

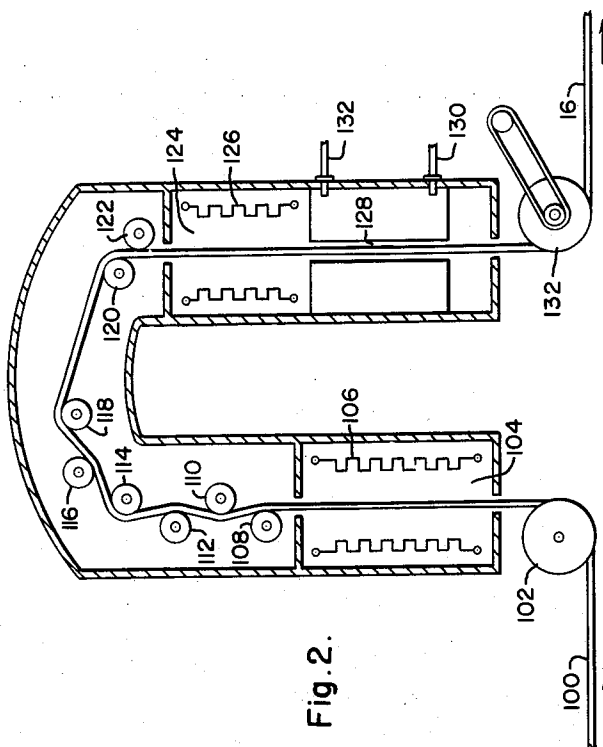
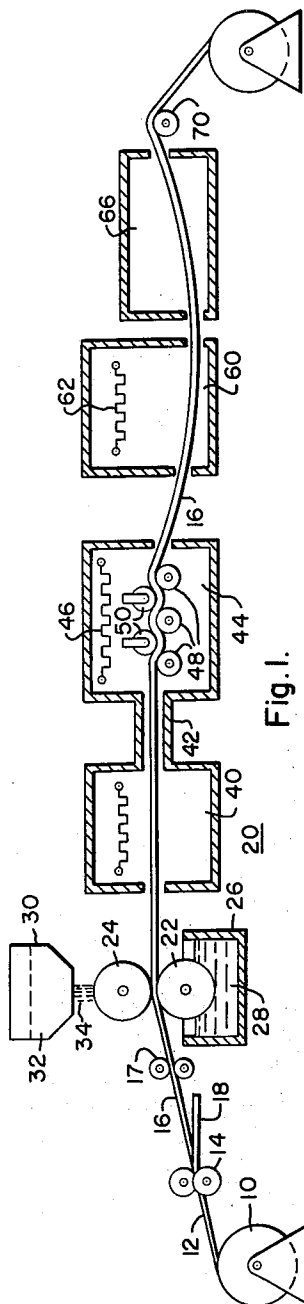
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J. G. FORD ET AL

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METHOD OF PRODUCING IMPROVED MAGNETIC STEEL STRIP

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WITNESSES:

Bernard R. Giegney
Robert C. Baird

INVENTORS

James G. Ford, Thomas J. Murrin
and John H. Bramble.
BY

BY

Frederick Shapiro
ATTORNEY.

1

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METHOD OF PRODUCING IMPROVED MAGNETIC STEEL STRIP

James G. Ford, Sharon, Pa., Thomas J. Murrin, Athens, Ga., and John H. Bramble, Brookfield, Ohio, assignors to Westinghouse Electric Corporation, East Pittsburgh, Pa., a corporation of Pennsylvania

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This invention relates to the process of working and heat-treating strips of magnetic steel in order to improve their flatness and magnetic properties.

