Nov. 5, 1968 H. B. FORSLUND 3,409,480

METHOD OF HEAT TREATING SILICON STEEL SHEET

Filed Jan. 7, 1965 4 Sheets-Sheet 1

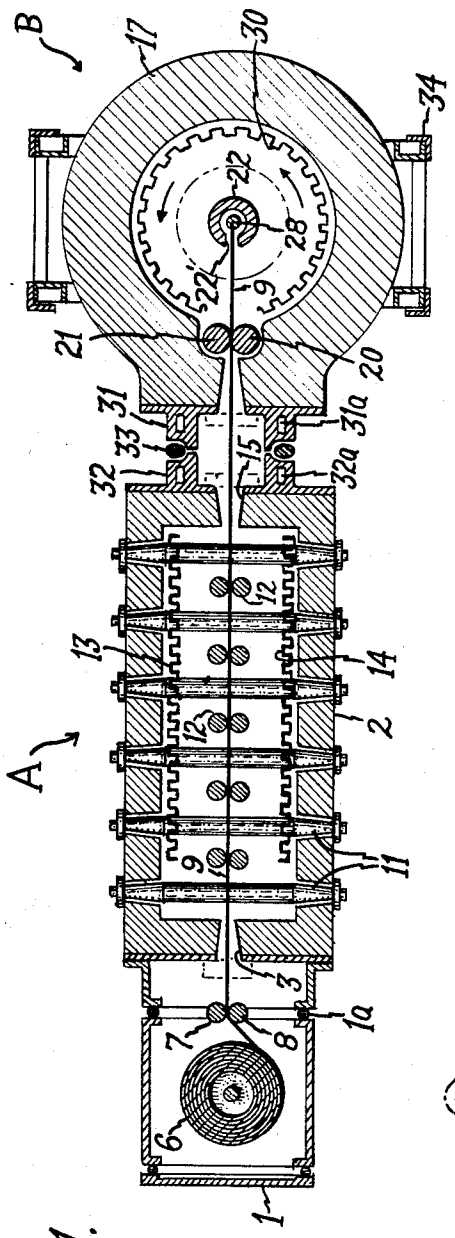


Fig. 1.

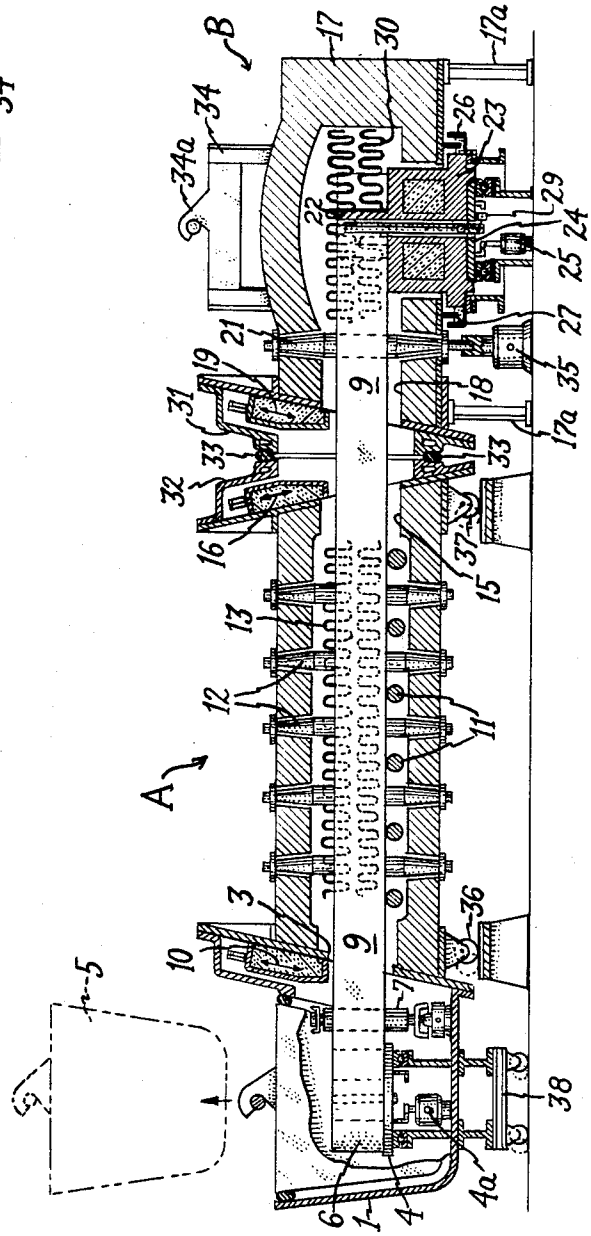


Fig. 2.

