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PROCESS OF PRODUCING SILICON STEEL LAMINATIONS

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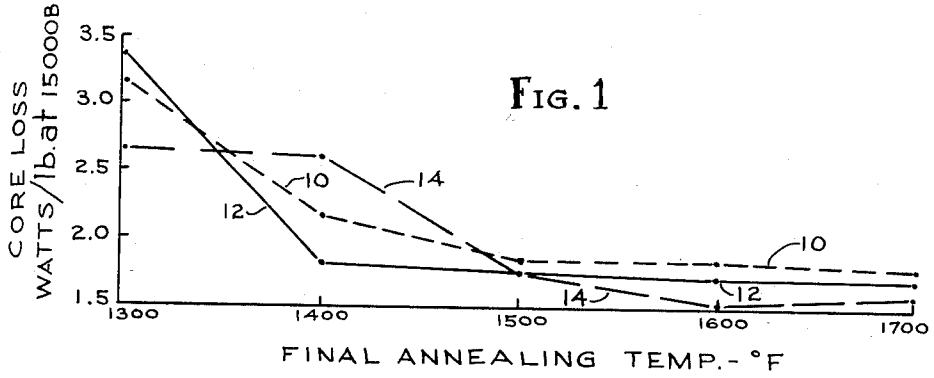


FIG. 1

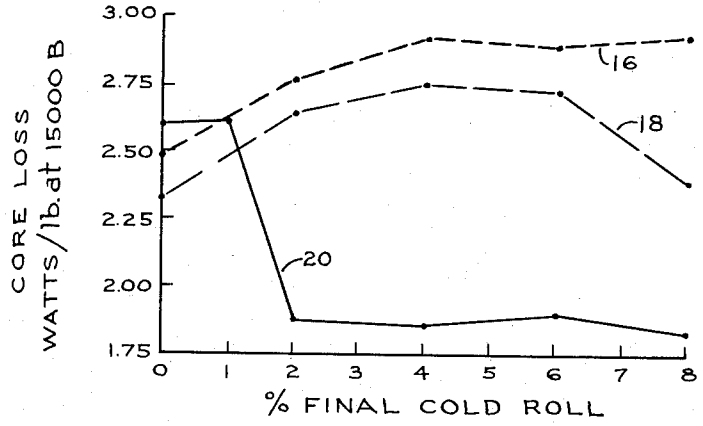


FIG. 2

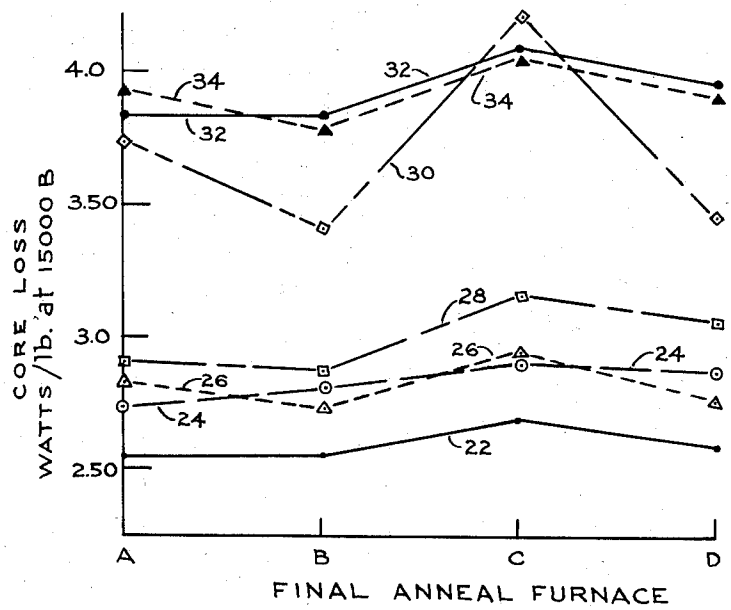


FIG. 3

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PROCESS OF PRODUCING SILICON STEEL LAMINATIONS

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4 Claims. (Cl. 148—113)

This invention relates to magnetic material and in particular to the process of producing silicon steel laminations and core components for electrical applications.

