

June 26, 1951

C. A. SCHARSCHU
PROCEDURE FOR MAKING NICKEL-IRON ALLOYS HAVING
RECTANGULAR HYSTERESIS LOOPS

2,558,104

Filed Feb. 23, 1949

2 Sheets-Sheet 1

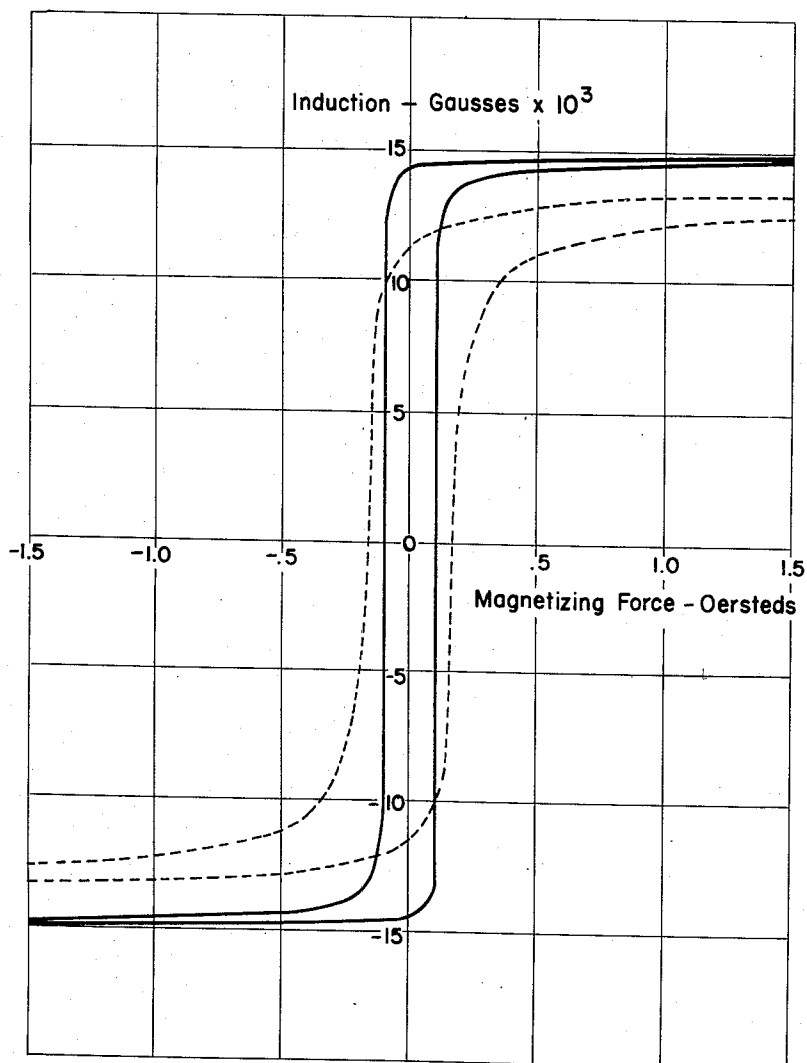


Fig.1

INVENTOR.
Charles A. Scharschu
BY
Green, McCallister & Miller
His ATTORNEYS

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2 Sheets-Sheet 2

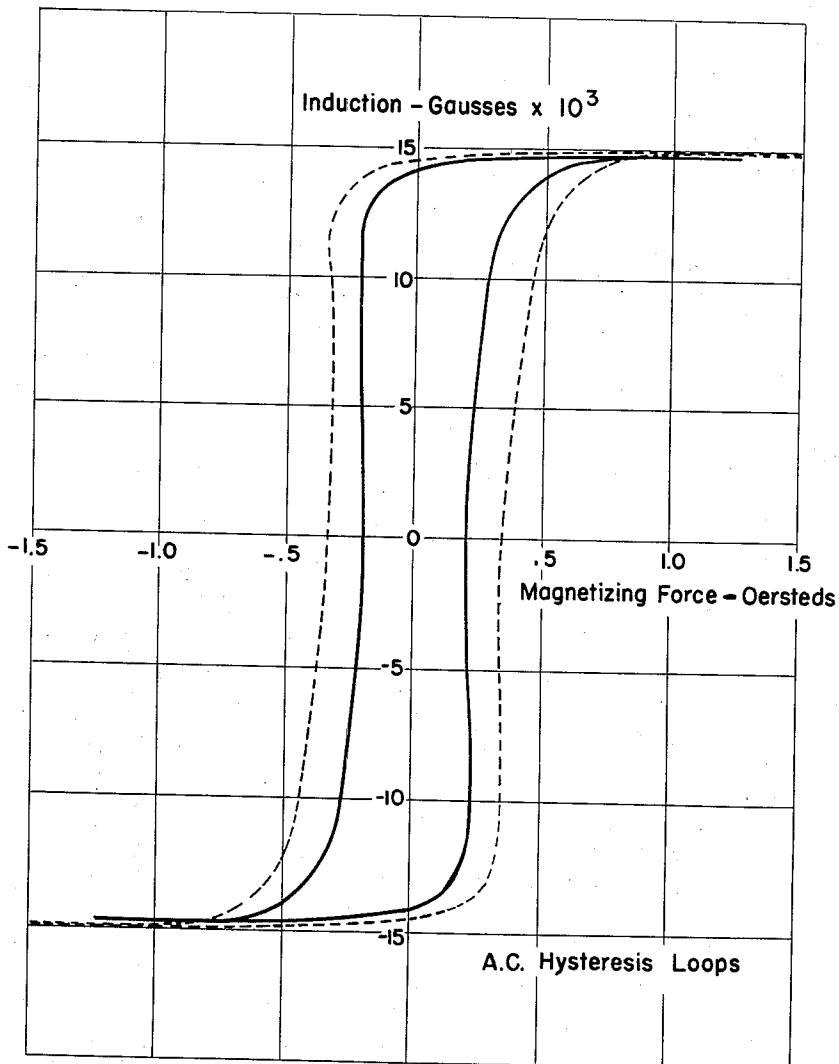


Fig. 2

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UNITED STATES PATENT OFFICE

2,558,104

PROCEDURE FOR MAKING NICKEL-IRON
ALLOYS HAVING RECTANGULAR HYS-
TERESIS LOOPSCharles A. Scharschu, Brackenridge, Pa., assignor
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burgh, Pa., a corporation of Pennsylvania

Application February 23, 1949, Serial No. 77,704

8 Claims. (Cl. 148—2)

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This invention relates to the production of nickel-iron alloys, the physical properties of which are such that their hysteresis loops are rectangular. My invention also relates to procedure for producing such alloys in the form of thin gauge material having a thickness of 0.010" and less.

A hysteresis loop is a graph showing the relationship between the cyclically changing magnetizing force applied to the material and the magnetic inductions in the material caused thereby. In Figure 1, the dotted line graph represents what may be termed a normal hysteresis loop. In a material producing a rectangular hysteresis loop, such a graph discloses that the major part of the change in the magnetic induction occurs with relatively little or no change in the magnetizing forces. This type of loop is represented by the solid line graph of Figure 1. The rectangular hysteresis loop may be further defined as the type of loop which results in a single crystal when the magnetizing force is applied in the direction of easiest magnetization.

While conditions such as produce rectangular hysteresis loops have been approximated in the magnetization of silicon steel which had been subjected to a cold reduction of approximately 60%, similar conditions have been closely approximated in nickel-iron alloys after they have been subjected to a cold reduction of at least 90%. Such cold reductions, coupled with other processing, results in a degree of crystal orientation in a polycrystalline magnetic material, such that the material has the magnetic properties of a single crystal and the application of a magnetizing force in the direction of easiest magnetization will result in a rectangular hysteresis loop closely approximating that of a single crystal.

As indicated nickel-iron alloys having so-called "rectangular hysteresis loops" are not new. Efforts to develop them on a commercial basis were started in Germany either immediately prior to or during World War II. However, the apparatus and procedure considered necessary for their production were such that production on a large commercial scale was not practical. As a matter of fact the cost of production in this country, employing apparatus such as was used in Germany, would be almost prohibitive.

