May 26, 1936. R. E. RENO, JR 2,042,124

ELECTRIC SHEET

Filed March 5, 1934 2 Sheets-Sheet 1

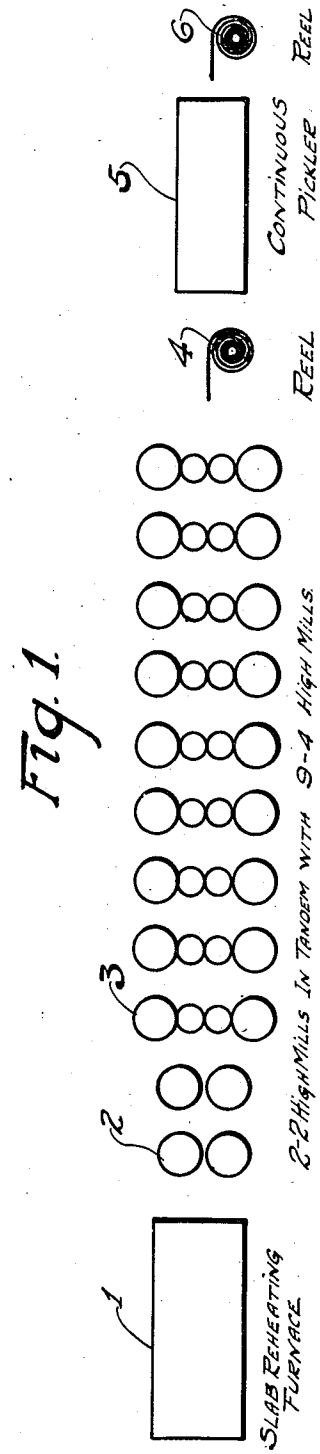


Fig. 1.

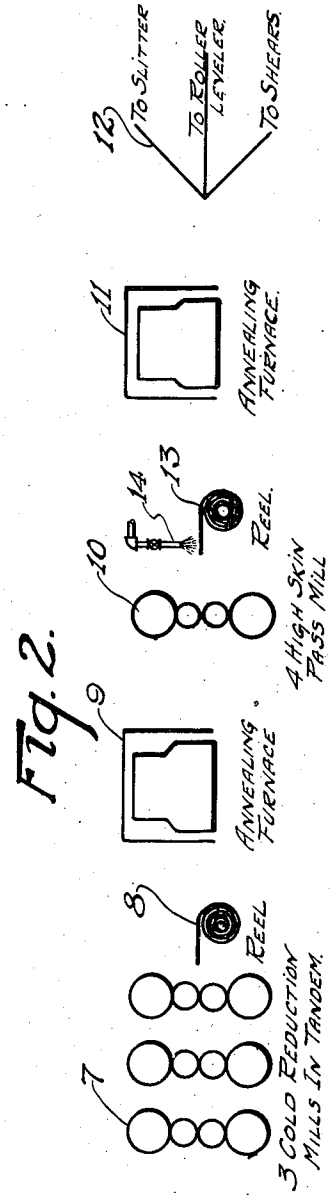


Fig. 2.

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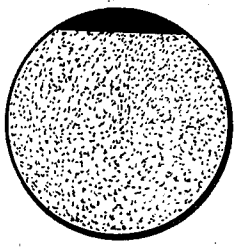
Attorney.

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ELECTRIC SHEET

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Fig. 3.



24 gauge
1.00% Si
HR-P-CR-A
CR 1% A
Coreless 2.37W

Fig. 4.



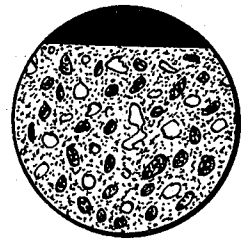
24 gauge
1% Si
HR-P-CR-A
CR-3%-A
Coreless 1.72

Fig. 5.



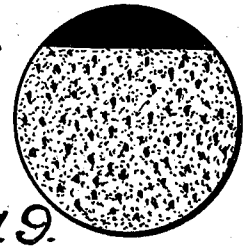
24 gauge
1% Si
HR-P-CR-A
CR-5%-A
Coreless 1.72

Fig. 6.