At the present time, sheets and strips of magnetic steel are produced by cold-rolling various alloys, such as silicon steel, aluminum steel, and the like. The cold-rolled sheets or strips, when examined carefully, show varying degrees of waviness and corrugations. Irregularities in the smoothness of the sheets from point to point are evident. If such sheets and strips are cut or punched into laminations and stacked into cores, the surface irregularities result in a core that has a relatively low space factor. In some cases, the space factor may be less than 95%, that is, less than 95% of the volume comprises the magnetic steel and the balance is air space. In the manufacture of many types of transformers, the stacked laminations forming the core are compressed between plates in order to improve the space factor of the core as well as to produce a mechanically, more rigid core structure. The pressures applied by the clamping plates deform the magnetic core, thereby introducing stresses into the magnetic material which result in increased core losses and other undesirable effects.

Magnetic sheet steel commonly manufactured at the present time carries on its surface an insulating coating of some form which functions to reduce the eddy current losses of magnetic cores produced from a plurality of assembled laminations of the magnetic material. However, the insulating films ordinarily vary greatly in their dielectric properties from point to point on the magnetic sheet to which they are applied. During the processing and handling of the sheets and strips, these films may be scratched, cracked, or even caused to flake off, or otherwise disrupt from the surface of the magnetic sheets, thereby leaving areas of poor dielectric insulation. It would be highly desirable to provide on the magnetic sheets more uniform insulating films of high dielectric properties.

While the magnetic sheets and strips are usually annealed after the final cold-rolling operation in order to develop the final crystal structure and good magnetic properties, there are subsequent handling operations including coiling of strips into rolls that introduce stresses into the strips which impair the magnetic properties thereof. Other sources introduce stresses into the factory-annealed magnetic sheets and strips.

These and other defects and shortcomings in commercially manufactured magnetic steel result in magnetic steel far below its optimum magnetic characteristics. Particularly pronounced deficiencies in magnetic properties are the relatively high alternating current losses and magnetostrictive noise levels, and lower permeabilities. The alternating current losses may rise by reason of increased eddy currents due to poor insulation on the surfaces of the sheets, burrs arising during slitting which cause contact between successive or adjacent laminations, and from stresses present in the magnetic laminations either as a result of the manufacturing operations or dur-

2

ing the fabrication of cores from irregular magnetic laminations characterized by lack of flatness. Other factors which result in impaired magnetic properties not mentioned here are known to those skilled in the art.

The object of the present invention is to provide for subjecting magnetic sheet steel to a hot roller leveling treatment in combination with a subsequent soaking heat treatment in order to produce improved flatness and magnetic properties.

A further object of the invention is to provide for improving the flatness and magnetic properties of magnetic strip material by applying a reactive insulating film to magnetic strip material, hot roller leveling the coated magnetic sheet material and finally applying a soaking stress relief anneal to the magnetic strip material.

A still further object of the invention is to provide for improved magnetic strips by slitting relatively narrow strip magnetic material, coating the strip magnetic material with a film of reactive insulation producing composition, hot roller leveling the insulated strip and applying a soaking stress relief under tension below the elastic limit, and cooling the strip substantially uniformly to produce a strip having greatly improved flatness and better magnetic properties.

Other objects of the invention will, in part, be obvious and will, in part, appear hereinafter. For a better understanding of the nature and objects of the invention, reference should be had to the following detailed description and drawing in which:

Figure 1 is a schematic view, partly in section, of apparatus for carrying out the processing of the present invention; and

Fig. 2 illustrates schematically in cross section a modified form of the apparatus for practicing the invention.

Briefly, it has been discovered that considerably improved magnetic steel sheet characterized by greater flatness and enhanced magnetic properties may be obtained by hot roller leveling magnetic sheets in a temperature range of from 700° C. to 850° C. in order to impart thereto an incremental stretching sufficient to remove waviness and other irregularities without introducing longitudinal corrugations, and then soaking the strip at temperatures of from 770° C. to 850° C. for a period of time sufficient to remove previously imparted stresses while applying to the strip a longitudinal tension of from 100 to 1000 pounds per square inch and finally cooling the strip substantially uniformly to a temperature below 300° C. without subjecting the strip to any stresses other than the applied longitudinal tension during the soaking and cooling operations. Preceding the hot roller leveling, the magnetic sheets will ordinarily be slit into one or more strips of predetermined width for desired core building operations.

