METHOD FOR PRODUCING IMPROVED METALLIC STRIP MATERIAL

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ABSTRACT OF THE DISCLOSURE
A method of continuously processing magnetic strip material which includes the steps of uncoiling, insulating, flattening, annealing and recoiling the strip material, while subjecting the strip material to three distinct tension zones which enables optimum temperature-tension relationships to be maintained for each processing step. An embodiment of the invention also continuously grades the strip material after annealing, to provide a continuous signal responsive to the electrical quality of the steel. Another embodiment controls the temperature-tension relationship of the strip material while it is being subjected to the flattening step, in response to the magnitude of the grading signal.

This invention relates in general to a process for producing improved metallic strip material, and more particularly to new and improved methods and apparatus for continuously insulating, flattening, annealing, and grading magnetic strip material.

Magnetic sheet or strip material of the type utilized in electrical apparatus, such as the magnetic steel used in transformers and dynamoelectric machines, must have certain predetermined characteristics in order to function efficiently in the end product. For example, the magnetic strip material must have a thin coating of electrical insulating material disposed thereon, in order to reduce losses due to eddy currents when a plurality of laminations formed from the magnetic strip material are superposed or stacked to form a magnetic core for electrical apparatus. Further, the magnetic material must have certain predetermined magnetic properties, with the strip being processed to provide the desired crystal structure, grain orientation, and magnetic permeability. The processing of the magnetic strip material by the strip manufacturer introduces stresses and strains into the material, however, which are deleterious to the magnetic properties of the steel. Even though the strip material is annealed by the strip manufacturer following the last cold rolling operation, in an effort to remove the process induced stresses and strains and to obtain the desired crystal structure and grain orientation, a variety of factors in subsequent processing and handling of the strip cooperate to provide magnetic steel in the end product, such as a magnetic core for a transformer, which is far below the optimum in electrical quality which the strip material is metallurgically capable of obtaining. For example, the magnetic permeability is lower than optimum, and the losses and magnetostriuctive noise levels are higher than optimum. Factors which contribute to the relatively poor electrical performance of the steel in the end product, from which losses and noise levels are derived, include:

- Impacts imparted to the magnetic strip during operations and handling subsequent to the initial high temperature batch processing of the coiled strip by the manufacturer of the strip, and stresses and strains imparted to the stacked laminations when they are clamped or bolted into a core structure, due to the lack of flatness in the strip material as received from the strip manufacturer and from which the laminations are formed. Thus, it would be desirable to provide magnetic strip material which will provide substantially the optimum in magnetic characteristics, losses, and magnetostriuctive noise level, when the magnetic material is cut into laminations and assembled to form a magnetic core.

It will thus be evident that the magnetic strip material must have the proper crystal structure and grain orientation, a tenacious coating of electrical insulating material, complete lack of stresses and strains, absence of coil set, and a high degree of flatness. Further, it would be desirable to know the electrical quality of the strip material being processed, for the purpose of controlling the processing steps to maintain the electrical quality at a maximum, and for the purpose of selecting the magnetic strip material having the highest electrical quality for the applications which demand the highest quality available.

In order to eliminate the factors which affect the electrical quality of the magnetic strip material due to the operations, handling and shipping of the strip material by the manufacturer of the strip, it would be desirable to provide a new and improved method of processing magnetic strip material, which will allow mill coils of magnetic strip to be purchased, scrubbed, uninsulated, and unflattened, instead of purchasing the conventional coils of steel which have already been insulated, partially flattened, and annealed. The mill coils could then be slit to the desired widths prior to processing, and the steps of insulating, flattening, annealing and grading the strip material could then be performed. Thus, it would be desirable to provide a new and improved method of processing magnetic strip material after it has been produced by the strip manufacturer, which will continuously insulate, flatten, anneal and grade the strip material to obtain the optimum in electrical performance.

Further, in the processing of strip material, certain relatively high strip tensions are required parallel to the longitudinal direction of the strip to remove coil set and to flatten the material, while the strip is at an elevated temperature. It thus becomes necessary to place driving rolls within heating means, which introduces the problem of creating sufficient friction between the hot rolls and the hot strip to provide the driving force and the desired tension. Conventional pinch drive rolls will not provide the desired friction at elevated temperatures, not only allowing the strip to slip, but also causing distortion in the strip. Thus, it would be desirable to provide a new and improved arrangement for providing his strip tensions while the strip is being heated to elevated temperatures, and to subsequently provide low strip tensions for annealing the strip.

Accordingly, it is an object of the invention to provide a new and improved method of processing magnetic strip material.

A further object of the invention is to provide a new and improved method of processing magnetic strip material to obtain substantially its optimum in electrical quality.

Another object of the invention is to provide a new and improved method of continuously insulating, flattening, annealing and grading magnetic strip material.