In accordance with prior practices it has been customary to provide various and different grades of silicon steel for electrical apparatus based on specified or anticipated core loss values which represent energy loss when a core of such silicon steel is subjected to an alternating current magnetizing force at a specified frequency and density of flux. Heretofore the steel manufacturer has produced and made available to the electrical apparatus manufacturer silicon steel having a silicon content ranging from about 0.25% to 3.50%. Core loss values have in the past been associated with the particular grade of silicon steel and the silicon content thereof.

Thus, for each grade of silicon steel there is a definite range of silicon content. In practice, the commercial grade having a low silicon content is usually classified as having relatively high core loss values whereas the grades having the higher silicon content are usually classified as having progressively lower core loss values as the silicon content is increased within maximum practical manufacturing limitations.

In producing these general purpose grades of silicon steel it has become the customary practice of the steel manufacturer to furnish to the electrical manufacturer material processed according to one of the following general practices:

1. In the form of sheets, hot rolled to gauge, and annealed to maximum guaranteed core loss values;

2. In the form of sheets, hot rolled to gauge, unannealed and without guaranteed core loss values, but with expected loss values after the annealing of laminations by the electrical manufacturer;

3. In the form of strip, processed by a series of two or more cold rolling and heat treatment cycles and furnished to the electrical manufacturer with guaranteed core loss values ;

4. In the form of strip, cold reduced at least 65% to gauge, unannealed and without guaranteed core loss values, but with expected core loss values after the annealing of laminations therefrom by the electrical manufacturer; and

5. In the form of strip, cold reduced at least 65%, semi-processed by heat treatment, and without guaranteed core loss values, but with expected core loss values after the annealing of laminations therefrom by the customer.

The steels identified in items 1 and 2 given hereinbefore shall hereafter be referred to as conventional hot rolled grades of silicon steel sheet whereas the silicon steel identified in items 3, 4 and 5 will be referred to as conventional cold reduced grades of silicon steel strip.

In addition to associating core loss values with the silicon content of the steel it has also become the practice to associate the permeability of the steel at different flux densities and the maximum flux density capacity (commonly referred to as the intrinsic saturation value) of the steel with the silicon content.

As is well known, in the design and manufacture of electrical apparatus in which energy is transferred through the medium of electromotive lines of force induced in steel core members, there are three primary magnetic characteristics of the steel which are commonly taken into consideration. Such characteristics are the core loss values, the permeability at operating flux densities and the saturation values.

Because the resistivity of steel increases markedly with increasing silicon content, the eddy component of core loss is reduced noticeably with increasing silicon content. Also the hysteresis component of core loss is reduced somewhat with increasing silicon content because it is believed that silicon has a favorable influence on the objectionable impurities of the steel, particularly such impurities as carbon and oxygen. In view of this it is well known that permeability becomes higher with increasing silicon content. However, it is also common knowledge that the intrinsic saturation of a silicon steel decreases with increasing silicon content. Thus, the grades of silicon steel having the higher silicon content have low energy losses and high permeability but fail to provide opportunities for designing electrical appaartus to operate at the higher values of intrinsic saturation. Conversely, the grades of silicon steel having the lower silicon content provide the opporunity for designing electrical apparatus to operate at the higher values of intrinsic saturation but at the same time afford higher energy losses and lower permeability.

In utilizing the silicon steel, the designer and manufacturer of electrical apparatus must also consider the mechanical properties of the steel as well as the magnetic properties. Thus the steel should have a surface and other physical characteristics which will make it possible to obtain a maximum of life of the dies used in punching or stamping laminations from the silicon steel. Further, the silicon steel should have a high degree of flatness to permit the production of laminations free from warpage. The surface of the steel and consequently the laminations formed therefrom should also be relatively smooth in order to promote a high space factor when the laminations are stacked in cores. Further, the steel should be capable of being utilized in coil form, the strip forming the coil having a continuous length of hundreds of feet to permit the automatic feeding of the strip to punch presses for forming the laminations. In addition, the steel strip should also be free from non-uniform or excessive internal strains which might cause distortion of the laminations punched therefrom.