The material was, however, produced to some extent in Germany under the trade name of "Permenorm 5000 Z." A great deal of work has been done in this country in an effort to produce the material in accordance with the German method of processing and the results obtained

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were made public during a Magnetic Materials Symposium sponsored by the Naval Ordnance Laboratory at Washington, D. C., on June 15, 1948. The procedure employed in Germany, and so far as I know the only procedure heretofore employed in producing the iron-nickel alloys in question, involves the preliminary selection of substantially pure metals and the processing of the same in a vacuum. That is to say, one phase of prior processes was the melting and processing in a vacuum of raw materials extremely low in impurities. This step has been considered extremely important since it was held, and experience had demonstrated, that impurities and particularly deoxidizing reagents must be kept as low as possible, and that vacuum melting not only prevented oxidation but aided deoxidation. It is of course apparent that vacuum melting adds materially to the cost of production and places a limit on quantity production since it necessitates the use of relatively small melting units. It also necessitates the installation of new equipment, since vacuum melting units are not usually employed as a part of the equipment of metal producing plants.

In order to develop the desired magnetic properties in ferrous nickel alloys, cold reduction, probably by rolling, appears to be essential. A second unusual feature of the process heretofore employed, involved the cold rolling procedure. By such procedure the strip is cold rolled to some intermediate gauge which depends upon the final thickness of the strip. For example, when strip ranging from 0.001" to 0.002" is to be produced the intermediate gauge selected is about 0.014". At that intermediate gauge the strip is slit to a width which is one per cent less than the required width of the strip of final gauge. To date material at the gauges designated has been used in extremely narrow widths, ranging from $\frac{1}{8}$ " to $1\frac{1}{2}$ ". From the nature of the product it is likely that these widths cannot be greatly increased since the material is extremely sensitive to strains induced by handling and winding the strips into magnetic cores. It is, therefore, apparent that the slitting of the strip to substantially final width at an intermediate stage of the cold rolling, increases the cold rolling procedure and materially increases the cost of production. That is to say, the cost of rolling such narrow strips to the final gauges involved, is from four to eight times that encountered in the production of strip 6" to 8" or wider and then slitting to the desired width after the final gauge has been reached.

An object of my invention is to produce nickel-

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iron alloys in which the nickel content ranges from approximately 45% to 55% with the balance principally iron except for manganese and silicon in quantities sufficient to enhance the hot working characteristics of the alloys and except also for such impurities as are impossible to remove without rendering the procedure prohibitive from the standpoint of cost.

A further object of my invention involves the production of such alloys containing a substantial amount of molybdenum or such equivalent thereof as will appreciably increase the electrical resistance of the alloy.

A more specific object of my invention is to produce a simple, relatively inexpensive and commercially practical procedure for making nickel-iron alloys of such character that crystal anisotropy or preferred orientation of the grain structure thereof can be induced by severe cold rolling in sufficient degree to produce a relationship between magnetizing force and the magnetic induction resulting therefrom, such that the graph thereof is in the form of a rectangular hysteresis loop.

A still further object is to produce simple and relatively inexpensive procedure for manufacturing nickel-iron alloys of the type exhibiting rectangular hysteresis loops and in the form of thin gauge material which may be effectively employed as the magnetic cores of various type of electrical equipment such for example as mechanical rectifiers and magnetic amplifiers.

These and other objects, made more apparent throughout the further description of my invention, are attained by means of procedure herein defined which produces magnetic material such that when the subjected to magnetization is characterized by an A. C. hysteresis loop such as is illustrated in full lines in Figure 2.

In the drawings Figure 1 discloses in dotted lines a more or less normal D. C. hysteresis loop and in full lines a D. C. hysteresis loop such as characterizes a nickel-iron alloy made and processed in accordance with my invention. Figure 2 discloses in full lines an A. C. hysteresis loop which characterizes a nickel-iron alloy made and processed in accordance with my invention, whereas the loop outlined in dotted lines is characteristic of nickel-iron material produced and processed by the heretofore described German procedure and subjected to a cold reduction of about 98%.

For the purpose of comparison I note that nickel-iron alloys heretofore produced which exhibit rectangular hysteresis loops, were produced by a process and under conditions such that there was no opportunity of removing impurities during the processing, except for the removal of some carbon and some oxides during the particular annealing procedure employed. It was, therefore, necessary to employ raw materials which were characterized by the fact that they were extremely low in impurities. These materials, i. e., iron and nickel constituents, were delivered to the furnace together with a complete charge of deoxidizing reagents such as silicon and manganese. Both the melting of the charge so formed and the pouring of the same was accomplished in a vacuum. Refining such as is ordinarily employed in the production of alloy steels, was impossible and the vacuum melting procedure confined the operation to small melts. The melts were cast into ingots as a preliminary to rolling. Hot rolling was carried forward in accordance with usual procedure to a

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gauge of about 0.235'', although gauge thickness was not critical.