Still another object of the invention is to provide a new and improved method of continuously processing magnetic strip material which provides insulating, flattened,
and annealed strip material, and a continuous indication of the electrical quality of the strip being processed, to allow automatic or manual control of the processing steps to provide the optimum electrical quality.

Briefly, the present invention accomplishes the above cited objectives by providing a new and improved method of continuously processing magnetic strip material, which includes, flattens, anneals and grades the magnetic strip. The strip is divided into three zones of controlled strip tension, with the temperature-tension relationship being controlled in two of the tension controlled zones to provide flat, tension free magnetic strip. The first strip tension controlled zone provides the temperature-tension relationship for hot roller leveling of the strip, which flattens the strip to a high degree of uniformity. The second strip tension controlled zone provides the temperature-tension relationship for heating and cooling the strip to provide strip that is free of internal stress and strains which deleteriously affect the electrical losses of the material, and the third tension controlled zone controls the tension of the strip while it is being wound into a coil of finished strip material, in order to obtain a tight finished coil without exceeding the tension that would reintroduce strain into the material.

The magnetic strip is continuously tested for watts loss per pound as it is being processed, which allows the various temperature-tension relationships to be either automatically or manually adjusted to control the dwell time to an accuracy of ±0.01 in. per minute, to obtain the minimum watts loss per pound of material, and also provides a grading of the material for future use, when the magnetic strip material is being selected for specific applications.

The desired strip tensions are produced while the strip is being heated in heating means to elevated temperatures, by utilizing a combination of drag means, tensioner unit, and driving means, with at least the driving means being disposed within the heating means. The driving means includes at least three driven rolls disposed in a bridle arrangement, in which the first two rolls each reverse the direction of the strip, and the third roll again changes the direction of the strip. The hot bridle drive provides the friction necessary between the hot rolls and the hot strip to drive the strip without slippage and without distortion of the strip at longitudinal tensions up to at least 1200 p.s.i.

Further objects and advantages of the invention will become more apparent as the following description proceeds and features of novelty which characterize the invention will be pointed out in particularity, in the claims annexed to and forming a part of this specification.

For a better understanding of the invention, reference may be had to the following detailed description, taken in connection with the accompanying drawings in which:

FIG. 1 is a functional, cross sectional view of apparatus which may be used in carrying out the teachings of the invention; and

FIG. 2 is a view of the process line of FIG. 1, illustrating certain control points, tension zones and strip driving points.

Referring now to the drawings, there is shown in FIG. 1 a functional view, in cross section, of a process line 10 for magnetic strip material, illustrating apparatus which may be utilized in carrying out the processing steps according to the teachings of the invention. FIG. 2 also shows the processing line of FIG. 1, and is included to illustrate certain control points, the various tension zones, and the strip driving locations. FIGS. 1 and 2 will both be referred to when describing the strip processing method.

In general, the processing line performs all of the steps necessary to electrically insulate, flatten, anneal and grade the magnetic strip material, and it possesses all of the necessary controls to provide the strip tensions, strip temperatures, and strip cooling to consistently produce magnetic strip material of high electrical quality which will perform up to its optimum capabilities when cut into laminations and stacked to form a magnetic core for electrical apparatus. More specifically, mill coils of magnetic strip material suitable for use in magnetic transformers, such as silicon-iron strip material having from 1 to 6% silicon, are slit to provide the desired widths and wound into coils. The strip in the mill coils has been processed to provide the desired crystal structure and grain orientation, but is uninsulated and un flattened. A slit coil 12 is loaded into an uncoiler 14 from a coil loading buggy (not shown). The uncoiler 14 is driven by an adjustable speed drive 16, as shown in FIG. 2. The end of the magnetic strip 20 which makes up coil 12 is threaded into a combination shear and welder 22. The trailing edge of the strip already threaded through the processing line is both electrically and magnetically secure. The weld from coil 12 are both sheared by the same blade to square the ends of the two strips, and assure excellent contact between the ends of the strips. The strips are butted together, clamped, and the two strips butt welded together with an arc welder. The complete processing line is stopped while the weld is taking place. As will be hereinafter explained, the stopping of the line does not adversely affect the quality of the strip. It is important that the welding operation be closely and accurately controlled, to produce a weld that is at least as strong as the parent metal, without buckling the thin strip or burning through. The welding process is further controlled in order to facilitate tracking on the various guide rolls in the line, in order for the strip to negotiate turns at high temperatures, and in order to eliminate any possibility of breakage of the strip at the weld.

