furnace.

13. Apparatus according to claim 12 wherein said coil-supporting car refractory has a projection extending transversely across the front of said car and a groove extending transversely across the back of said car and said projection and said groove are adapted to cooperate with the groove and projection of adjacent cars to form a refractory shield between the coil area of said furnace and the track area of said furnace.

14. Apparatus according to claim 13 including an angular cap of heat conductive material adapted to be disposed circumferentially around the exposed edge of said coil and a conductive tubular mandrel adapted to be disposed through the center of said coil and in seating engagement of said hearth plate.

15. Apparatus according to claim 1 wherein said elongated furnace structure comprises a first and second line disposed in parallel arrangement so that the direction of advance of said coils of strip of said second line is opposite to the direction of advance of said coils of strip of said first line, said vistibule being operably connected to the entry end of said first line and the exit end of said second line and a transfer chamber connecting the opposite ends of said lines.

References Cited

UNITED STATES PATENTS

1,321,388	11/1919	Owens	263—28
1,556,209	10/1925	Dressler	263—28
1,560,618	11/1925	Stevens	263—28
1,627,979	5/1927	Ludwig	263—28
1,867,772	7/1932	Smalley	263—28
2,083,638	6/1937	Cope	266—5
2,432,239	12/1947	Hoak	266—5
2,746,740	5/1956	Weaver	266—2
2,891,659	6/1959	Westeren	266—5
2,928,158	3/1960	Miller	263—28
2,955,062	10/1960	Cullen et al.	266—5
3,105,863	10/1963	Holcroft et al.	266—5

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