The hot roll material was pickled under conditions such as to thoroughly remove the scale and was then annealed in a dry hydrogen atmosphere for at least two hours at a temperature of about 1832° F. The annealed material was then cold rolled to a thickness of about 0.10''. It was again annealed for about five hours in a carefully prepared atmosphere of dry and substantially pure hydrogen within a temperature range of from 1292° to 1472° F. although the annealing temperature is not extremely critical. The annealed material was then cold rolled to a thickness of about 0.014''. The strip so formed was then slit lengthwise so as to form a number of strips or tapes each of which was 1% less in width than the desired width of the finished product. The slitting was performed at this stage of the cold rolling operation because the magnetic characteristics of the material are detrimentally affected by mechanical strains and it was found that cutting the material after it had been reduced to final gauge resulted in detrimental strains which impaired orientation in the final anneal. The slit strips were then cold rolled to final gauge and final width after which they were annealed in dry and substantially pure hydrogen to develop magnetic properties.

While my procedure is somewhat similar to this prior procedure, it differs in such a way as to not only reduce the cost of processing but also to produce an improved material, the cost of which is reduced because of the simplified procedure and the reduced cost of the raw materials employed.

In carrying out my procedure I select raw materials consistent with good electric furnace practice employed in the production of high grade alloy steels. The steel is melted under atmospheric pressure in a basic arc furnace of conventional design. The melt is refined to remove impurities and deoxidized by the use of strong deoxidizing reagents. The deoxidation is carried forward to the point of complete deoxidation as that term is employed in steel mill practice. The refined melt is then poured and teemed into ingots in the usual manner. The ingots are hot rolled in accordance with usual hot rolling procedure to a thickness of about 0.160'', although the final gauge reached in the hot rolling is not critical. Pickling is carried forward so as to remove scale and oxides from the hot rolled strip and pickled strip is then cold rolled to a thickness of about 0.100''. The cold rolled product is then annealed at a temperature of about 1450° F. for about 5 hours in an atmosphere of dry and substantially pure hydrogen. The temperature is not extremely critical but the annealing time is important. The annealed strip is then cold rolled to final gauge without further annealing, i. e., it is cold rolled to a thickness ranging from 0.001'' to 0.002''. It is then slit longitudinally into widths such as are employed in producing the magnetic cores of electrical equipment and the core material thus produced is subjected to the final anneal for developing its magnetic characteristics.

It is understood that the rolling procedure outlined above is illustrative of the procedure when 0.001'' or 0.002'' thick strip is produced and where final cold reductions of 98 to 99% are employed. Where suitable hot rolling equipment is available, the strip may be hot rolled to the desired cold rolled starting gauge for the final cold

reduction. When strip either lighter or heavier than 0.001" or 0.002" is required, the intermediate gauge at which the strip is annealed will vary depending upon the final gauge and the amount of final cold reduction desired which will be 90% or more.

In carrying forward my simplified procedure I employ an arc furnace with a basic lining such as is used in regular steel production. The nickel-iron alloy is made from a good grade of steel scrap or steel and nickel-steel scrap which is charged directly into the furnace. It is desirable to have sufficient carbon in the charge so that when the charge is melted some carbon is present in the bath. Either during the melting or after the charge is melted, I charge iron ore into the furnace so as to refine the bath by removing harmful impurities. Instead of employing iron ore as a refining reagent I may employ other metallic oxides or introduce gaseous oxygen into the bath. The introduction of oxygen may be substituted for, or may be employed in conjunction with oxides such as iron ore.

The refining operation is preferably carried forward until the carbon content of the bath is reduced below 0.03%. When this is accomplished the silicon of the bath will have been substantially eliminated and the manganese will have been reduced to about the same content as the carbon. The refining period should be of sufficient duration to reduce all harmful impurities to very small amounts or mere traces. Impurities such as copper are not eliminated by refining operations such as described and it is, therefore, necessary to select the initial charge so as to avoid including objectionable amounts of copper and similar metals.