After the welding operation, the coil 12 is rotated to pay off the strip 20 in a horizontal line to pinch rolls 24. Pinch rolls 24 are the first of a plurality of strip driving points, with the rolls 24 being driven by adjustable speed driving means 26, as shown in FIG. 2. From the strip drive rolls 24, the strip 20 is spliced into an accumulator pit 28, where it forms a free hanging slack loop 29, supported by suitable supporting and guiding means (not shown) on each side of the pit 28. The purpose of the accumulator pit 28 is to isolate the uncoiling function from the processing line, and provide a reserve of strip material which may fluctuate in length, to avoid the strip tensions and linear speed on both sides of the pit 28 to vary relative to one another without danger of rupturing the strip 20. Suitable loop sensing means 30 is provided in the pit 28, which senses the length of the loop 29 and applies signals to control means 32, shown in FIG. 2, which controls adjustable speed driving means 16 and 26, to maintain the loop length within predetermined limits. For example, the loop sensing means 30 may be drawings in which the loop 29 interrupts the light between the lower light source and photocell, the control 32 would signal driving means 16 and 26 to decrease their speed and decrease the speed of the strip 20. The loop 29 would then decrease in length until the light from the upper light source is able to contact the upper photocell. This signals the driving means 16 and 26 to increase their speed and the speed of the strip 20, and the length of the loop 29 again increases. Thus, the loop length continuously varies between the preset limits. It may be desirable to provide a third light source and photocell near the top of the pit 28, and a fourth light source and photocell near the bottom of the pit 28 as emergency switches which will deactivate the processing line 10 in the event the loop length becomes dangerously short or long. This would prevent the loop from disappearing entirely with the possibility of subjecting the strip 20 to two different tensioning zones, which could rupture the strip 20, and would also prevent lowering the strip in the accumulator pit.

The strip 20 leaves the accumulator pit 28 and proceeds between edge deburring rolls 34 which remove any burrs on the edges of the strip 20. After the strip 20...
is deburred, it enters the first tension controlled zone and passes between drag rolls 36, tensiometer rolls 37, driven coating rolls 44, and around strip drive rolls 60, 62 and 63 in a bridge arrangement 59. The strip tension, which is set at a temperature the motor drive is programmed to keep within the tension drag rolls 36 with strip drive rolls 60, 62 and 63. The drag rolls 36 are driven by driving means 40, and driving rolls 60, 62 and 63 are driven by driving means 42, both shown in FIG. 2. By properly coordinating driving means 40 and 42, the tension applied to strip 20, between drag rolls 36 and driving rolls 60, 62 and 63, may be set at any magnitude within a predetermined range. As will be hereinafter explained, the tension in tension zone 1 is controlled and coordinated with the strip temperature in order to roll flatten the strip to an extremely high degree of flatness.

More specifically, after passing between the drag rolls 36, the strip 20 passes between coating rolls 44, which apply a thin uniform coating of a suitable electrical insulating means to the strip 20, which will react with the strip at an elevated temperature to form an adherent solid insulating film. The insulating means may comprise aqueous phosphoric acid, mixed with magnesium oxide, magnesium hydroxide, or other suitable refractory materials. The lower roll of the coating rolls 44 may be partially submerged in a container which contains a quantity of the insulating means, thus picking up and depositing a thin film on the bottom of the strip 20 as the rolling means. The upper roll of the coating rolls 44 may have the insulating means applied thereto from a supply of the insulating means disposed over the upper roll, and which deposits the insulating means onto the upper roll at a predetermined rate.

After leaving the coating rolls 44, the strip 20 enters heating zone 45, which heats the strip 20 to a temperature of 500–550 °C, driving off the liquid vehicle in the insulating means, and reacting the acids in the insulating means with the outer surfaces of the strip, to form a tenacious solid film of electrical insulation on the strip. Since the gases driven off of the strip from the insulating means must be collected and discharged to the atmosphere, the heating means 46 may be a radiant gas furnace, with the means utilized for removing the products of combustion from the gas furnace also being used to remove the gases produced by the heating of the insulating means.

The next step in process 10 is hot roller leveling, which requires a temperature in the range of 750–900 °C. Thus, the strip 20, which leaves the heating means 46 at a temperature in the range of 500–550 °C, must pass through heating means 48 to have its temperature increased to the roller leveling range. Since it is desirable to operate the processing line at a high rate of speed, such as 400 feet per minute, and since it is desirable to keep the processing line as short as possible, and thus conserve valuable plant floor space, the heating means 48 for raising the temperature to the hot roller leveling range may be in the form of an induction coil 50. Induction coil 50 is connected to a suitable source of high frequency energy, and it quickly and uniformly inductively heats the strip in a very short length of time, requiring very little space in the processing line. Induction preheating of the strip, after the insulating strip has had the coating of electrical insulation applied thereto and before the hot roller leveling step, provides many advantages. First, the volatiles from the liquid insulating means have been driven off in heating means 46, and will thus not be present to corrode the induction coil 50, and provide low impedance arcing paths for the high voltage power, so that the induction heating may be utilized without the coil maintenance problem which would be associated with heating the strip while the insulating means is still in its liquid state. Further, hot roller leveling requires that the strip be heated to a temperature which is close to the Curie temperature (about 750 °C.) of the magnetic strip material 20. Induction heating of thin magnetic strips at frequencies in the 70–450 kc. range, or higher, is very efficient up to the Curie temperature of the strip. At the Curie temperature the magnetic material loses its magnetic permeability and the magnetic flux approaches that of air which reduces the amount of magnetic flux within the strip material. This, along with current cancellation due to the increased depth of current penetration in the strip above the Curie temperature, makes the heating very inefficient, and acts as an automatic temperature control of the induction heating. Thus, the induction coil 50 will rapidly raise the temperature of the strip 20 from the exit temperature from the heating means 46 to approximately 750 °C, which is near the desired temperature for hot roller leveling.