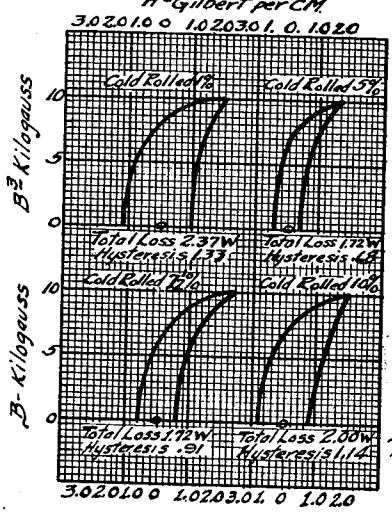
24 gauge
1% Si
HR-P-CR-A
CR 7½% A
Coreless 1.72

Fig. 7.



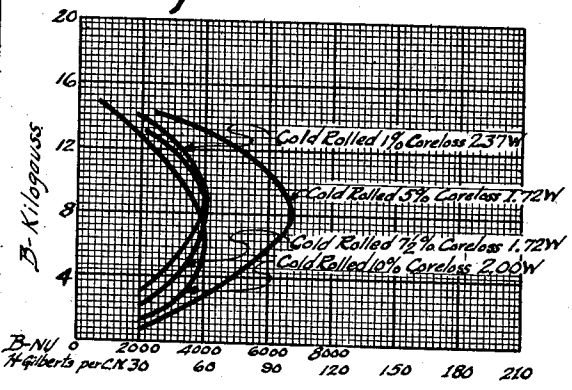
24 gauge
1% Si
HR-P-CR-A
CR 10% -A
Coreless 2.00

Fig. 8.



Graph of 1% Silicon steel Showing effect of varying reductions in 2nd cold rolling on hysteresis, and Watt Loss.

Fig. 9.



Graph of 1% Silicon Steel Showing effect of varying reductions in 2nd cold rolling on permeability.

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Patented May 26, 1936 2,042,124

UNITED STATES PATENT OFFICE

2,042,124

ELECTRIC SHEET

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Application March 5, 1934, Serial No. 714,295

2 Claims. (Cl. 148—12)

This invention relates to a process for the manufacture of silicon steel for use in the manufacture of electrical apparatus, and the present application is a continuation in part of an application serially numbered 634,535 filed September 23, 1932.

It is a primary object of the invention to provide an improved process for working silicon steels in coil form that will be productive of the desirable electrical properties.

The invention further provides for the making of silicon steel in the shape of coiled sheet strips by continuous process whereby it is most economically produced and the quality of the product is definitely controlled.

The production of silicon steel in coils is desirable both from the manufacturer's viewpoint and for the consumer's use. Production costs are quite an item in the production of electrical motors and transformers, and coils lend themselves to speeded production since they can be automatically fed to the press and also reduce the end scrap resulting from the use of sheets. The steel manufacturer reduces the cost of manufacture and improves the quality of the product, and some of the advantages to be expected are uniformity of gage, increased stacking factor, due to smoother surface and uniform punching quality.

Further advantages of the use of coils is the handling in shipping and it may be slit to narrow widths. Also, where it is desired to produce a core plated material, it can be readily varnished by passing the coiled material through a solution of insulating material.

The improvement of the electrical properties of steel by the addition of silicon has been well established in the art and it is also well known that the watt loss of the silicon steel is essentially dependent upon the kind of treatment which the material undergoes. It is also recognized that the size of the grain structure of the material is of greatest influence on the electrical properties and is dependent upon the treatment to which the material is subjected.

The manufacture of silicon steel for use in laminated core structures has not been successful in coil form because of characteristics inherent to cold reduction. Excessive strain set up in reducing hot bands from about .093 to .063 inch to the light gage, .025 to .014 inch, make it impossible to secure the necessary electrical properties by the regular temperature time cycles used for sheets rolled on the conventional two-high hot mill.

The present invention is for a process of manufacturing silicon steel in coils by initially hot rolling and subsequently cold rolling the strip with proper heat treatment after the several rolling operations to obtain improved electrical properties of increased permeability and lower hysteresis while maintaining a low watt loss incidental to the silicon content.