The refining operation is preferably carried out under a lime slag and when completed the slag is removed, thus removing objectionable oxidizable metals which were present in the initial charge. A new slag consisting principally of dry lime is then delivered to the surface of the melt within the furnace. Small amounts of fluorspar, silica and alumina may be added to the lime to produce a more fluid slag, but usually such additions are not necessary since the reaction products from the reducing reagents are sufficient to provide a fluid basic slag which can be worked to refine the heat. When the lime has reached a fluid state, metallic additions may be made to the bath for the purpose of adjusting its composition. For example, metallic nickel of high purity may be added to the bath, or if clean nickel-bearing scrap of necessary purity and adequate nickel content is available, it may be added instead of the metallic nickel. It might be noted that no nickel is lost during the refining operations and that, therefore, the quantity of nickel necessary to complete the nickel content of the finished alloy may be included with the materials initially charged into the furnace.

After all additions have been made to the bath, I add to the slag a strong deoxidizer such as aluminum or magnesium in substantial amounts, such for example as at least about 0.10% of the metallic content of the bath. During this step of the procedure all of the metallic oxides are reduced from the slag by the additions thereto of ferrosilicon or aluminum in a finely divided state. This produces a perfectly white slag. The excess of aluminum and/or magnesium added to the bath is then eliminated by increasing the temperature of the melt by about 50°-150° F., i. e., to a temperature within the range of from

about 2800° to about 2950° F., or by the addition of a small amount of oxygen. If the slag changes color finely divided deoxidizing agents should again be added and the processing continued until the slag is again perfectly white.

The refining operations should be sufficiently vigorous to reduce the gases of the bath, and particularly the hydrogen, to a minimum. After refining, the silicon content of the bath should preferably be not more than a trace while the manganese content is about the same as the carbon content. Where aluminum is used subsequently to reduce the oxides in the slag or is added to the metal to insure complete deoxidation, the aluminum content of the melt should preferably not be more than 0.05%.

For comparison purposes I have set forth under Example No. 1 an analysis of a typical melt made in accordance with my procedure as here outlined. After refining, manganese and silicon were intentionally added to facilitate hot workability. Under Example No. 2, I have set forth an analysis of an iron-nickel alloy prepared in Germany in accordance with the vacuum melting procedure previously defined:

	Examples	
	No. 1	No. 2
Carbon.....	.024	.037
Manganese.....	.39	.58
Phosphorus.....	.015	.011
Sulfur.....	.008	.011
Silicon.....	.21	.075
Chromium.....	Trace	Nil
Nickel.....	49.79	48.06
Aluminum.....	.038	.044
Cobalt.....	.49	.41
Copper.....	.08	Nil

It will be noted that the alloy contains an appreciable amount of cobalt and some copper. Cobalt is usually present in electrolytic nickel in amounts up to 1.00% or slightly higher and is not removed in the refining operation. Copper is also present in varying amounts in the raw materials. However, since both of these impurities exert no appreciable effect upon the magnetic properties of the alloy, their presence in moderate amounts is not objectionable.

After the melt is completed additions of ferrosilicon and ferromanganese may be made either to the furnace or to the ladle for the purpose of providing the desired amount of silicon and manganese in the finished alloy. It should be pointed out that neither manganese nor silicon has any material effect upon the rectangular hysteresis loop characteristics. However, silicon markedly affects the magnetic saturation. Where extremely high magnetic saturation values are desired such for example, in excess of 15,000 B, the silicon should be limited to 0.25%. Where, however, low coercive force is desired with some sacrifice of the saturation value, silicon up to 0.35% may be permitted. Where molybdenum is desired as one of the minor constituents of the alloy, it may be added to the furnace near the end of the refining operation in the form of calcium molybdate, or in the form of scrap or ferromolybdenum with the original charge.

Thus the alloy which is produced and processed by the procedure constituting my invention may include from about 45% to about 55% nickel, from about 0.02% to about 0.03% carbon, from a trace to not more than 0.35% silicon, from a trace up to 0.50% manganese and may include not more than about 0.05% aluminum, together

with copper usually not in excess of 0.25% and cobalt in amounts up to approximately 0.60% with phosphorus and sulfur below .020%. The alloy may also include molybdenum in an amount ranging from about 2% to about 5%.