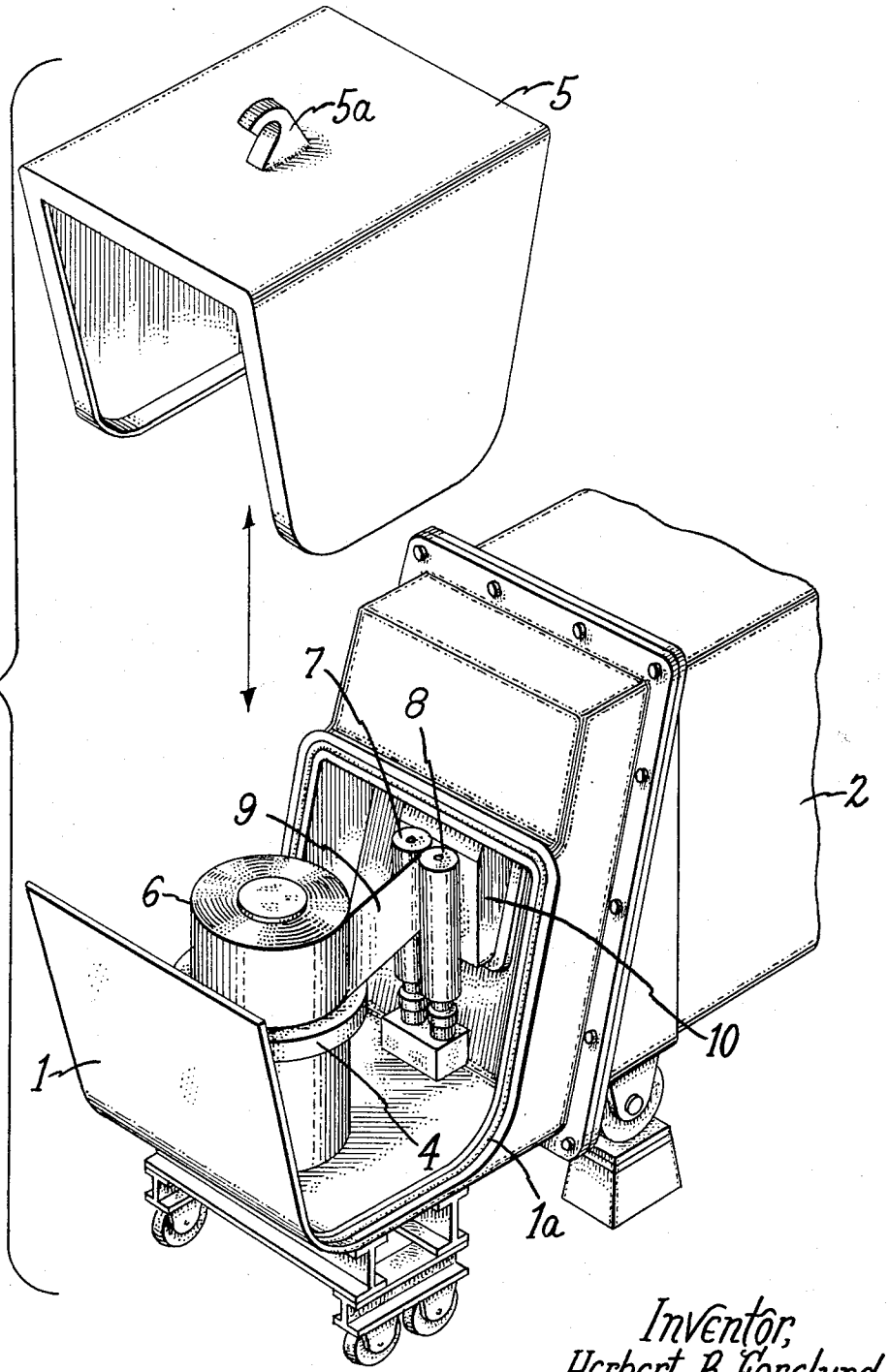
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METHOD OF HEAT TREATING SILICON STEEL SHEET

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Fig. 3.