While the desirability of these characteristics has been known for some time, it has been impossible to produce such characteristics simultaneously with the expected magnetic properties referred to hereinbefore when the silicon steel laminations were produced by the prior art methods. For example, hot rolled silicon steel sheets have in the past had good magnetic characteristics but failed to satisfy the electrical manufacturers' desire for mechanical convenience and economy associated with cold reduced strip. Similarly, conventional prior art methods of cold reducing silicon steel strip satisfies the condition of mechanical convenience but without providing a magnetic quality equivalent to that of hot rolled sheets of the same silicon content. Hence products produced by the prior art methods of cold reducing have higher energy losses at operating densities, lower permeabilities at nearly all densities and generally require greater magnetizing force at operating densities than is required for steels of equivalent silicon content made according to the invention to be described.

In addition conventional methods of producing cold reduced silicon steel strip are apparently more sensitive to variations in the control of the final annealing operation

given by the electrical manufacturer to punched laminations. Moreover, conventional methods of producing cold reduced silicon steel strip require more temperature and time at temperature for laminations produced therefrom during the final annealing operation. This latter factor is especially detrimental because of the increase of annealing cost with an increase in temperature and because the higher temperatures which are required result in excessive sticking of lamination assemblies. Further, it has been found that in general the cold reduced silicon steels produced heretofore either are (1) relatively soft steel with good low density permeability but extremely poor punching or stamping properties, or (2) if the steel has fair punching properties, then the steel usually has erratic variations in low density permeability.

An object of this invention is to provide for producing cold rolled silicon steel laminations having improved magnetic characteristics as measured by energy loss, normal permeability at all flux densities and values of magnetizing force associated with operating flux densities.

Another object of this invention is to provide a simplified process of producing laminations of a general purpose electrical silicon steel having a lower energy loss and greater permeability at all flux densities through 15,000 B than corresponding magnetic characteristics associated with conventional grades of cold reduced silicon steel of equivalent gauge and silicon content produced by known processes.

Another object of this invention is to provide a simplified process of producing laminations of a general purpose electrical silicon steel having magnetic characteristics at least equal to those obtained with laminations of hot rolled sheets of silicon steel of equivalent gauge and silicon content as produced by known methods.

A further object of this invention is to provide for reducing the annealing steps in the production of silicon steel laminations whereby improved magnetic characteristics are obtained for the laminations.

Other objects of this invention will become apparent from the following description when taken in conjunction with the accompanying drawing in which:

Figure 1 is a graph, the curves of which illustrate the effect of normalizing treatment on the "with grain" core losses of silicon steel laminations produced in accordance with this invention;

Figure 2 is a graph, the curves of which illustrate the effect of final annealing temperature on the "with grain" core losses of silicon steel laminations produced in accordance with this invention; and

Figure 3 is a graph, the curves of which illustrate the substantially constant core loss values of laminations produced in accordance with the teachings of this invention as compared with laminations of the same composition produced by prior art methods, representative laminations of each group being subjected to four different and independent final annealing treatments.

In practicing the present invention, the steel can be melted by ordinary commercial open-hearth or electric furnace practice and preferably comprises by weight:

Silicon	.25 to 3.50%.
Manganese	.20 to .40%.
Aluminum	.0 to .60%.
Phosphorous	.05% maximum.
Sulphur	.03% maximum.
Carbon	.05% maximum.

with the balance iron and the usual impurities in the usual amounts. It is preferred that the carbon content be maintained at not more than .03% to .05% maximum.