In order to raise the temperature of the strip 20 from approximately 750 °C, the exit temperature from the induction coil 50, to the hot roller leveling range of 750 °C. to 900 °C., and in order to maintain the desired temperature while the strip 20 is passing between leveling rolls 52 and 53, the strip 20 enters heating means 54, within which the flattening or leveling rolls 52 and 53 are disposed. Heating means 54 should not have the air flow used with products of combustion, making it desirable to utilize a radiant electric furnace for heating means 54, along with its associated control 56 (shown in FIG. 2). Heating means 54 raises the temperature of the strip from the inductively heated range of 750 °C. to 900 °C. to the desired range of 750 °C. to 900 °C, before the strip passes between the rolls 52 and 53 of the roller leveling process. The plurality of rolls 52 are disposed above the strip, and the plurality of rolls 53 are disposed below the strip, in a manner which cooperates with the temperature and tension of the strip to provide the predetermined incremental stretching and flexing necessary to remove irregularities in the flatness of the strip. The tension applied to the strip, which is sensed by tensiometer rolls 37 and controlled by drag rolls 36 and driven rolls 60, 62 and 63, and the temperature of the strip, controlled by control 56, may all be preset to predetermined quantities, or, as will hereinafter be explained, they may be constantly controlled responsive to a feedback signal to obtain the optimum in electrical quality of the strip material 20. The strip tension should be controllable in the range of 300 p.s.i. to 1200 p.s.i., and the temperature of the strip should be controllable in the range of 750 °C. to 900 °C. The exact temperature-tension relationship is selected and controlled to produce strip which is at its optimum in electrical quality.

The rolls 53 disposed below the surface of the strip 20 are permanently mounted, and the rolls 52 disposed above the strip are adjustable, and preferably disposed substantially intermediate to the lower rolls. In the usual operating condition, the lowest point of the upper rolls 52 will be adjusted to be above the uppermost point of the lower rolls 53, in order to flex the strip up and down as it passes between the rolls. The rolls 52 and 53 are preferably driven, with incremental stretching being accomplished, by the flexing of the strip. If desired, incremental stretching may also be introduced, in addition to the flexing, by driving succeeding rolls slightly faster than the preceding rolls. The incremental stretching should be controlled to remove surface irregularities without introducing longitudinal corrugations, and without adversely affecting the magnetic properties of the strip. Since the rolls 52 and 53 operate at the temperature of the electric furnace 54, they should be formed of an alloy suitable for withstanding the operating temperatures.

In order to achieve controllable strip tensions in the range of 300 p.s.i. to 1200 p.s.i., required for roller leveling of the strip, it is necessary to provide tension rolls 60, 62 and 63, disposed in a bridge arrangement 59. At the roller leveling temperatures of 750 °C. to 900 °C., it is difficult to obtain strip tensions in the range of 300 p.s.i. to 1200 p.s.i. with the conventional pinch drive rolls.
The friction developed by pinch rolls may not be sufficient to prevent slippage, and efforts to prevent slippage with pinch rolls installed in the direction of the strip material 20. Thus, at least three driven rolls 60, 62 and 63 are disposed in a bridle arrangement 59 within heating means 54, near its exit end. Driven roll 60 is disposed with its upper surface in substantial alignment with the upper surfaces of the lower flattening rolls 53, and the strip 20 is disposed to proceed over the upper surface of roll 60 and around the roll to reverse its direction and proceed back towards the start of the process line 10. Roll 62 is disposed below the previous level of the strip 20, and closer to the start of the process line than roll 60. Strip 20 proceeds over the upper surface of roll 62 and around the roll to agon 66.  This exerts tension on the strip 20 in the direction of the line until reaching drive roll 63. Upon reaching drive roll 63, the strip 20 passes over its upper surface and is wrapped partially around the roll until it reaches a substantially vertical position. Thus, the direction of the strip is reversed at least twice by rolls 60, 62 and 63 within a relatively small diameter compared to the other drive rolls in the process line, and are formed of a suitable alloy which will withstand the temperature within the heating means 54.