After the furnace is tapped the melt is teemed into ingot molds of the desired size. Prior to hot rolling, the ingots are raised to a temperature within the range of from about 2250° F. to 2350° F. The hot rolling is carried forward to a gauge such that the requisite cold reduction may be accomplished for the purpose of obtaining the desired magnetic characteristics in the finished product. For example, when strip having a final gauge of 0.001" to 0.002" is desired, the alloy is hot rolled to strip having a thickness of about 0.100". As is apparent this procedure is not critical and the hot rolling may be completed with the formation of thicker strip material. It, however, is essential that the material be rolled to a gauge preliminary to the final cold rolling operations, such as will permit the necessary cold reduction to final gauge without any intermediate anneals.

At the completion of the hot rolling the strip is pickled and annealed for about five hours in pure dry hydrogen. The temperature is not critical and longer periods or higher temperatures may be employed. As will be apparent the annealing procedure accomplished a further purification of the metal. The annealed hot rolled strip is then cold rolled to final gauge without an additional annealing. This cold reduction is in excess of 90% and, as in the example given, preferably ranges from 98% to 99%. Inasmuch as cold rolling mills now available for producing exceedingly thin gauges are limited to narrow widths, the hot rolling and the cold rolling will probably be best accomplished in widths of 12" or less.

After the cold rolling is completed the strip so formed may be slit longitudinally and otherwise cut to sizes such as are required for the production of magnetic cores. In view of the final gauges involved (0.001"—0.002") and the lack of inherent strength of such material, the magnetic properties are developed by annealing the material after it is formed into cores. This anneal is also accomplished in dry hydrogen and is carried forward at a temperature and for a period such as is essential to fully develop the magnetic characteristics of the material. The annealing temperature varies somewhat for different alloys and it is therefore desirable to determine the best annealing temperature for each different alloy by the preliminary annealing of a small sample cut from the strip to be annealed.

In Figure 2 of the drawings the A. C. hysteresis loop outlined by broken lines is a loop such as is obtained with the so-called "5000 Z" material, whereas the full line loop is the loop of material produced in accordance with my simplified procedure as herein set forth. Comparison of the two loops discloses that while the two alloys are quite similar from the standpoint of their constituents, they are materially different in magnetic characteristics. The material processed by my method as indicated by the full line D. C. hysteresis loop (Figure 1) shows a lower coercive force since values in the order of 0.06 to 0.08 oersted are obtained, while the values on the 5000 Z material run from 0.10 to 0.12 oersted. This lower coercive force is usually advantageous in material of this type. Material made by my process is also superior in retentivity which is a

measure of the degree of perfection attained in the material when comparison is made as to the magnetic saturation values. The

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ratio, i. e., the ratio of retentivity to saturation, for the German material of the order of 95% represents very high quality, whereas I have been able to get values consistently as high as 97%. This ratio is a measure of the degree to which the rectangular hysteresis loop of the single crystal in the direction of easiest magnetization has been approached and also may be taken as indicating the completeness of orientation of the individual grains in the preferred direction. The intrinsic saturation of the material is determined by the composition and the presence of other metals either purposely added or present as an impurity. Where highest values are desirable, care should be exercised in limiting silicon and manganese additions to the least amount necessary to commercially hot roll the material to the desired size.

A comparison of the magnetic quality of the material produced by my simplified procedure shows definitely that it is capable of producing results that are superior magnetically to the best results obtained on vacuum melted material which was slit to a final width at an intermediate gauge and then cold rolled to finished gauge.

What I claim is:

1. A method of producing magnetic material consisting essentially of a nickel-iron alloy containing from about 45% to about 55% nickel, from a trace to not more than 0.35% silicon, from a trace up to 0.50% manganese, carbon about 0.025%, with the remainder substantially all iron except for usual impurities in common amounts and characterized by a rectangular hysteresis loop which consists in melting raw materials in an electric furnace of the conventional arc type and refining the same in such furnace to the extent of removing substantially all oxidizable impurities therefrom and of reducing the carbon content thereof to not more than 0.030%, removing the slag from the melt, adding a new slag, completely deoxidizing the melt by adding thereto an active deoxidizing agent in substantial amounts; making small additions to the melt of manganese and silicon; casting the melt into at least one ingot; roller reducing the ingot by usual procedure to a thickness of from 10 to 100 times that of the final gauge desired; annealing the material so reduced in substantially dry and substantially pure hydrogen; and then without further annealing, subjecting the annealed material to a cold rolling reduction of from about 90% to about 99%; slitting the cold rolled material to final widths and annealing the slit material to develop the magnetic properties of the alloy.