The ingot having the composition given is first reduced to a slab or strip by hot rolling to an intermediate gauge of between 0.07 and .125 inch after which it is pickled to remove scale. The pickled strip is then cold rolled to an intermediate gauge within 2 to 8% of the final gauge desired. Thereafter the steel strip is subjected to a normalizing treatment in a reducing atmosphere such as cracked ammonia having a ratio of air to gas of 7 to 1 up to 9 to 1 at a temperature within the range of 1500 to 1825° F. for a time ranging from 3 to 8 minutes depending upon the gauge of the strip. The normalizing treatment described is effective to remove the prior plastic deformation and to completely recrystallize the fragmented grains of the cold rolled steel to produce a uniform equiaxed grain structure. In addition, the normalizing treatment also effects some degree of decarburization.

With the steel in this condition, it is again subjected to a cold reducing operation of from 2 to 8% to effectively reduce the strip to final gauge. Such cold reduction strains the steel and conditions it for subsequent magnetic response upon final annealing of the laminations. The reduction, however, is insufficient to render the steel strip so brittle as to interfere with the shipping of the steel strip in coil form to the fabricator. Instead, the final cold reduction has the advantages of (1) inducing a critical and uniform strain which renders the steel susceptible to abnormal grain growth when reannealed, (2) the work hardening effect of such a reduction improves the punchability of the steel, and (3) serves as a flattening operation.

In accordance with this invention the steel strip in coil form as produced directly from the last cold reduction just described, is shipped to the fabricator in coil form without any further annealing. The strip is then punched, stamped or wound by the fabricator into laminations of any predetermined shape and size depending upon the ultimate use of the laminations and the design of the apparatus in which the laminations are to be used.

In order to develop and stabilize the maximum magnetic properties of the laminations so formed, the laminations are then annealed at a temperature of not less than about 1450° F. and preferably at a temperature within the range of 1450° F. to 1600° F. in a prepared atmosphere having a decarburizing and slightly oxidizing potential such as line hydrogen or a cracked natural gas having an air to gas ratio of 6½ to 1 or 7½ to 1. The time of anneal at the temperature given will vary depending upon the size of the load, it being also understood that the time at which the load is at temperature varies inversely as the temperature increases or decreases. In practice it is found that for best results the laminations should be subjected to the annealing temperature for from ½ to 2 hours after all parts of the load have reached the annealing temperature. Thereafter the load may be furnace cooled to about room temperature or cooled in the furnace to a temperature in the range of 700 to 800° F., at which temperature the load of laminations is removed from the furnace.

As illustrative of the effect of the final annealing temperature on the watt loss of cores formed of silicon steel laminations having a thickness of 0.025 inch processed in accordance with this invention and at different normalizing temperatures but given a constant 4% final cold reduction prior to forming the laminations, reference may be had to Figure 1 of the drawing. The silicon steel employed for the laminations upon which this figure is based had a composition of 2.84% silicon, .33% aluminum and the balance iron with incidental impurities such as .03% carbon, .28% manganese, .008% phosphorous, .02% sulphur, .08% nickel, .008% copper and .008% tin. As illustrated curve 10 represents the watt loss at 15,000 B obtained after the silicon steel was normalized at 1525° F., given a final 4% cold roll to gauge, formed into laminations and then given the final annealing treatment for 30 minutes at the temperatures indicated and in the range of 1300° F. to 1700° F. Curves 12 and 14 are similar curves except that the normalizing treatment applied prior to the 4% cold roll to gauge was at a temperature of 1625° F. and 1825° F. respectively. In all cases the watt loss is indicated for the "with grain"

direction as a quality check, it being found that where good results are obtained as measured "with the grain" a good level of results is also obtained as measured "across the grain."

From the results shown in Figure 1 it is apparent that a final anneal at 1300° F. is not satisfactory whereas a final anneal at 1400° F. is satisfactory in only certain cases. Therefore, in practice it is preferred to employ a temperature of not less than 1450° F. as the minimum final annealing temperature. On the other hand, while a definite improvement is obtained with the final anneal at 1700° F. for 30 minutes as illustrated in Figure 1, nevertheless, in practice it is not practical to anneal the laminations in ordinary atmospheres at temperatures over 1600° F. and for that reason we prefer to limit the upper range for the final anneal to a temperature of about 1600° F.