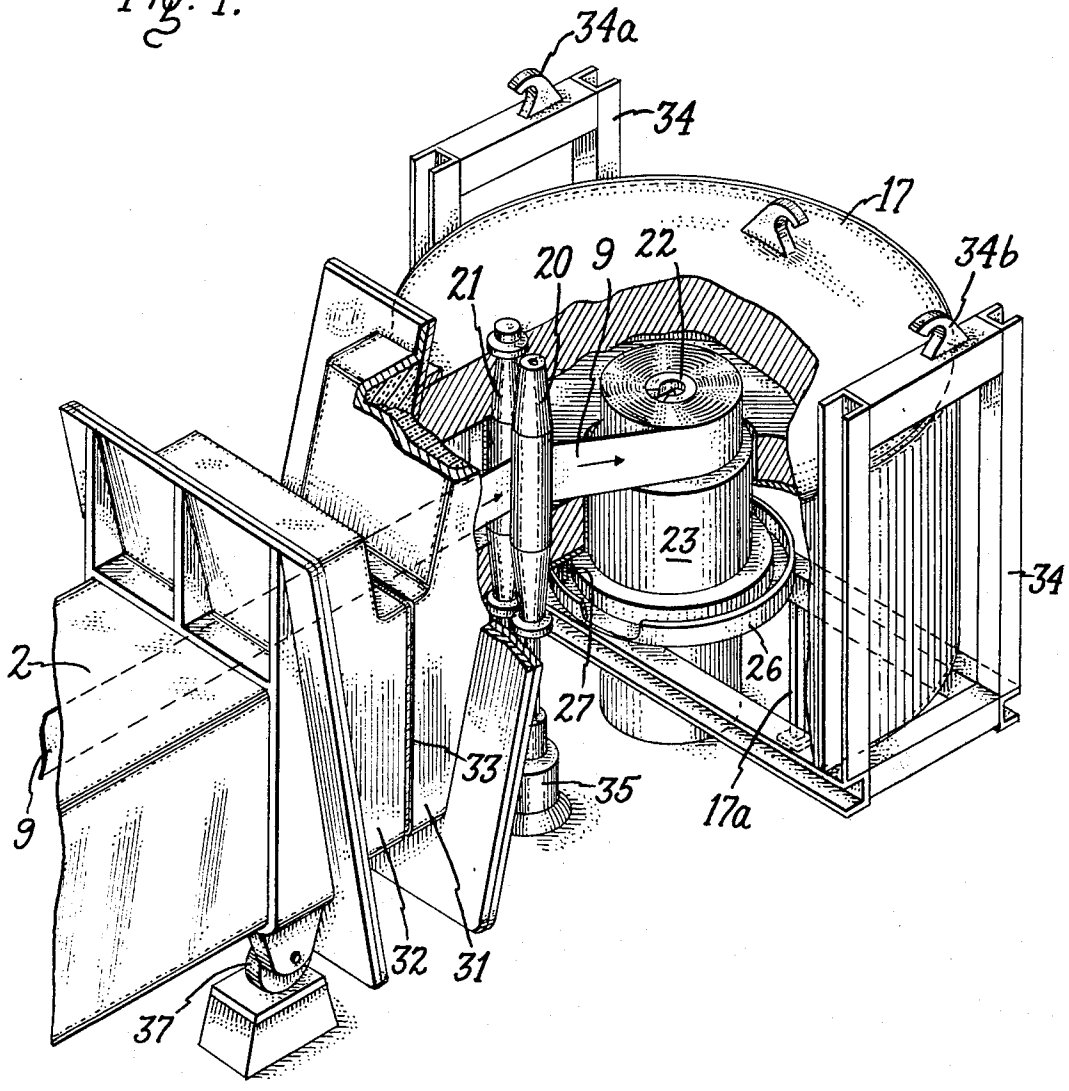
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Fig. 4.