After roller leveling of the strip 20, the next step in the process 10 is to anneal the strip and remove all of the internal stresses and strains which have been imparted to the strip during its manufacture and during the present processing of the strip. The strip 20 should be heated to a uniform predetermined temperature in the range of 800° C. to 900° C., and soaked for a predetermined period of time at temperature, and uniformly cooled in a radiation zone of still air down to a temperature of at least 475° C. The heating, soaking and cooling should be accomplished at a uniformly low strip tension, preferably not to exceed 100 p.s.i. This forms tension zone 2.

The annealing of strip 20 is accomplished by spilling the strip into a free hanging loop 67, supported at one end by the bridle arrangement 59 and at the other end by guide rolls 64, disposed at the top of a vertical cooling tower 66. The strip 20 between these two points is the weight of the strip itself, as it hangs in a free forming catenary loop 67. Thus, the complete annealing process is performed without having the strip 20 in contact with any external guides or driving means, insuring that the strip tension is uniform and also insuring that there will be no chill quenching of the strip which could reintroduce stresses into the strip.

When the strip material 20 is spilled from the bridle arrangement 59, it is at a temperature in the range of 700° C.—830° C. In order to heat this strip 20 to the desired temperature in the annealing-soaking temperature range of 800° C.—900° C., the strip 20 immediately enters heating means 70. Since it is essential that there be no air flow in the heating means 70, heating means 70 is preferably a radiant electric furnace which includes associated control 72 (shown in FIG. 2).

The free hanging loop 67, in addition to providing the benefits of allowing the soaking and controlled cooling of the strip 20 to occur without contacting external guiding and driving means and at a low uniform tension, also provides the additional benefits of greatly reducing the overall length of the process line. In order to maintain the length of the loop 67 within predetermined limits, loop sensing means 74 and its associated control 76 are provided, and it may operate in a manner similar to the loop control 32 and loop sensing means 30 hereinbefore described. However, since the strip 20 will be heated to a light producing temperature, the loop sensing means 74 should be selected such that light from the strip will not interfere with its operation. For example, the signal sources may transmit signals of a predetermined wavelength, with the targets being sensitive only to that particular frequency.

As shown in FIG. 2, control 76 delivers appropriate signals to driving means 40 for drag rolls 36, driving means 42 for bridle arrangement 59, and driving means 81, which control the drive of the lower flattening rolls 53 to the vertical cooling tower 66. In addition to controlling driving means 42 and 81, driving means 40 for drag rolls 36 must simultaneously be adjusted to maintain the predetermined roller leveling tension between bridle arrangement 59 and drag rolls 36.

Upon being heated to a predetermined annealing temperature in the range of 800° C. to 900° C., the strip 20 is soaked at temperature in heating means 70 for a predetermined period of time sufficient to remove all internal stresses. The soaking of the strip 20 to remove stresses has a time-temperature characteristic, which is influenced by the thickness of the strip and the higher the temperature and the thinner the strip, the less the required soaking time. Thus, the soaking period may be in the range of a few seconds to a minute or more. Protracted soaking is not detrimental to the magnetic properties of the strip, however. Thus, even when the process line 10 has been stopped for purposes of welding the ends of one strip to the start of the next, or any other purpose, the increased soaking time of the strip in heating means 70 is not deleterious to the magnetic qualities of the strip. It should be noted that by utilizing radiant heating for heating means 46, 54 and 70, that the temperature gradient will be low enough to allow the process line 10 to stop for welding or other purposes without overheating the strip. The induction coil 50 may be interlocked with the line to remove its power source when the process line 10 stops. However, as hereinbefore stated, the induction heating efficiency becomes so low once the strip 20 becomes non-magnetic at its Curie temperature, that there is little danger of overheating the strip with the induction coil 50.

After soaking the strip 20 at the desired annealing temperature for a predetermined period of time, the strip 20 enters the vertical cooling tower 66. Cooling tower 66 has two distinct cooling zones 82 and 84, which are interconnected at the upper end of the tower through a throat which is baffled to prevent air from circulating between the two zones. The first zone 82 includes black body radiators 80 and a still or dead atmosphere. Black body radiators 80 may be water cooled metallic radiators, constructed of any suitable material. Blowers (not shown) may be incorporated at the top of zone 82 to offset any chimney effect produced in the vertical column, and thus maintain an absolutely dead atmosphere which is required for proper radiation cooling. The strip 20 enters the bottom of the cooling tower into zone 82, and proceeds upwardly to guide rolls 64 disposed at the top of zone 82. The height of the cooler tower 66 is coordinated with the line speed and the strip incoming temperature to deliver the strip to guide roll 64 at a maximum temperature of 475° C. Below this temperature, the strip 20 may be rapidly cooled without adversely affecting its magnetic characteristics, allowing it to be rapidly cooled to zone 84. The strip 20 enters and contacts guide roll 86 which changes the direction of the strip to a vertically downward direction. The strip 20 traverses zone 84 to guide rolls 88 and 92, then proceeds to the exiting point 96 of the cooling tower 66. Strip 20 is convection cooled by forced air jets 90 during its travel through cooling zone 84. The strip 20 should
be cooled to a maximum temperature of 60 °C at the exit of cooling zone 84, in order to allow the strip to be recoiled without introducing stresses into the coiled strip when it completes its cooling.