2. A method of producing a nickel-iron alloy consisting essentially of nickel within the range of from about 45% to about 55%, silicon ranging from a trace to not more than 0.35%, manganese ranging from a trace up to about 0.50%, carbon ranging from about 0.02% to 0.030% and the remainder iron except for usual impurities in common amounts together with some cobalt and copper in amounts approximating 0.60% and 0.25% respectively, which comprises melting raw material such as carbon-containing steel scrap, iron ore and iron oxide in an electric furnace of the conventional arc type; refining the resultant

melt within such furnace and while subject to atmospheric pressure and while covered by a basic slag until substantially all oxidizable impurities are removed therefrom and the carbon content thereof is reduced to not more than 0.030%; completely deoxidizing the melt by adding thereto an active deoxidizing agent in an amount of at least about 0.10% of the melt; raising the temperature of the bath by from 50° to 150°; casting the melt into ingot form; roller reducing the ingot at least in part by a hot rolling reduction to a thickness substantially greater than the desired final gauge; pickling the hot rolled product; annealing the same in substantially pure and dry hydrogen for about five hours at a temperature of about 1400° F.; and then without further annealing, subjecting the annealed material to a cold rolling reduction of from 90% to 99%; slitting the cold rolled material to final widths and annealing the slit material to develop the magnetic properties of the alloy.

3. A method of producing a nickel-iron alloy characterized by a rectangular hysteresis loop and consisting essentially of from about 45% to about 55% nickel, not more than 0.35% silicon, up to about 0.50% manganese, carbon ranging from about 0.02% to about 0.025%, molybdenum ranging from about 2% to about 5%, with the remainder iron except for small amounts of copper and cobalt and usual impurities in common amounts and characterized by a

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ratio of at least 95%, which consists in melting carbon-containing scrap and other raw materials in an electric furnace of the conventional arc type; refining the same in such furnace while under atmospheric pressure and while covered by a slag consisting principally of lime to remove substantially all oxidizable impurities therefrom and to reduce the carbon content to not more than 0.030%; removing the slag; delivering a new slag to the melt consisting principally of dry lime; delivering metallic additions to the melt to adjust the composition thereof; adding a strong deoxidizing reagent in an amount of 0.10% of the melt; eliminating the excess of deoxidizer by raising the temperature of the bath by 50° to 150° F.; casting the melt into at least one ingot; roller reducing the ingot in part at least by hot rolling reductions to a thickness of from 33 to 100 times the final gauge; pickling the roller reduced product; annealing the same in substantially pure, dry hydrogen and then without further annealing, subjecting the annealed product to a cold rolling reduction of from about 97% to about 99%; slitting and cutting to final widths and forms and annealing the same to develop the magnetic properties of the alloy.

4. A method of producing an alloy containing 45% to 55% nickel and 2% to 5% molybdenum with the balance iron except for usual impurities in common amounts and characterized by a rectangular hysteresis loop, which consists in vigorously refining the raw materials in a conventional basic electric arc furnace to reduce all oxidizable impurities and hydrogen and other gases to a minimum while such materials are subjected to atmospheric pressure; thoroughly deoxidizing the molten bath, adjusting the composition by addition of needed amounts of nickel, silicon and manganese or molybdenum; casting the melt into at least one ingot; reducing the ingot by hot roll-

ing to 10 to 100 times that of the final gauge desired, pickling the hot rolled material, annealing the pickled material in substantially dry and substantially pure hydrogen, reducing the gauge of the material from 90% to 99% by cold rolling without further anneals; slitting the cold rolled material to final widths and annealing the slit material to develop the magnetic properties of the alloy.