While the magnetic sheets, as received from the commercial manufacturer, ordinarily have present thereon an insulating coating, as mentioned previously, these coatings may not be uniform or may be defective by reason of cracking, flaking or other failure. Therefore, preceding the hot roller leveling operation and following the slitting operation, the strips are coated with a thin layer of a composition capable of reacting with the ferrous material forming the magnetic sheet while at an elevated temperature to produce an adherent solid insulating film of high magnetic properties on the surfaces of the strips. Particularly suitable coating compositions are aqueous phosphoric acid solutions. Aqueous phosphoric acid containing from 5% to 60% H_3PO_4 by weight is suitable for this purpose. The aqueous phosphoric compositions may have dissolved or suspended therein magnesium oxide or magnesium hydroxide, aluminum hydrate and other ingredients. Thus, there may be suspended finely divided mica and alumina in the phos-

phoric acid compositions. A particularly suitable coating composition will comprise from 20% to 50% H_3PO_4 and from 0.1 to 1 pound of magnesium oxide per gallon of the solution.

Referring to Fig. 1 of the drawing, there is illustrated schematically the process of the present invention and apparatus suitable for carrying it out. A coil of sheet steel, for example, silicon iron, which may comprise up to 6% silicon or aluminum iron containing up to 7% aluminum, or a ternary alloy comprising up to 7% of both silicon and aluminum with the balance being iron, is uncoiled, and the sheet 12 is passed to slitting rolls 14 which produce strips 16 and 18. Only the single strip 16 will be followed through the subsequent process, but it will be understood that two, three or more strips may be simultaneously treated in the same manner. The strip 16 passes through pairs of compression rolls 17 which reduce any edge burrs substantially to zero. Also, the strips 16 and 18 may be coiled after slitting and stored before further processing.

The strip 16 passes to a coating device 20 comprising coating rolls 22 and 24. The roll 22 dips into the pan 26 containing the coating composition 28 of which a thin film is carried on the surface of the roll 22 and is thereby imparted to the undersurface of the strip 16. A pan 30 containing a quantity of the coating composition 32 drips predetermined quantities 34 onto the upper roll 24 which applies it uniformly over the upper surface of the strip 16. The strip 16 with the applied aqueous coating on both surfaces then passes into a pre-heating furnace 40 in which it is heated to a temperature of from 700° C. to 850° C. In the furnace, a suitable atmosphere is air. If the strips are not coated or do not have any previously applied insulating film, then it may be necessary to provide a protective atmosphere, such as hydrogen, cracked ammonia or other non-carburizing atmosphere. However, an oxidizing atmosphere, such as air, has given good results with phosphoric acid treated silicon steel. The coated sheets are subjected to the high temperature for a sufficient period of time to cause a reaction to take place between the ferrous metal and the phosphoric acid solution, whereby to produce suitable phosphates and solid complexes therewith, such as silicates or aluminates. In any event, by the time the strip reaches the exit end of the furnace 40, the composition previously applied thereto has been converted into a solid insulating film which is not sticky or adherent. The hot strip then passes through a tunnel 42 into a roller leveling furnace 44. The roller leveling furnace 44 is provided with suitable heating means 46 to maintain the temperature of the strip in the range of 700° C. to 850° C. Disposed within the furnace 44 are a series of lower rolls 48 and adjustable upper rolls 50 which are disposed intermediate to the lower rolls 48. The upper rolls 50 are mounted on suitable vertically adjustable bearings that they may be brought into closer or further separation from the rolls 48. Ordinarily, the rolls 50 will be so disposed that the lowermost surface is substantially below the uppermost surface of the rolls 48, whereby the strip 16 passing therebetween is first flexed downwardly over the first roll 48 and then upwardly past the first upper roll 50 and thence down and up over successive rolls 48 and 50. The rolls 48 and 50 may be free running though usually it will be desired to drive them externally. It may be desirable to so operate the succeeding rolls that the surfaces move slightly faster than the preceding roll so that the hot strip is subjected to an incremental stretching, in addition to the flexing. A total incremental stretching of from 0.1% to 2% of the length of the strip should be effected by the time the strip passes over the last roll 48. The stretching will remove waviness and other irregularities but should not be such as to introduce longitudinal corrugations to the strip or deleteriously affect the grain orientation of the strip.