Upon leaving the cooling tower, the strip 20 passes through an X-ray gauge 100, which determines the thickness of the strip. X-ray gauge 100 produces a signal responsive to the strip thickness, which is utilized by quality testing apparatus disposed subsequently in the processing line.

The strip 20 then passes between pinch drive rolls 83, which splits the strip through quality test apparatus 102 into an accumulator pit 104, to form a controlled loop 106 supported by drive rolls 83 and other appropriate guides at one end, and tension drag rolls 108 and other appropriate guides at the other end of the loop. Loop 106 isolates the annealing step of the process from the recoiling step. Accumulator pit 104 includes loop sensing means 110 and associated control 112 for controlling the length of the loop 106. The loop sensing means 110 and control 112 may operate in a manner similar to loop sensing means 30 and control 32, hereinbefore described.

The quality test apparatus 102 includes suitable coils, control, and recording means 114 (shown in FIG. 2), for determining the quality of the magnetic strip 20. For example, the test apparatus may include the conventional "M" coil for applying a magnetic force of predetermined strength, strip 20, an H coil for measuring the total flux in the strip and surrounding air, and an "H" coil for measuring the flux in the surrounding air only. The signals from the "B" and "H" coils may be coupled with the signal from the X-ray gauge to produce a continuous record of the watts loss per pound of the material, thus providing a record of the electrical quality of the steel simultaneously with the processing of the strip material. This record may be utilized to manually make adjustments to the various temperatures and tensions throughout the line to maintain the electrical quality of the strip at a maximum, as well as for each coil of strip for use in selecting magnetic strip material for various applications. This quality test step in the process may also be utilized to automatically control the complete process to produce the optimum in electrical quality, as will be described hereinafter.

After leaving the accumulator pit 104, the strip passes through tension drag rolls 108, and enters a strip squaring shear 116, where the strip is sheared when the recoiled strip has reached a predetermined outside diameter, or when the strip width changes and it is necessary to start a new coil. The strip 20 then passes through an edge control guide 118, which automatically controls the axial position of a drive recoiler 120, which recoils the strip 20 into coils 122 having straight sides. The recoiler is driven by an adjustable speed driving means 123, and the drag rolls 108 are driven by an adjustable speed driving means 124. The driving means 123 and 124 are adjusted relative to one another to provide the desired strip tension for recoiling, which forms the third tension zone. It is important that the recoiling tension be accurately controlled, in order to form a tight coil without exceeding a tension that would reintroduce stresses into the coiled strip. The tension of the strip 20 in tension zone 3 is controlled to a predetermined value within the range of 500 p.s.i. to 2000 p.s.i.

The control 112 for loop 106 controls driving means 123 and 124 to maintain loop 106 within predetermined limits. Both driving means 123 and 124 must be simultaneously controlled when controlling the loop size, in order to maintain the tension of the strip at the predetermined value.

The continuous testing of the quality of the strip 20 after processing allows an immediate determination of the effectiveness of the various processing steps, and allows the temperatures and strip tensions in the various steps to be changed to produce the optimum in electrical quality. The record of the quality of each coil processed may also be used in selecting core material for different electrical applications. The intelligence received from the test equipment may also be used to automatically control the strip temperature and tension to obtain the optimum in electrical quality. As shown in FIG. 2, the information from the test apparatus 102 may be delivered to a computer 130, which controls the tension in tension zone 1 by appropriate signals to drag roll driving means 40 and driving means 42 for bridle 59, and controls the temperature of heating means 54 and the temperature of heating means 70. The temperature-tension relationship in tension zone 1, which is where the hot roller leveling occurs, and the annealing temperature, which will produce the lowest watts loss per pound of material, will be automatically selected and maintained by computer 130.

Processing line 10 includes three important tension controlled zones, with slack loops 29, 67 and 106 making it possible to achieve the different tensions throughout the line. Slack loop 29 isolates the uncoiling step from the insulating and hot roller leveling steps. The insulating and hot roller leveling steps are further isolated by slack loop 67. Thus, tension zone 1 generally comprises the portion of the line between slack loops 29 and 67, and specifically is created between drag rolls 36 and bridle arrangement 89.

The annealing step is isolated from the hot roller leveling step and the recoiling step by slack loops 67 and 106. In this instance, the isolating slack loop 67 actually forms a vital part of the annealing step, as it produces tension control zone 2. Thus, tension zone 2 is generally between slack loops 67 and 106, and specifically includes only slack loop 67. The recoiling step is isolated from the annealing step by slack loop 106. Tension control zone 3 is thus generally between slack loop 106 and recoiler 120, and is specifically between drag rolls 108 and recoiler 120.