The curves of Figure 2 of the drawing illustrate the effect of both the final cold rolling to gauge and the final annealing treatment on a silicon steel of the motor grade having the composition given hereinbefore for the steel upon which the results of Figure 1 are based. These curves are based on the results obtained where the silicon steel is hot rolled to a thickness between 0.07 and 0.125 inch, pickled and then cold rolled to a thickness ranging up to 8% greater than the final gauge of 0.025 inch, normalized at 1725° F. in a reducing atmosphere, and then cold rolled at 0, 1, 2, 4, 6 and 8%, respectively, to gauge as indicated, formed into laminations and given a final anneal at temperatures of 1300° F., 1400° F. and 1600° F. as illustrated by curves **16**, **18** and **20**, respectively, and thereafter tested for watt loss at 15,000 B. Reductions slightly greater than 8%, for example 10% and higher, while beneficial from the watt loss tests, are not satisfactory because of the decreased permeability values obtained at the higher flux densities of 12,000 to 16,000 gausses.

The results obtained as illustrated in curve form in Figure 2 again illustrate that final annealing temperatures of 1300 and 1400° F. are in general too low to obtain satisfactory results. On the other hand a final annealing temperature of 1600° F. is entirely satisfactory where the steel has been given a final cold reduction to gauge of from 2 to 8% prior to forming the laminations. Comparable results are obtained over the entire preferred range of final annealing temperature of from 1450 to 1600° F. where the final cold reduction to gauge after the normalizing treatment ranges from 2 to 8%.

As a further illustration of the outstanding improvement obtained by practicing the process of this invention, steels having the analyses of:

Heat No.	Percent Si	Percent Al	Percent C
5855	2.81	.27	.022
5861	2.89	.32	.026
5862	2.82	.28	.028
5864	2.90	.26	.030

with the balance iron and incidental impurities when processed as described heretofore within 4% of the finished

thickness and then normalized at 1700° F. in cracked ammonia for a period of about 5 minutes and then subjected to a 4% cold reduction to a finished thickness of .025 inch, punched to the shape of the laminations and thereafter annealed at 1600° F. gave the following "with grain" watt loss and A. C. permeability when standard Epstein strips of 3 x 28 cm. were tested.

Heat No.	Watt Loss, W./lb.		A. C. Permeability	
	10,000 B	15,000 B	200 B	2,000 B
5855	.700	1.756	2,760	7,120
5861	.652	1.672	2,760	7,265
5862	.755	1.917	2,270	6,270
5864	.655	1.731	2,390	6,279

Experimental D. C. permeability values were also obtained as evidenced by the results given in the following table as found on Epstein strips punched from the strips of heats 5864 and 5862 after the final 4% cold reduction to thickness and then given the 1600° F. final anneal for ½ hour.

Heat No.	B at 200 H	B at 100 H	u at 15,000 B	u at 10,000 B	u Max.	At B	u at 2,000 B
5864	19,340	18,300	2,600	17,000	18,500	7,800	12,000
5862	19,370	18,300	2,800	17,500	18,000	7,000	10,500

As evidence of the improved low density properties obtained on laminations formed by normalizing the strip at a temperature of 1700° F., then applying a 4% cold reduction to reduce the strip to a finished thickness of .025 inch thickness, punching to the shape of E and I laminations and then finally annealing at 1475° F., 1550° F. and 1600° F., respectively, for ½ hour, reference may be had to the following table giving the A. C. permeability and watt losses obtained with strips from heats 5855, 5861 and 5864 identified hereinbefore.