5. A method of producing an alloy containing from about 45% to about 55% nickel, a maximum of 0.03% carbon, a maximum of 0.35% silicon, a maximum of 0.50% manganese, a maximum of 0.05% aluminum, a maximum of about 0.25% copper, a maximum of about 0.60% cobalt with the remainder iron except for usual impurities in common amounts, which consists in melting and vigorously refining carbon-containing raw materials to reduce all oxidizable impurities, hydrogen and other gases to a minimum while the same as subjected to atmospheric pressure; thoroughly deoxidizing the melt; adjusting the composition of the melt by adding needed amounts of nickel, manganese and silicon; casting the melt into at least one ingot; reducing the ingot at least in part by hot rolling to from about 10 to 100 times that of the final gauge desired; pickling the reduced material; annealing the pickled material in substantially pure and substantially dry hydrogen; cold rolling the material without further anneals to reduce the same from 90% to 99%; slitting the cold rolled material to final widths and annealing the slit material to develop the magnetic properties of the alloy.

6. A method of producing an alloy containing 45% to 55% nickel, less than 0.03% carbon, with the remainder iron except for usual impurities in common amounts and characterized by a rectangular hysteresis loop and a high magnetic saturation which consists in excess of 15,000 B; melting and vigorously refining the raw materials to reduce all oxidizable impurities and hydrogen and other gases to a minimum; thoroughly deoxidizing the melt; adjusting the composition of the melt by additions of needed amounts of nickel, manganese and silicon while limiting the silicon to a maximum of 0.25%; casting the melt into at least one ingot; reducing the ingot by hot rolling to 10 to 100 times that of the final gauge desired; annealing the material in substantially dry and substantially pure hydrogen; reducing the gauge of the material from 90% to 99% by cold rolling without further annealing; slitting the material to final widths and annealing the slit material to develop the magnetic properties of the alloy.

7. A method for making a nickel-iron alloy containing from 45% to 55% nickel, 2% to 5% molybdenum with the balance iron except for usual impurities in common amounts characterized by a rectangular hysteresis loop which consists in vigorously refining the raw materials in a basic electric arc furnace of conventional type until the silicon is reduced to a trace, manganese and carbon to less than 0.03%, hydrogen and other gases to a minimum; thoroughly deoxidizing the metal by the addition of substantial amounts of aluminum or magnesium to the bath and by additions of finely divided aluminum or ferro-silicon to the slag; eliminating excess deoxidizer from the metal; adjusting the composition; casting the melt into at least one ingot; reducing the ingot at least in part by a hot rolling reduction to an intermediate gauge of such thickness that the final gauge will be obtained by excess of 90% cold reduction; pickling the hot rolled product; annealing the pickled product in sub-

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stantially pure and substantially dry hydrogen; subjecting the annealed product to a cold reduction of at least 90% without further anneals; slitting the cold rolled material to final widths and annealing the slit material to develop magnetic properties.

8. A method of making a nickel-iron alloy consisting of from 45% to 55% nickel, from a trace to about 0.35% silicon, from a trace to about 0.50% manganese, a maximum of 0.03% carbon, a maximum of 0.05 aluminum, a maximum of 0.25% copper, a maximum of 0.60% cobalt, with the balance iron except for usual impurities in small amounts and characterized by a rectangular hysteresis loop, such property resulting from melting in a basic electric furnace metallic raw materials containing nickel, iron and carbon to form an initial melt; vigorously refining the melt to reduce the hydrogen and other gases to a minimum, the silicon to a trace, the carbon and the manganese to not more than 0.03% and oxidizable impurities to a minimum; strongly deoxidizing the melt; eliminating excess deoxidizer from the melt; adjusting the composition of the melt by metallic additions thereto; casting the melt into at least one ingot; reducing the cast ingot at least in part by a hot rolling reduction to a thickness

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from 10 to 100 times that of final gauge; pickling the reduced product; annealing the same in substantially pure and substantially dry hydrogen for about five hours at about 1400° F. then without further annealing, subjecting the annealed product to a cold rolling reduction of from 90% to 99% slitting and cutting the cold rolled product to final widths and lengths and annealing the same to develop the magnetic properties of the alloy.

CHARLES A. SCHARSCHU.

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Certificate of Correction

Patent No. 2,558,104

June 26, 1951

CHARLES A. SCHARSCHU

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows:

Column 10, line 21, for the words "as subjected" read *are subjected*; column 11, line 11, for "0.05 aluminum" read *0.05% aluminum*;

and that the said Letters Patent should be read as corrected above, so that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 28th day of August, A. D. 1951.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.

Certificate of Correction

Patent No. 2,558,104

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CHARLES A. SCHARSCHU

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[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.