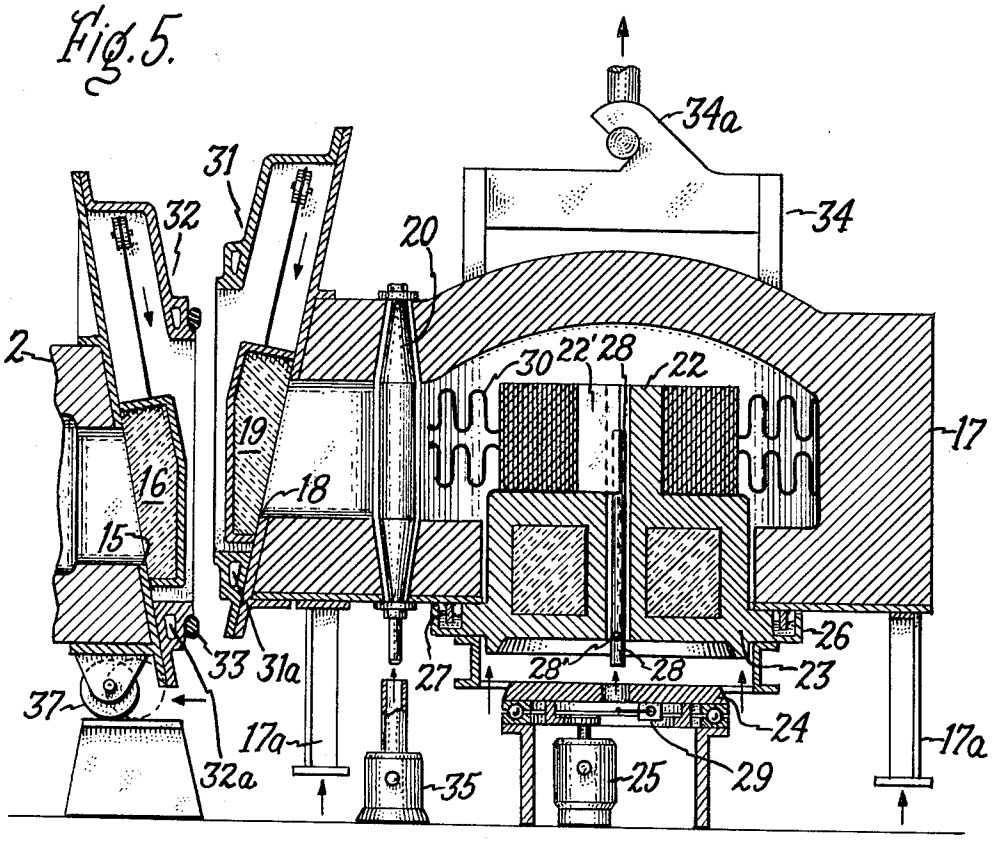
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METHOD OF HEAT TREATING SILICON STEEL SHEET

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Fig. 5.



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3,409,480

METHOD OF HEAT TREATING SILICON STEEL SHEET

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1 Claim. (Cl. 148—112)

ABSTRACT OF THE DISCLOSURE

The method of treating silicon steel sheet material which comprises moving a strand of the silicon steel through a heating chamber for raising the temperature thereof to at least about 900° C. such that no part of the silicon steel material is subjected to the temperature range of about 800° C. to about 900° C. for a period longer than ten minutes, and immediately thereafter without a cooling interval heating the thus preheated silicon steel sheet material in coiled form in a heating chamber in two temperature stages, in the first stage of which said coiled silicon steel sheet material is held for at least one hour in the range of about 950° C. to about 1050° C., and in the second stage of which said coiled silicon steel sheet material is held for at least one hour in the range of about 1100° C. to about 1200° C. Apparatus is disclosed for carrying out the claimed process.

The present invention relates to a furnace apparatus and method for processing metal strip material, and more particularly to such apparatus and method for heat treatment of magnetic silicon steel for electrical uses such as in transformers, motors and other electromagnetic apparatus.

The silicon steel material to which this invention relates is usually referred to in the art as "flat rolled electrical steel" and is conventionally composed principally of iron alloyed with about 1–4% silicon, preferably 2.5 to 3.5% silicon, and containing relatively minor amounts of various impurities such as sulfur, manganese and phosphorus and having low carbon content as finished material.

In the processing of silicon steel strip of the above type to produce material of good magnetic and electrical properties, the strip is normally subjected, after a series of rolling stages, to an annealing treatment in which two purposes are sought to be accomplished. First, the anneal should develop in the steel a crystal structure (texture) so oriented that good magnetic properties are obtained in the strip. The grain orientation of the steels produced by this process may be of different types such as those referred to as the (110) [001], (100) [001], or other types, the notations being in Miller indices, as understood in the art. Such crystal structures are usually developed by secondary recrystallization, as explained below. Second, the anneal should remove impurities such as sulfur and carbon which may cause excessive watt loss in the oriented strip. In general, low watt loss cannot be obtained without good crystal orientation and without suitable purification of the material.

By secondary grain growth, or secondary recrystallization as referred to herein, is meant the process whereby in the final texture-producing annealing treatment, strain-free crystal grains grow in size by absorbing each other. Such secondary grain growth usually follows primary recrystallization, which is a process whereby the distorted grain structure of a cold worked metal is replaced by a new strain-free grain structure by annealing above a specific minimum temperature. It is the secondary recrystallization that produces the highly preferred orientation sought in high quality magnetic strip, and the orientation thus obtained is usually completely different

from that obtained merely as the primary recrystallization. The magnetic strip is generally in a primary recrystallized state when it is ready for the final high temperature anneal. The grains in a primary recrystallized material are on the average considerably smaller than those of a secondary recrystallized material and, also, while primary recrystallized strip usually has only a small percentage of orientation, e.g., 15–20%, the large grained secondary recrystallized strip has a much higher degree of orientation, with values of 70–95% being the rule.