Heat No.	Final Anneal—1,475° F.				Final Anneal—1,550° F.				Final Anneal—1,600° F.			
	40 B	200 B	2,000 B	W./lb. at 10,000 B	40 B	200 B	2,000 B	W./lb. at 10,000 B	40 B	200 B	2,000 B	W./lb. at 10,000 B
5855	1,170	2,140	5,160	.933	720	1,555	4,620	.925	1,230	2,280	5,450	.918
	1,180	2,140	5,160		720	1,545	4,620		1,230	2,250	5,280	
	1,195	2,140	5,160		700	1,555	4,800		1,260	2,280	5,315	
5861	1,145	2,220	5,485	.925	695	1,500	4,590	.870	1,115	2,195	5,350	.912
	1,130	2,125	5,350		660	1,430	4,300		1,135	2,195	5,315	
	1,105	2,140	5,200		625	1,370	4,285		1,135	2,250	5,400	
5864	1,250	2,155	5,160	.940	745	1,495	4,300	.890	1,265	2,250	5,400	.912
	1,275	2,195	5,250		835	1,730	4,875		1,280	2,280	5,530	
	1,265	2,170	5,250		715	1,435	4,280		1,285	2,280	5,575	

As illustrative of the improvement obtained when silicon steel is processed in accordance with this invention and the substantially constant results obtained regardless of the furnace utilized for applying the final anneal to the resulting laminations, reference may be had to Figure 3 of the drawing, the curves of which are based on the watt loss at 15,000 B obtained on cores of laminations having the same composition of about 1.86% silicon and the balance iron, but, with the exception of curve **22**, processed in accordance with prior art practice, the final anneal A, B, C and D being applied in different furnaces at different processing plants.

Curve **22** illustrates the watt loss obtained where the steel is processed in accordance with this invention being subjected to a normalizing temperature of 1725° F., followed by a final cold reduction of 4% to gauge, punched to the required shape and size of the laminations and then finally annealed in four different furnaces as represented at stations A, B, C and D. For stations A and B the final anneal consisted of maintaining the load at a temperature of 1450° F. in air for a period of ½ hour and then furnace cooling the load, whereas stations C and

D represent two other furnaces in which the load was maintained in a slightly oxidizing temperature while the load temperature increased from about 1500° F. to 1600° F. in about 1 hour, the load thereafter being furnace cooled to about 750° F. in a period of 1 hour. Curve **22** clearly illustrates that comparable results are obtained for the different furnace final anneals when the silicon steel is processed in accordance with this invention as described.

In comparison, curve **24** represents results obtained on laminations of the same material processed in the same manner as the steel of curve **22** with the exception that a box anneal at 1725° F. is employed instead of the short time normalizing treatment at 1725° F. prior to the final cold reduction. Curve **26** represents results obtained on the inside laminations of the annealed pack formed from conventional hot rolled silicon steel sheet. Curve **28** represents results obtained on the outside laminations of the annealed pack formed from conventional hot rolled silicon sheets. Curve **30** represents results obtained where the silicon steel is cold rolled at least 65% to gauge and then normalized at 1725° F. prior to punching and final anneal whereas curve **32** represents results obtained for the same processing except that the steel is not normalized after the cold rolling to gauge. Curve **34** represents results obtained by another conventional cold rolling process in which the steel is cold rolled at least 65% to gauge and then box annealed at 1475° F. prior to forming the laminations. As illustrated, none of the conventional hot rolling or cold rolling processes gave results comparable to those obtained when the process of this invention is followed nor do the prior art processes give the same constant results regardless of the furnace, usually the customers, in which the final anneal is applied.

The following table is also illustrative of the improvement obtained on a (1) motor grade of silicon steel having an analysis of 2.87% silicon, .24% aluminum, .03% carbon, .30% manganese and the balance iron, (2) an electical grade having an analysis of 1.45% silicon, .42% aluminum, .029% carbon and the balance iron, (3) a second electrical grade having an analysis of 1.70% silicon, .30% manganese, .053% carbon and the balance iron, and (4) an armature grade having an analysis of .55% silicon, .30% manganese, .045% carbon and the balance iron, when such steels are processed into laminations in accordance with this invention as compared with results obtained when the same steels are processed by conventional cold rolling practices, identified as items 4 and 5 hereinbefore. In the case of the (1) motor grade identified hereinbefore the final anneal applied to the laminations consisted of an anneal at 1600° F. in air, whereas the final anneal for the (2) and (3) electrical grades and the (4) armature grade consisted of an anneal in air at a temperature of 1475° F. Also such steels as referred to in the table as "Our Process" were processed as disclosed hereinbefore employing a normalizing treatment

of 1725° F. followed by a 4% cold reduction to gauge before forming the laminations.