After the hot roller leveling, the strip is passed into a soaking furnace 60 provided with suitable heating means 62 for uniformly heating the strip 16 to a temperature of from 770° C. to 850° C. In the furnace 60, the strip 16 is subjected to a longitudinal tension of from 100 to 1000 pounds per square inch, an optimum value being from 400 to 600 p.s.i. The soaking heat treatment is applied for a period of time sufficient to remove previously imparted stresses, such, for example, as those introduced during the roller leveling treatment. At the highest temperature and for thin sheets of the order of 8 mils, a period of time of as short as 5 seconds may be adequate. However, the most certain stress relief may require from 1 to 2 minutes in the soaking furnace thereof. Periods of up to 10 minutes may be employed, if desired. Prolonged heating in the soaking furnace does not produce adverse results.

After leaving the soaking furnace, the strip 16 is cooled substantially uniformly to a temperature of about 300° C. Exposing the strip emerging from the soaking furnace to still air, care being taken to prevent any strong drafts being present, has been effective. However, for best results, the strip may be passed through a cooling chamber 66 wherein uniform radiant cooling, free from irregularities in air circulation, may be effected. It is highly desirable that there be a substantially uniform temperature along any transverse line on the strip such that between the sheet edge and the center the temperature difference does not exceed 10° and is preferably only several degrees. Uniform cooling will result in less thermal stresses being imparted to the strip. Particular attention should be provided to the processing so that the strip 16 from the time it leaves the roller leveling stage until it reaches a temperature of about 300° C. is not stressed beyond its elastic limit. Particularly good results have been obtained when the strip 16 is suspended as a catenary from the last roll in the roller leveling furnace to a roll 70 at the exit end of the cooling chamber 66. Such catenary suspension of the strip helps apply the predetermined tolerable longitudinal tension without introducing any other stress. Once past the supporting roll 70, the cooled strip may be processed by coiling or punching, or cutting into magnetic laminations, as desired.

During the coating and heat treatments in the pre-heating furnace 40 and the soaking furnace 60, any burrs or flattened burrs arising from the slitting operation are removed and the slit edge is reacted with the coating composition being thereby converted into an insulated portion. Any uncoated spaces in the previously applied coating or any cracks have been filled with the applied coating composition and have also been reinsulated. Tests made on the insulating coatings produced by following the complete process of the present invention have indicated a marked increase in the dielectric insulation of the surface film, in addition to a marked improvement in the uniformity of insulation from spot to spot on the strips.

Very substantial improvements in flatness of the strips have been secured by the practice of the present invention. Stacked laminations produced from strips processed, as disclosed herein, have an extremely high space factor of up to 98%. The laminations are so flat that clamping means applied under considerable pressure give very little increase in space factor and further do not cause any significant increase in losses due to stresses arising from flattening of wavy portions or bulging spots. A particularly significant improvement in magnetostriction has been attained by the practice of the present invention. Not only is the average magnetostriction reduced, but the variations in magnetostriction from lamination to lamination cut from such processed strips is more uniform.