It has previously been found that in order to develop the maximum degree of secondary recrystallization in the annealing stage, the heat treatment is best carried out at a temperature which is lower than the optimum purification temperature. For example, a temperature of 925° C. for grain growth and of 1175° C. for purification has been taught by the prior art. In such processes, the steel strip was held at the lower temperature for a substantial period of time, at least several hours, to allow adequate grain growth (secondary recrystallization), after which the strip was subjected for several more hours to the higher purifying anneal temperature.

In the patent to Fitz et al. 2,986,485, there is disclosed the treating of silicon steel strip by a continuous strand annealing method wherein the period allotted for the two annealing stages are markedly reduced, so as to considerably shorten the overall time required to produce high quality electrical steel. It has been found, however, that all lots of silicon steel, for reasons not fully known, do not respond favorably to such rapid annealing procedures. It appears, for example, that certain silicon steel is characterized by relatively slow crystal growth at the optimum growth temperatures, for example, over 900° C., and accordingly it is necessary to hold such steel for a sufficiently long period at the proper annealing temperatures to ensure completion of secondary recrystallization to produce high quality steel strip. On the other hand, unsatisfactory results have been experienced with certain silicon steel where it has been held too long at the lower annealing temperatures, specifically, in the range of about 800° C. to about 900° C. Thus, it appears that due to characteristics of certain silicon steels, the properties of the finally processed steel are degraded by heating too slowly at the lower temperature stages, (i.e., 800° to 900° C.) whereas inadequate crystal grain growth results in certain silicon steel if heated for too short a period at the higher annealing temperatures (i.e., over 900° C.). The variability which characterizes silicon steel in these respects occurs not only as between different lots of steel but also within the same lot.

It is an object of the present invention to provide an apparatus and method for processing silicon steel which overcomes the above disadvantages.

It is another object of the invention to provide a furnace apparatus for annealing of silicon steel strip subject to the above discussed characteristics, wherein the annealing is carried out at least in part on a continuous basis.

It is another object of the invention to provide a furnace apparatus and method having a combination of strand annealing and batch annealing features for optimum processing of silicon steel of the above type.

It is a particular object of the invention to provide a furnace apparatus which provides for relatively short preheating of silicon steel strip and thereafter for relatively longer heating at higher grain growth and purification temperatures.

Other objects and advantages will become apparent from the following description and the appended claim.

With the above objects in view, the present invention concerns in one of its embodiments a furnace apparatus and method for processing electrical silicon steel which

provides for rapidly heating the steel strip to a temperature of not less than about 900° C.–950° C., and for thereafter heating the steel at a temperature between about 950° C. to about 1050° C. for a period sufficient to substantially complete secondary recrystallization thereof and then at a temperature between about 1100° C. and 1200° C. for a period sufficient to purify the steel.

In accordance with a preferred embodiment, the furnace apparatus of the invention comprises a first elongated furnace chamber for passing a strand of silicon steel therethrough and for rapidly heating the steel strand to a temperature of not less than about 900–950° C., and a second furnace chamber for receiving the thus-heated silicon steel and for heating it to a temperature between about 950° C. to about 1200° C. for a relatively longer period than in the first furnace chamber. In a preferred arrangement, the second furnace chamber includes means for reeling the preheated silicon steel strand into a coil, in which form it is heated to a terminal temperature within the last mentioned temperature range.

The invention will be better understood from the following description taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a plan view in horizontal section of an embodiment of the furnace apparatus of the invention;

FIGURE 2 is an elevational view in vertical section of the FIGURE 1 furnace apparatus;

FIGURE 3 is an exploded perspective view of the entrance portion of the furnace apparatus;

FIGURE 4 is a perspective view of another portion of the furnace apparatus; and

FIGURE 5 is a sectional view of the furnace unit shown in FIG. 4, with the unit in raised position.

Referring now to the drawings, and particularly to FIGURES 1 and 2, there is shown a furnace assembly comprising a preheating furnace A and a high temperature annealing furnace B which communicate with one another, but which are separable from each other at their adjoining connecting housings **31**, **32** as more fully described hereinafter. Preheat furnace A has, at its opposite end, a housing **1** connected thereto forming an entrance chamber, as shown more clearly in FIGURE 3, housing **1** being removably secured to preheat furnace section **2** by bolts or other suitable means and opening into the chamber of section **2** through an aperture **3**. Entrance chamber **1** is equipped with a turntable **4** for rotatably supporting a coil of steel **6** to be processed. Chamber **1** is open at its sides as shown to provide ready access to its interior, and thereby facilitate placement therein of the coiled steel strip. A cover **5** with walls complementary to those of housing **1** is provided for closing the latter during operation of the furnace, and it is normally moved vertically with the aid of hook **5***a* for movement into and out of closed position over chamber **1**. Suitable gasketing **1***a* is provided to afford a gas-tight seal between cover **5** and housing **1**. Synchronously driven pinch rollers **7**, **8** are arranged in chamber **1** adjacent aperture **3** to receive and move steel strand **9** through aperture **3** with the plane of the strip vertical as it unwinds from coil **6**. A door **10** is provided for closing aperture **3** as shown in FIGURE 3, the door being movable upwardly to the position shown in FIGURE 2 to uncover aperture **3** to allow passage therethrough of strip **9** during operation of the furnace.