The process and the properties of the finished material are more clearly shown in connection with the accompanying drawings constituting a part hereof in which like reference characters designate like parts and in which:

Figure 1 is a view diagrammatically illustrating the apparatus for heating, hot rolling and pickling the coil by continuous process;

Figure 2 a similar view diagrammatically illustrating the cold rolling and annealing steps following the hot rolling operation;

Figs. 3 to 7 inclusive are diagrammatic views illustrating the grain structure as effected by the working of the material, these views being reproductions of micrographs;

Figure 8 a view graphically illustrating the effects of working the metal on hysteresis and watt loss, and;

Figure 9 is a view graphically showing the effect of the working of the metal on permeability.

Silicon steel in ingot form having the required silicon content is first heated in soaking pits and the ingot is then rolled into slabs of the width of the finished coil and of a thickness and length which will give the desired weight in the finished coil. The slab is then placed in the slab reheating furnace designated by the reference numeral 1, in Figure 1, or rolled direct from the ingot without reheating, and is then passed through a series of two-high, four-high mills in tandem designated by the reference numerals 2 and 3 respectively, there being a sufficient number of mills through which the slab passes to reduce the metal to a coil of 0.100 inch or less in thickness. As the coil passes from the four-high mills, it is reeled into a coil as designated by the reference numeral 4 and is then passed through a pickling bath 5 to remove the scale produced by the hot rolling, and is again coiled as shown at 6. While pickling is desirable for the cold reduction mills, it can be eliminated particularly in gages heavier than .021.

The pickled coil is then subjected to the first cold roll reduction by passing it through a series of four-high mills designated by the reference numeral 7 there being three shown in Figure 2

of the drawings, and in these mills the coil is rolled to a thickness within a few percent of the desired gage and is again coiled as shown at 8.

The coil is then passed through an annealing furnace designated by the reference numeral 9 to recrystallize the grain changing them from a striated to a very fine rounded structure such as is illustrated in Figure 3. The annealed coil is then recold rolled in a four-high mill designated by the reference numeral 10 in which it is reduced to the desired gage by a skin pass, and the final cold roll in the mill 10 sets up the strain which is productive of a desirable grain size upon subsequent annealing in the furnace 11 after which it is routed as indicated either to a slitting machine, a roll leveller, or shears 12 as is graphically illustrated at the extreme right of Figure 2. The metal when subjected to the final skin pass in mill 10 is coiled as shown by the reference numeral 13.

The final anneal in the furnace 11 causes grain growth changing the very fine grain to very large grains and producing a steel of low hysteresis and high permeability.

A nozzle 14 may be disposed between the mill 10 and coil 13 for coating the coil with some refractory material, such as lime, which will prevent sticking regardless of the temperature of the final anneal.

The effect of the working of the metal by the process hereinbefore described is graphically and diagrammatically illustrated in Figures 3 to 9 inclusive of the drawings for a silicon steel having a 1% silicon content, it being understood that the diagrams and graphs are illustrative only and that my method may be usefully employed in the fabrication of electrical sheets of lower or higher silicon content.

Silicon steel with a silicon content as low as 1% when given a one-percent reduction in the second cold-roll mill 10 and subsequently annealed in the furnace 11 possesses a very fine grain structure graphically shown in Figure 3 of the drawings with a high core loss of 2.371. The same steel, when reduced three percent in the second cold-roll and subsequently annealed, shows a coarser grain size graphically shown in Figure 4 of the drawings with a lower core loss. The metal when reduced five percent in the second cold-roll operation and subsequently annealed is productive of a maximum grain size shown in Figure 5 of the drawings. In Figure 6, the grain structure is reduced as the result of excessive strain set up by the second or final cold-roll with a seven and one-half percent reduction, and as shown in Figure 7 a ten percent reduction in the second cold-roll produces a fine grain size after annealing with consequent greater core loss.

The effect of the varying reductions and consequent varying grain size on the electrical properties of the steel is graphically shown in Figures 8 and 9 of the drawings. The curves in Figure 8 illustrate the varying reductions in the second cold-roll on hysteresis and watt loss. The curve under the heading "Cold rolled 1%" showing poor electrical properties with a total loss of 2.37 watts and hysteresis 1.33. The three-percent reduction is omitted and the five percent reduction shows a total loss of 1.72 watts and hysteresis .68. Seven and one-half percent reduction is productive of favorable properties with a watt loss the same as produced by the five percent reduction while ten percent reduction again produces high losses.