Particularly good results have been obtained in the practice of the invention in processing silicon iron sheets

of a thickness of from 8 to 25 mils. Exceptional results have been obtained for 3% to 3½% silicon steel sheets of a thickness of from 10 to 14 mils. These sheets have been processed by slitting them into strips of suitable widths. The strips were then coated with a composition containing, for example, 40% H_3PO_4 and about ¼ pound of magnesium oxide per gallon of the solution. This composition was applied in an amount to coat 1000 square feet of the surface with one gallon of the composition. The strips were then preheated to a temperature of from between 800° C. and 825° C. in air for about 1 minute and then roller leveling the sheets while at this temperature to produce an incremental stretching in the lengthwise direction of approximately 0.5%. The roller leveling sheets were suspended as a catenary and soaked at a temperature of from 790° C. to 825° C. for 1 minute. The strips were then cooled to 300° C. while suspended as a catenary from the roller leveling operation to the point at which the temperature of the sheet reached 300° C. A tension of 500 p.s.i. was applied longitudinally of the strip while it was passing through the soaking and cooling operations. Very substantial improvements in waviness and magnetic properties including lowered core losses and reduced magnetostriction were obtained as compared to the original untreated sheets.

Referring to Fig. 2 of the drawing, there is illustrated a modified form of apparatus for practicing the invention. The strip 100, which may or may not be coated with the phosphoric acid solution, passes over a roll 102 and thence vertically into a chamber 104 provided with heating elements 106 to produce a temperature of from 700° C. to 850° C. Thence, the heated strip passes over the successive alternate rollers 108, 110, 112, 114, 116, 118, whereby it is subjected to incremental stretching of from 0.1% to 2% of its length. The strip then passes over rolls 120 and 122 into a soaking or normalizing zone 124 provided with heating elements 126. Thereafter, the strip passes downwardly through a cooling chamber 128 which is maintained at uniform low temperatures, whereby the strip is cooled rapidly but uniformly to temperatures of the order of 300° C. The cooling chamber 128 is provided with a suitable cooling fluid by means of inlets 130 and exit outlets 132 to remove the heat from the strip. A driven pulley 132 at the exit of the chamber provides for imparting a longitudinal tension of from 100 to 2000 p.s.i. between the rolls 120, 122 and the roller 132. The treated strip 16, passing from the roller 132, may be then coiled or otherwise processed.

It will be understood that other forms of apparatus may be employed for practicing the present invention. However, it is critical for the purpose of the present invention that the ferrous magnetic steel be subjected to a hot roller leveling in order to provide the incremental stretching which is followed by a soaking heating under a tension below the elastic limit, namely from 100 to 2000 p.s.i., and then cooled uniformly whereby all previously imparted stresses are substantially removed.

It will be understood that the above detailed description and drawing are illustrative only.

We claim as our invention:

1. In the process of improving the flatness and the magnetic properties of a sheet of ferrous magnetic steel, the steps comprising preheating the sheet to a temperature of from 700° C. to 850° C., hot roller leveling the sheet while it is at the temperature in order to impart thereto an incremental stretching to remove waviness and other irregularities without introducing longitudinal corrugations to the sheet, soaking the sheet at a temperature of from 770° C. to 850° C. following the hot roller leveling for a period of time to remove previously imparted stresses from the sheet while applying a longitudinal tension of from 100 to 1000 p.s.i. and cooling the sheet substantially uniformly to a temperature of below 300° C. without subjecting the sheet to any stresses other than the

applied longitudinal tension during the soaking and cooling operations.

2. In the process of improving the flatness and the magnetic properties of a sheet of ferrous magnetic steel, the steps comprising preheating the sheet to a temperature of from 700° C. to 850° C., hot roller leveling the sheet while it is at the temperature in order to impart thereto an incremental stretching to remove waviness and other irregularities without introducing longitudinal corrugations to the sheet, soaking the sheet at a temperature of from 770° C. to 850° C. following the hot roller leveling for a period of time to remove previously imparted stresses from the sheet while applying a longitudinal tension of from 100 to 1000 p.s.i. and cooling the sheet substantially uniformly to a temperature of below 300° C. without subjecting the sheet to any stresses other than the applied longitudinal tension during the soaking and cooling operations, the sheet being freely suspended as a catenary from a point immediately following the roller leveling to the point at which its temperature is below about 300° C.