Furnace section **2** comprises an enclosed elongated heating chamber through which steel strand **9** is continuously passed while being heated during its movement toward and into high temperature anneal furnace B. During this passage, strip **9** rests at its lower edge on horizontal rollers **11** as it is moved and guided by synchronously driven pairs of opposed vertical rollers **12** arranged along the path of strip **9**. Furnace chamber **2** has heating elements **13** and **14** arranged along its opposite inner sidewalls for raising the temperature of strip **9**, as disclosed hereinafter, as it passes through preheat chamber **2**. At its exit end, furnace section **2** has an aperture **15** through which strip **9** leaves the preheat chamber and a door **16** closes aperture **15** when lowered from the raised position shown in FIGURE 2.

Arranged adjoining the exit end of furnace section **2** during operation of the furnace assembly is shown a bell furnace **17** formed of a domed enclosure open at its bottom and provided with supporting legs **17***a* attached at its bottom. Furnace **17** has an entrance aperture **18** through which steel strip **9** may enter and which is closed by a liftable door **19** similar to doors **10** and **16** previously described. Vertical pinch rollers **20**, **21** at entrance aperture **18** receive strip **9** and move it toward the interior of bell furnace **17**, where a spindle **22** is rotatably mounted for winding strip **9** into coil form. Spindle **22** is an integral part of platform **23** which in turn is carried by turntable **24**, the latter being driven by motor **25** through suitable gearing means. The arrangement is such, as seen in FIG. 2, that when furnace **17** is in lowered operative position supported by legs **17***a*, platform **23** is free to rotate within stationary furnace **17**. Platform **23** has a hollow interior of annular form filled with heat insulating material. Platform **23** is also formed with a radially extending peripheral base portion which has a further peripheral extension **26** forming an annular trough for holding liquid sealing material, e.g., molten Wood's metal, such that annular projection **27** which extends downwardly from the bottom of bell furnace **17** is immersed in the sealing material and thereby seals off the bottom of the bell furnace during rotation of platform **23**. In the embodiment illustrated, as best seen in FIGURE 1, spindle **22** is tubular and is formed with a slot **22'** through which the leading end of steel strip **9** is received at the start of the reeling operation. Extending vertically through the hollow interior of reel **22** and aligned axial passages in platform **23** and turntable **24**, as shown more clearly in FIGURE 5, is an actuating arm **28** pivotally attached intermediate its ends by pivot pin **28'** to platform **23** for turning about a horizontal axis and detachably connected at its lower end (when furnace **17** is in operative assembly) to a switch mechanism **29** which effects the starting of motor **25**. The arrangement is such that the leading edge of strip **9** passes into the hollow interior of reel **22** through slot **22'** and strikes the upper portion of arm **28** resulting in the latter turning about its pivot **28'** and actuating the motor starting switch **29** at its lower end to initiate the coil reeling operation.

Along the interior wall of bell furnace **17** is arranged heating element **30** for raising the temperature of the furnace to a suitable level, as hereinafter described. At the side adjoining preheat section **2**, bell furnace **17** is formed with an entrance chamber housing **31** which mates with a corresponding exit chamber housing **32** formed in the adjoining end of preheat section **2** to form a composite connecting chamber. The mating portions of housings **31** and **32** include complementary peripheral recesses which together form a groove for receiving a resilient sealing gasket **33**, made of suitable heat resistant material such as a silicone rubber tubing, attached to one or the other of housing **31** or **32**, so that gasket **33** effectively seals the joint between the preheat furnace section **2** and the bell furnace **17** when these units are brought into assembly with one another as shown. Connecting housings **31**, **32** are also each preferably formed with interior passages **31***a*, **32***a*, respectively, through which cooling liquid may be circulated in order to keep gasket **33** sufficiently cool to avoid undue damage thereto.