In summary, there has been disclosed a new and improved processing line for magnetic strip material which provides a complete high speed processing of uninsulated, unheattreated magnetic strip material in a minimum of floor space, to provide magnetic strip material which will realize its optimum in electrical performance when assembled into electrical apparatus. The process line performs the steps of uncoiling, deburring, insulating, flattening, annealing, testing or grading and recoiling, while providing the complete control of strip temperatures, strip tensions, and strip temperature-tension relationships required to provide the minimum watts loss per pound of strip material that the strip is capable of achieving.

Further, there has been disclosed new and improved apparatus for achieving predetermined tensions while the magnetic strip material 20 is at an elevated temperature. Specifically, the apparatus includes the combination of heating means, strip drag rolls, and a plurality of driving rolls disposed within the heating means and arranged in a bridle arrangement to provide the necessary friction between the hot driving rolls 118 and hot strip to develop the predetermined tensions in the strip without slippage and without distortion of the strip.

Since numerous changes may be made in the above described process and apparatus and different embodiments of the invention may be made without departing from the spirit thereof, it is intended that the invention be not contained in the foregoing description or shown in the accompanying drawings shall be interpreted as illustrative, and not in a limiting sense.

We claim:
1. A method of continuously processing magnetic strip material comprising the steps of applying a coating of electrical insulating material to the strip material, heating the strip material to a first predetermined temperature which reacts the insulating material with the strip material to provide an adherent solid insulating film on the surfaces of the strip material, heating the strip material to a
second predetermined temperature, applying a first predetermined longitudinal tension to the strip material while it is being heated to the second predetermined temperature, flattening the strip material while it is at said second predetermined temperature and first predetermined tension, heating the strip material to a third predetermined temperature, cooling said strip material at a predetermined rate, applying a second predetermined longitudinal tension to the strip material, which is less than the first longitudinal tension, while it is being heated to the third predetermined temperature and while it is being cooled, to remove stresses from the strip material, applying a third predetermined tension to the strip material, and coiling the strip material while it is being subjected to the third predetermined tension.

2. A method of continuously processing magnetic strip material comprising the steps of uncoiling the strip material, accumulating a predetermined quantity of strip material to provide and maintain a first slack loop, applying a coating of electrical insulating material to the strip material, heating the strip material to a first predetermined temperature which reacts the insulating material with the strip material to provide an adherent solid insulating film on the surfaces of the strip material, heating the strip material to a second predetermined temperature applying a first predetermined longitudinal tension to the strip material while it is being heated to the second predetermined temperature, flattening the strip material while it is at said second predetermined temperature and first predetermined tension, accumulating the strip material to provide a maintain a second slack loop which has a second longitudinal tension determined by the weight of the strip material in the loop, heating the strip material to a third predetermined temperature while the strip is in the second slack loop, cooling the strip material at a predetermined rate while the strip is in the second slack loop, accumulating the strip material to provide a third slack loop, applying a third predetermined tension to the strip material, and recoiling the strip material while it is under the third predetermined tension.

3. A method of continuously processing magnetic strip material comprising the steps of uncoiling the strip material, accumulating a predetermined quantity of strip material to provide and maintain a first slack loop, applying a coating of electrical insulating material to the strip material, radiantly heating the strip material to a first predetermined temperature which reacts the insulating material with the strip material to provide an adherent solid insulating film on the surfaces of the strip material, inductively heating the strip material to a second predetermined temperature, radiantly heating the strip material to a third predetermined temperature, applying a first predetermined longitudinal tension to the strip material at least while it is being heated to the third predetermined temperature, flattening the strip material while it is at said third predetermined temperature and first predetermined tension, accumulating the strip material to provide and maintain a second slack loop which has a second longitudinal tension determined by the weight of the strip material in the loop, radiantly heating the strip material to a fourth predetermined temperature while the strip is in the second slack loop, cooling the strip material at the fourth predetermined temperature while the strip is in the second slack loop, convection cooling the strip material at a predetermined rate to a maximum temperature of 475° C. while the strip is in the second slack loop, accumulating the strip material to provide a third slack loop, applying a third predetermined tension between 500 p.s.i. and 2000 p.s.i. to the strip material, and recoiling the strip material while it is being subjected to the third predetermined tension.

4. A method of continuously processing magnetic strip material comprising the steps of uncoiling the strip material, accumulating a predetermined quantity of strip material to provide and maintain a first slack loop, applying a coating of electrical insulating material to the strip material, heating the strip material to a first predetermined temperature between 500° C. and 550° C. which reacts the insulating material with the strip material to provide an adherent solid insulating film on the surfaces of the strip material, heating the strip material to a second predetermined temperature between 750° C. and 900° C. applying a first predetermined longitudinal tension between 300 p.s.i. and 1200 p.s.i. to the strip material while it is being heated to the second predetermined temperature, flattening the strip material while it is at said second predetermined temperature and first predetermined tension, accumulating the strip material to provide a second slack loop which has a second longitudinal tension determined by the weight of the strip material in the loop, heating the strip material to a third predetermined temperature between 800° C. and 900° C. while the strip is in the second slack loop, cooling the strip material at a predetermined rate to a maximum temperature of 475° C. while the strip is in the second slack loop, accumulating the strip material to provide a third slack loop, applying a third predetermined tension between 500 p.s.i. and 2000 p.s.i. to the strip material, and recoiling the strip material while it is under the third predetermined tension.