Grade	Processing	60 cycle core loss (Watts/lb.)			
		10,000 B		15,000 B	
		With Grain	Across Grain	With Grain	Across Grain
(1) Motor	Cold Rolled—Item 4	1.030	1.127	2.475	2.662
	Cold Rolled—Item 5	1.154	1.213	2.631	2.768
	Our Process	.694	1.025	1.724	2.439
(2) Elect	Cold Rolled—Item 5	1.27	1.45	2.92	3.22
	Our Process	.82	1.18	1.99	2.92
(3) Elect	Cold Rolled—Item 4	1.685	1.735	3.851	3.935
	Cold Rolled—Item 5	1.780	1.835	3.950	4.152
	Our Process	1.099	1.335	2.555	3.256
(4) Armature	Cold Rolled—Item 5			4.40	4.80
	Our Process			3.33	3.62

As a further example of improvement in silicon steel laminations as produced in accordance with this invention reference may be had to the following table illustrating comparative results of permeability values obtained from D. C. magnetization "with grain" of laminations processed from steel having a composition of 2.84% silicon, .33% aluminium, .03% carbon, .28% manganese, .008% phosphorous, .02% sulphur and the balance iron. The steel was processed by (1) conventional cold rolling practice identified as Item 5 hereinbefore and (2) and (3) in accordance with this invention, the variation in the processing in (2) and (3) being that (2) was subjected to a normalizing treatment at 1825° F. whereas the normalizing treatment of (3) was at 1725° F. Both (2) and (3) was subjected to a final cold reduction of 4% after being normalized and the laminations formed thereafter as well as the laminations of steel (1) were subjected to a final anneal for 30 minutes in air at a temperature of 1600° F.

Heat No.	Processing	2,000 B	4,000 B	8,000 B	10,000 B	12,000 B	15,000 B
2848, Lot X6890	Cold Rolled—Item 5	3,340	5,120	6,500	6,250	5,220	1,500
2848, Lot X6899	Our Process—Steel 2	8,000	11,750	14,280	13,150	10,000	2,580
2848, Lot X6893	Our Process—Steel 3	9,080	13,100	15,100	13,500	12,000	3,330

Considerable improvement in normal permeability values from A. C. magnetization is also obtained as evidence of the following results obtained on "with grain" tests of laminations produced from steel having a composition of 2.87% silicon, .24% aluminum, .03% carbon, .30% manganese, .008% phosphorous, .03% sulphur and the balance iron as conventionally cold roll produced and as processed in accordance with this invention by subjecting the steel strip to a normalizing treatment at 1725° F., cold rolling it 4% to gauge, forming laminations and subjecting the laminations to an anneal in cracked gas for one hour at 1600° F. The conventional cold rolled steel laminations were also given the same final anneal as the laminations formed in accordance with our process.

Heat No.	Processing	2,000 B	4,000 B	8,000 B	10,000 B	12,000 B	15,000 B
5810, Lot X4729	Conventional Cold Roll	3,500	4,860	6,750	7,350	6,830	1,730
5810, Lot X4727	Our Process	6,400	8,750	10,750	11,550	10,550	3,890

As a further example of the permeability values from A. C. magnetization reference may be had to the following table giving results obtained on "with grain" tests of laminations produced from steel having a composition of 1.7% silicon, .053% carbon, .30% manganese, .01% phosphorous, .03% sulphur and the balance iron and processed by both conventional cold rolling practice and

by our process as given in the preceding example except that the final anneal was at a temperature of 1510° F.