The construction of bell furnace **17** as described makes it readily movable into and out of assembly with furnace section **2**, so that after strip **9** is fully reeled therein into a coil, bell furnace **17** may be removed to a different location for continuing the annealing process of the steel coil, while a replacement bell furnace is moved into assembly with preheat furnace section **2** to receive another pre-heated strip of silicon steel therefrom. For this purpose, a carrying cradle **34** is provided for holding bell

furnace 17 including platform 23, the latter resting on cradle 34 in the carrying position. Thus, at the end of the coil reeling operation, the lifting of cradle 34 by means of its hooks 34*a*, *b* raises platform 23 off turntable 24, and the radially projecting base of platform 23 then engages the bottom of the dome portion of furnace 17 as it rises, so that the unit may be removed with the steel coil therein, as shown in FIGURE 5. The lower ends of pinch rollers 20, 21 are provided with shaft portions or other suitable connections separable from drive motor 35 so that rollers 20, 21 may be readily disengaged from motor 35 during the removal of bell furnace 17.

To facilitate the assembly and disassembly of furnace units 2 and 17 relative to one another, furnace section 2 is preferably provided with wheeled supports 36, 37 and entrance chamber 1 is supported on a mobile carriage 38, whereby furnace section 2 with attached entrance chamber 1 may be rolled toward and away from the position occupied by bell furnace 17. Thus, to disassemble the connected units, furnace section 2 is rolled away from furnace 17 a short distance to break the seal at the gasketed joint therebetween and provide the necessary clearance to permit bell furnace 17 to be lifted off from its operating position. After a replacement bell furnace is lowered into operating position, section 2 is rolled toward it until the adjoining housings 31 and 32 mate with each other and gasket 33 is compressed therebetween to form a gas-tight seal between the furnace units.

It will be understood that the component parts of the assembly as illustrated in the drawings are shown somewhat schematically and the relative sizes of the devices as drawn, particularly the length of preheat furnace section 2, are not intended necessarily to correspond to those used in actual practice.

In the operation of the apparatus disclosed, a coil 6 of rolled silicon steel strip, e.g., about 11 to 14 mils thick and about 30–36 inches wide, which is to be heat treated for optimum grain growth and purification and on the surfaces of which an insulating separator coating such as magnesium hydroxide has been applied, is placed on turntable 4 in entrance chamber 1 with the coil axis vertical, and the free end of steel strand 9 is then threaded between pinch rollers 7, 8. Cover 5 is then placed in position, and with door 10 to furnace section 2 closed, chamber 1 is purged with nitrogen by suitable means, not shown. After the nitrogen purge, pure dry hydrogen gas is introduced into chamber 1 and all doors 10, 16 and 19 are opened to provide communication from chamber 1 through preheat chamber 2 to the interior of bell furnace 17, all portions of the interior of the furnace assembly thus being filled with the hydrogen atmosphere. Steel strip 9 is then rapidly threaded through the guide rollers in section 2 and bell furnace 17 until the leading edge of strip 9 strikes actuating arm 28 in bell furnace 17 as previously described, to start the reeling operation. Sensing switch 29 also initiates a synchronous drive train (not shown) which synchronously drives rollers 7, 8, 12, 20 and 21, as well as turnable drive motor 4*a* in entrance chamber 1 and turntable drive motor 25 below bell furnace 17. The temperature within preheat furnace chamber 2 is held at a level such that, taking into account the speed of travel of the steel strip through furnace 2 and other factors, the temperature of the moving steel strand is raised from room temperature to about 950° C.–975° C. by the time it reaches the exit end of furnace 2. Preferably, the temperature of furnace 2 is maintained such that there is a gradient beginning at about 500° C. at the entrance end to about 1000° C. at its exit end. In general, it is desirable to employ furnace temperatures designed to bring the steel gradually but rapidly to a temperature above about 900° C. The length of preheat chamber 2 and the speed of movement of steel strip 9 therethrough will be governed mainly by production requirements. Thus, in general, for larger production levels, the rate of the steel strip movement will be faster and thus require a longer preheat chamber to enable the strip to attain the desired temperature by the time it reaches the exit end. To avoid degradation of the steel properties which might result from prolonged exposure of the steel in the temperature range of about 800° C.–900° C., it is essential that the time for any portion of the steel in this temperature range be less than ten minutes. Tests have shown that silicon steel in strand form can be raised from room temperature to about 975° C. in about twenty seconds where the heating chamber has a heat gradient from 500° C. at the entrance end to 1000° C. at the exit end. In an illustrative arrangement, therefore, the preheat chamber 2 with such a heat gradient from end to end may be about 17 feet long, and the steel strand is passed therethrough at a rate of about .85 feet per second. In another arrangement, the rate of movement of the strand may be 2.85 feet per second through a preheat furnace 57 feet long.