3. In the process of improving the flatness and the magnetic properties of a sheet of ferrous magnetic steel, the steps comprising applying a thin uniform coating of an aqueous phosphoric acid solution to the sheet, preheating the sheet to a temperature of from 700° C. to 850° C., the preheating causing the applied aqueous phosphoric acid reacting with the ferrous magnetic steel to produce an adherent solid insulating film on the surface thereof, hot roller leveling the sheet while it is at the temperature in order to impart thereto an incremental stretching of from 0.1% to 2% of the length to remove waviness and other irregularities without introducing longitudinal corrugations to the sheet, soaking the sheet at a temperature of from 770° C. to 850° C. following the hot roller leveling for a period of time to remove previously imparted stresses from the sheet while applying a longitudinal tension of from 100 to 1000 p.s.i. and cooling the sheet substantially uniformly to a temperature of below 300° C. without subjecting the sheet to any stresses other than the applied longitudinal tension during the soaking and cooling operations.

4. In the process of improving the flatness and the magnetic properties of a sheet of ferrous magnetic steel, the steps comprising slitting the sheet into strips, applying a thin uniform coating of an aqueous phosphoric acid solution to the surface of the strips, heating the strips to a temperature of from 700° C. to 850° C. to cause the aqueous phosphoric acid solution to react with the ferrous magnetic sheet surface to produce an adherent solid insulating film thereon, hot roller leveling the strips while they are maintained at a temperature of from 700° C. to 850° C. to impart thereto an incremental stretching of from 0.1% to 2% of the length thereof in order to remove waviness and other irregularities without introducing longitudinal corrugations, soaking the strips at a temperature of from 770° C. to 850° C. following the hot roller leveling for a period of at least 5 seconds to remove previously imparted stresses while applying a longitudinal tension of from 100 to 1000 p.s.i. and cooling the sheet substantially uniformly to a temperature below about 300° C. so that the temperature from the edge to the center at any transverse line of a strip does not vary by more than a few degrees, the soaking and cooling being effected without subjecting the strips to any stresses other than the applied longitudinal tension, the heat treatments and roller leveling being conducted in air and producing relatively flat strips with good insulating films thereon, any burrs on the strip edges produced during slitting being reduced and coated, and stresses in the strips being relieved so that the magnetic properties are improved and magnetostriction is reduced.

5. In the process of improving the flatness and the magnetic properties of a sheet of ferrous magnetic steel, the steps comprising slitting the sheet into strips, applying to

the surface of the strips a thin uniform coating of an aqueous phosphoric acid solution comprising essentially from 20% to 50% of H_3PO_4 and from 0.1 to 1 pound of magnesium oxide per gallon of solution, heating the strips to a temperature of from 700° C. to 850° C. to cause the aqueous phosphoric acid solution to react with the ferrous magnetic sheet surface to produce an adherent solid insulating film thereon, hot roller leveling the strips while they are maintained at a temperature of from 700° C. to 850° C. to impart thereto an incremental stretching of from 0.1% to 2% of the length thereof in order to remove waviness and other irregularities without introducing longitudinal corrugations, soaking the strips at a temperature of from 770° C. to 850° C. following the hot roller leveling for a period of at least 5 seconds to remove previously imparted stresses while applying a longitudinal tension of from 100 to 1000 p.s.i. and cooling the sheet substantially uniformly to a temperature below about 300° C. so that the temperature from the edge to the center at any transverse line of a strip does not vary by more than a few degrees, the soaking and cooling being effected without subjecting the strips to any stresses

other than the applied longitudinal tension, the heat treatments and roller leveling being conducted in air and producing relatively flat strips with good insulating films thereon, any burrs on the strip edges produced during slitting being oxidized, and stresses in the strips being relieved so that the magnetic properties are improved and magnetostriction is reduced.

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