5. A method of continuously processing magnetic strip material comprising the steps of uncoiling the strip material, accumulating a predetermined quantity of strip material to provide and maintain a first slack loop, applying a coating of electrical insulating material to the strip material, radiantly heating the strip material to a first predetermined temperature between 700° C. and 750° C., radiantly heating the strip material to a third predetermined temperature between 750° C. and 900° C., applying a first predetermined longitudinal tension between 300 p.s.i. and 1200 p.s.i. to the strip material at least while it is being heated to the third predetermined temperature, flattening the strip material while it is at said third predetermined temperature, accumulating the strip material to a second predetermined temperature, radiantly heating the strip material to a third predetermined temperature, applying a first predetermined longitudinal tension to the strip material at least while it is being heated to the third predetermined temperature, flattening the strip material while it is at said third predetermined temperature and first predetermined tension, accumulating the strip material to provide and maintain a second slack loop which has a second longitudinal tension determined by the weight of the strip material in the loop, radiantly heating the strip material to a fourth predetermined temperature between 500° C. and 900° C. while the strip is in the second slack loop, soaking the strip material at the fourth predetermined temperature while the strip is in the second slack loop, radiantly cooling the strip material at a predetermined rate to a maximum temperature of 475° C. while the strip material is in the second slack loop, convection cooling the strip material at a predetermined rate to a maximum temperature of 60° C. following the second slack loop, accumulating the strip material to provide a third slack loop, applying a third predetermined tension between 500 p.s.i. and 2000 p.s.i. to the strip material, and recoiling the strip material while it is being subjected to the third predetermined tension.
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13. A method of continuously processing magnetic strip material comprising the steps of: uncoiling the strip material, accumulating a predetermined quantity of strip material to provide and maintain a first slack loop, applying a coating of electrical insulating material to the strip material, providing the first slack loop, heating the strip material to a first predetermined temperature, flattening the strip material while it is being heated to the first predetermined temperature, and providing a second tension, longitudinally tensioning the strip material, providing a second predetermined longitudinal tension to the strip material, which is less than the first longitudinal tension, while it is being heated to the second predetermined temperature and while it is being cooled, stress relief annealing the strip material while it is at the second predetermined temperature and second predetermined tension, applying a third predetermined tension to the strip material, and coiling the strip material while it is being subjected to the third predetermined tension.

14. The method of claim 13 including the steps of: providing a first, second, and third spaced slack loops in the strip material, providing a first tension in the strip material, which is in the range of 300–1200 p.s.i., while the strip material is between the first and second loops, applying a coating of electrical insulating material to the strip material while it is between the first and second loops, heating the strip material to a first predetermined temperature while it is between the first and second loops, and providing a second tension, longitudinally tensioning the strip material, which is in the range of 750–900°C, while the strip material is between the first and second loops, providing a second tension in the strip material while the strip material is in the second loop, which does not exceed 100 p.s.i., heating the strip material to a temperature in the range of 800–900°C while it is in the second loop, cooling the strip material at a controlled rate while the strip material is in the second loop, to remove stresses therein, providing a third predetermined tension in the strip material, following the third slack loop, and coiling the strip material while it is being subjected to the third predetermined tension.

15. The method of claim 14 including the step of: heating the strip material to a second predetermined temperature in the range of 750–900°C while the strip material is between the first and second loops, flattening the strip material while the strip material is at the second predetermined temperature, between the first and second loops, providing a second tension in the strip material while the strip material is in the second loop, which does not exceed 100 p.s.i., heating the strip material to a temperature in the range of 800–900°C while it is in the second loop, cooling the strip material at a controlled rate while the strip material is in the second loop, to remove stresses therein, providing a third predetermined tension in the strip material, following the third slack loop, and coiling the strip material while it is being subjected to the third predetermined tension.
the stress relief annealing step, of continuously grading
the strip material to provide a signal responsive to the
electrical quality of the strip material.

18. The method of claim 17, including the step of con-
trolling the magnitude of the first predetermined tension
and the magnitude of the first elevated temperature, in
response to the signal provided by the grading step.

19. The method of claim 13 wherein the step of driv-
ing the strip material at the second point is performed by
the steps of passing the strip over at least three driven
rolls, with the rolls being disposed to obtain driving fric-
tion by each substantially changing the direction of the
strip material.