During the rewinding of the preheated strip 9 in bell furnace 17 as the strip leaves furnace section 2, the temperature in bell furnace 17 is maintained in the range of about 950° C. to about 1050° C. After the rewinding of strip 9 into a coil in bell furnace 17 is complete, doors 16 and 19 in connecting housings 31, 32 are closed, and the connecting chamber formed between housings 31, 32 is purged with nitrogen. When the purge is complete, preheat furnace section 2 is retracted from bell furnace 17 in the manner previously described, bell furnace 17 and associated platform 23 are then lifted and transported by cradle 34 to remote location to complete the balance of the high temperature annealing cycle, another bell furnace is put into position replacing the previous bell furnace, and preheat furnace 2 is moved into assembly with the new bell furnace for repeating the preheating operation as already described.

In the meantime, the coiled steel in the removed bell furnace is held at temperatures in the range of about 950° C. to about 1200° C. in a reducing atmosphere such as pure dry hydrogen to provide for continued growth of crystals of preferred orientation and to purify the steel by removal of sulfur and other undesirable impurities. In the grain growth stage, the heating at from about 950° C. to about 1050° C. should be continued for at least 1 hour and thereafter as long as necessary to accommodate even the slowest crystal growth rate of the variable steels which are processed. It has been found that even those steels which are characterized by relatively rapid crystal growth are not significantly harmed by heating for longer times than necessary during such grain growth temperature (i.e., about 950° C. to about 1050° C.).

Normally, the coil is held in the high temperature stage for chemical purification (i.e., about 1100° to about 1200° C.) until the cold spot in the coil has been at 1150° C. or higher for at least one hour. The overall time in this stage may vary from about one hour to well over 24 hours, depending upon the rate of chemical purification taking place. In most cases, however, not more than two hours is necessary. Thereafter, the coil is usually cooled at the rate of about 100° C. per hour from about 1175° C. to about 500° C. in the hydrogen atmosphere. The coil is then transferred to a cooling chamber with a nitrogen atmosphere where it is held until it reaches a temperature of about 300° C. Removal of the coil from this cooling chamber completes the processing cycle.

A number of advantages are obtained in the use of the described method and apparatus in processing electrical grade silicon steel. By rapidly preheating the steel in strand form in the presence of the hydrogen atmosphere, the water present in the magnesium hydroxide slurry coating is quickly removed so that minimum reaction of the water with the steel is permitted. Reaction of the water with the silicon steel forms silica which in turn reacts with the magnesia coating, leaving less magnesia for the subsequent desulfurizing action, to which the magnesia

contributes, in the purifying anneal. Thus, rapid removal of the water in the strand preheating step preserves the magnesia coating and enables the use of thinner coatings of magnesium hydroxide without sacrifice in the intended function of this material. Moreover, the rapid preheating cycle brings the steel strand quickly through the critical temperature of about 800° C.–900° C., wherein certain steels are subject to marked degradation of properties if held too long at such temperatures, such as often occurs in coil heating procedures. It is believed that during a slow heat-up rate, the sulfide particles in the steel, which aid in oriented steel crystal growth but which are critical as to size and dispersion, may possibly undergo a change in condition and thereby fail to contribute to the optimum orientation sought. In combination with the foregoing advantages of rapid preheating, the described apparatus provides the further advantage of heat treating coils of the steel at optimum crystal growth temperatures for as long a period as necessary for completion of the slowest crystal growth, and this cycle proceeds without interfering with or delaying the rapid preheat processing of the steel.

It will be understood that modifications can be made in the apparatus shown while still obtaining the benefits of the invention. For example, instead of employing removable bell furnaces as shown, it may be found desirable to use a tunnel-type furnace through which coils preheated steel strands pass sequentially through the necessary temperature gradients required for the grain growth and purifying stages of the anneal. Alternatively, a rotary hearth type furnace may be used for the high temperature anneal, wherein the steel strands received from preheat chamber 2 may be coiled in place at spaced positions on the rotary hearth which rotates intermittently, so that each coil is maintained for a sufficient period of time at the various annealing temperature ranges during its travel around to its discharge station.

While the present invention has been described with reference to particular embodiments thereof, it will be understood that numerous modifications may be made by those skilled in the art without actually departing from the scope of the invention. Therefore, the appended claim is intended to cover all such equivalent variations as come within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. The method of treating silicon steel sheet material which comprises moving a strand of the silicon steel through a heating chamber for raising the temperature thereof to at least about 900° C. such that no part of the silicon steel material is subjected to the temperaure range of about 800° C. to about 900° C. for a period longer than ten minutes, and immediately thereafter without a cooling interval heating the thus preheated silicon steel sheet material in coiled form in a heating chamber in two temperature stages, in the first stage of which said coiled silicon steel sheet material is held for at least one hour in the range of about 950° C. to about 1050° C., and in the second stage of which said coiled silicon steel sheet material is held for at least one hour in the range of about 1100° C. to about 1200° C.

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