Heat No.	Processing	2,000 B	4,000 B	8,000 B	10,000 B	12,000 B	15,000 B
5347, Lot 7184	Conventional Cold Roll	1,720	2,740	4,075	4,520	4,250	2,015
5347, Lot 7185	Our Process	4,740	7,130	8,300	7,920	7,350	2,640

The process of this invention has been successfully applied to silicon steels of all grades such as the lower silicon grades, the electrical grades containing about 1.29% silicon, 1.57% silicon and 1.70% silicon and the armature grades containing about .55% silicon. In all cases improved watt loss values and high permeability at all densities up to 15,000 B have been simultaneously obtained. Further, it has been found that after the final cold reduction of from 2 to 8% to gauge is applied, the strip material is in a condition suitable for punching or for stamping operations for forming laminations therefrom. The strip has a high degree of flatness in such condition and makes it possible to form laminations free from warpage. The efficiency of electrical apparatus with laminations formed in accordance with this invention is higher than the efficiency of corresponding apparatus formed of laminations of the same steel processed in accordance with the prior art practices.

We claim:

1. The process of producing laminations of cold rolled steel having a silicon content between 0.25% and 3.5% comprising, producing a hot rolled silicon steel strip having a thickness between 0.07 and 0.125 inch, removing scale from the hot rolled strip, cold roll reducing the strip to a thickness 2 to 8% greater than final gauge, normalizing the strip at a temperature of 1500 to 1825° F. in a reducing atmosphere for a time of three to eight minutes to produce a fine grain structure, cold roll reducing the strip to final gauge, forming laminations of predetermined shape and size therefrom, and annealing the laminations at a temperature of 1450° F. to 1600° F. for from one-half to two hours to relieve the strains and develop the magnetic characteristics of the steel.

2. The process of producing laminations of cold rolled steel having a silicon content between about 0.25% and 3.5% comprising, hot rolling an ingot of the steel to strip having a thickness between 0.07 and 0.125 inch, pickling the hot rolled strip to remove scale therefrom, cold roll reducing the strip to a thickness 2 to 8% greater than the final gauge, normalizing the strip at a temperature of 1500 to 1825° F. in an atmosphere of cracked ammonia for a time of three to eight minutes to produce a fine grain structure, cold roll reducing the normalized strip to final gauge, forming laminations of predetermined shape and size therefrom, and annealing the laminations at a temperature of 1450° F. to 1600° F. for from one-half to two hours to relieve the strains and develop the magnetic characteristics of the steel.

3. The process of producing laminations of cold rolled steel having a silicon content between about 0.25% and 3.5% comprising, hot rolling an ingot of the steel to strip having a thickness between 0.07 and 0.125 inch, pickling the hot rolled strip to remove scale therefrom, cold roll reducing the strip to a thickness 2 to 8% greater than the final gauge, normalizing the strip at a temperature of 1500 to 1825° F. in a reducing atmosphere for a time of three to eight minutes to produce a fine grain structure, cold roll reducing the normalized strip to final gauge, forming laminations of predetermined shape and size therefrom, annealing the laminations in an oxidizing atmosphere at a temperature of 1450 to 1600° F. for from ½ to 2 hours, and cooling the laminations from such annealing temperature while in the oxidizing atmosphere to a temperature of 700 to 800° F.

4. The process of producing laminations of cold rolled steel containing a substantial amount of silicon not exceeding 3.5% comprising, producing a hot rolled silicon steel strip having a thickness between 0.07 and 0.125 inch, removing scale therefrom, cold roll reducing the strip to a thickness about 4% greater than final gauge, normalizing the strip at a temperature of 1500 to 1825° F. in a reducing atmosphere for a time of three to eight minutes to produce a fine grain structure, cold roll reducing the normalized strip to final gauge, forming laminations of predetermined shape and size therefrom, and annealing the laminations at a temperature of 1450° F. to 1600° F. for from one-half to two hours to relieve the strains and develop the magnetic characteristics of the steel.

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