While the three, five and seven and one-half percent reductions in the second cold-roll produce substantially the same core loss for different grain sizes shown in Figures 4, 5 and 6, the hysteresis is shown in Figure 8 to be lowest for the maximum grain size which is the result of a five percent reduction as shown in Figure 5, and Figure 9 graphically shows that the maximum grain size of Figure 5 produces maximum permeability while the metal subjected to the three and seven and one-half percent reductions have substantially the same permeability as the one and ten percent reductions.

I have found that the critical diminution in cross-section, in the critical or final cold rolling of the strip for producing maximum grain growth upon final annealing, varies with the silicon content of the steel. For example, steels with a silicon content of from 2% to 3% will produce maximum grain growth when the critical or final cold rolling after annealing effects a reduction of no less than 1% and no more than 3%, and higher silicon content of from 3% to 5% will produce maximum grain growth when the critical or final cold rolling effects a reduction of no less than ½% and no more than 1½%. Thus for the commercial grades of electrical sheets or strip having a silicon content from 1% to 5% the critical cold rolling range after annealing will vary between ½% to 7½% reduction. The critical cold rolling varies inversely with the silicon content.

From the foregoing illustrations it is evident that grain size produced by the strain of cold rolling is the most important factor in producing electrical steels of desirable electrical properties. By means of the initial hot reduction and the subsequent cold reductions, which latter set up the strain that upon final annealing produce the large grain, an electrical steel of low or high silicon content may be produced without the brittle properties incident to metals fabricated in accordance with prior art methods of treatment.

The steel temperature for annealing the sheet after the first and second cold rolling varies also with the silicon content; the temperature varying from 1200 to 1400° F. for the first anneal and from 1200 to 1750° F. in the second anneal; the temperature being proportional to the silicon content, the highest temperature with the highest silicon content.

The ability to substantially reduce the metal to the desirable gage by cold rolling before the critical cold rolling step lends the process to the fabrication of silicon steel in coil form and the employment of the four-high mills permits its manufacture by continuous process. The first annealing furnace 9 through which the coil is passed after the first cold rolling in the mills 7 may be an open fired furnace equipped with reels permitting continuous annealing, and the furnace 11 a closed or muffle furnace to prevent oxidation and the formation of scale.

While the process herein above described features the employment of two-high, four-high mills on account of the relatively large reductions for the wide commercial sheets or coils, it is apparent that the conventional two-high mill may be utilized for narrow strips or coils.

The continuous process for making coiled silicon steels could be carried out by the employment of two-high mills exclusively even for the wide strip when the silicon content is so high as to require very little strain in the skin pass or final cold-roll.

claim:

1. The method of making steel containing a substantial amount of silicon not exceeding 5% to produce the most favorable electrical properties with minimum brittleness, which consists of mechanically working an ingot of steel of the desired silicon content to reduce it to a thickness of approximately 0.1 inch, passing the steel through a pickling solution to remove the scale, reducing the steel by cold working, without intermediate heat treatment, to within ½% to 7½% of the final gage, the percentage varying inversely as the silicon content to produce maximum grain growth by annealing after final cold working and being within ½% to 1½% for 3% to 5% silicon content and 1% to 3% for 2% to 3% silicon content, then heating the steel to no less than 1200° F. to remove all strain, then cold working the steel to final gage by a single reduction step, and re-annealing the finished steel at a temperature from 1200° F. to 1750° F., the temperature being proportional to the silicon content, the higher the silicon content, the higher the temperature.

2. The method of making steel containing a substantial amount of silicon not exceeding 5% to produce the most favorable electrical properties with minimum brittleness, which consists of reducing an ingot of the desired silicon content by continuous hot rolling to approximately 0.1 inch to coil form, extending the coiled sheet and passing it through a pickling solution to remove the scale, reducing the steel by cold rolling without intermediate heat treatment to within ½% to 7½% of the final gage, the percentage varying inversely as the silicon content to produce maximum grain growth by annealing after final cold rolling and being within ½% to 1½% for 3% to 5% silicon content and 1% to 3% for 2% to 3% silicon content, then heating the coil to no less than 1200° F. to remove all strain, then cold rolling to final gage by a single reduction pass, and re-annealing the finished sheet or strip at a temperature from 1200° F. to 1750° F., the temperature being proportional to the silicon content, the higher the silicon content, the higher the temperature.

ROBERT E. RENO, JR.