UNITED STATES PATENT OFFICE.

TRYGVE D. YENSEN, OF SWISSVALE, PENNSYLVANIA.

MAGNETIC IRON PRODUCT AND METHOD OF MAKING SAME.

1,277,523. Specification of Letters Patent. Patented Sept. 3, 1918.

No Drawing. Application filed March 6, 1916. Serial No. 82,340.

To all whom it may concern:

Be it known that I, TRYGVE D. YENSEN, a citizen of the United States, residing at Swissvale, county of Allegheny, and State of Pennsylvania, have invented certain new and useful Improvements in Magnetic Iron Products and Methods of Making Same, of which the following is a specification.

The present invention relates to iron products having unusual magnetic properties and to methods of making the same, and it seeks to obtain products of this nature which combine in a high degree certain desirable qualities not found hitherto in any product.

The metals resulting from the improved process of production possess an extraordinarily high degree of magnetic quality including remarkably high magnetic permeability and unusually low coercive force and hysteresis loss. (Magnetic permeability is a measure of the ease with which a substance can be magnetized to a certain degree and is expressed by the variable quantity,

$$\mu = \frac{B}{H},$$

where H is the magnetizing force—in gilberts per cm.—required to produce the magnetic induction *b*—in gausses—in the substance. Hysteresis loss is the energy lost on reversal of the magnetism due to molecular friction.) Coercive force H_c is the value of H necessary to demagnetize the iron after it has been previously magnetized.

The products may take the form of rolling mill or bloomery ingots or castings or further products worked therefrom into suitable form and treated in the manner described hereinafter, and may or may not contain alloying elements.

In carrying out my improved process, I make use of a low carbon iron from which impurities such as phosphorus, sulfur and manganese have been reduced to a low figure, preferably to 0.05 per cent. or less, taken in the aggregate, by well known methods. Electrolytically refined iron may be used for this purpose, but this is not essential. After the iron is cleaned it may be placed in a suitable receptacle, for instance, a magnesia-lined crucible, which is introduced into a vacuum furnace where the iron is melted and further refined by subjecting it to the action of the vacuum, the process to be carried on in any suitable manner at such a high temperature, at such a pressure, and for such a length of time (for example from ½ to 2 hours, at an absolute pressure of about 2 cm. of mercury or even less, and at a bath temperature of at least 1550° C.) that gases to a large extent will be eliminated from the bath, and furthermore, that the carbon content of the finished product will be reduced to not more than a few hundredths of one per cent. For the best results the final carbon content should not be more than 0.01 per cent. As the carbon is eliminated by oxidation by the iron oxid present in the iron

$$(C + FeO \rightleftarrows CO + Fe)$$

it may be necessary in some cases in which the iron does not contain sufficient oxid to supplement this by adding the required amount.

The heat for the operation *in vacuo* may be supplied by means of electrical energy or by any other means that can be applied *in vacuo* without adding impurities to the iron. By using an alternating electric current, however, eddy currents are produced in the iron, having a very desirable stirring and mixing effect, and for this reason such a current is recommended.

After the elimination of the carbon and the gases, the metal is to be further deoxidized if necessary to such an extent that the oxygen content of the finished products is 0.05 per cent. or preferably less. This deoxidation may be accomplished very satisfactorily by the addition of silicon or aluminum to the molten bath while *in vacuo*.

The reason for keeping the aforesaid impurities below the figures specified is that as the iron cools the impurities are precipitated from the solution (either liquid or solid) and lodge between the iron crystals so as to obstruct the path of the magnetic flux from crystal to crystal. Furthermore the impurities are not generally precipitated as such, but rather in the form of iron compounds such as Fe_3C, Fe_3P, FeS, etc., which have magnetic properties much inferior to those of pure iron. For example, in iron containing 0.10 per cent. carbon a precipitate containing 15× 0.10 or 1.50 per cent. Fe_3C will form between the iron crystals. On the other hand, elements that are not precipitated but remain in solid solution

with the iron in cooling to room temperature, do not affect the magnetic permeability to the same extent at low and medium flux densities as do the intercrystalline precipitate forming elements.

The refined iron may be allowed to solidify while *in vacuo*, and should be cooled very slowly from a high temperature (900° to 1200° C.) down to normal temperature. (The total time occupied in cooling may be twelve hours or more). By this treatment the iron will have attained the high magnetic qualities hereinbefore mentioned for low and medium flux densities. But should it be necessary or desirable to forge, roll, machine, or otherwise mechanically treat the iron, this may be done, and in such cases the previous annealing and slow cooling may be omitted, but it is essential to follow this treatment by annealing the products (at 900° to 1200° C.), followed by slow cooling (at approximately the rate above referred to) to give the iron the high magnetic quality sought. In practice the products have been cooled at the rate of 30° C. per hour from 900° to 1100° C. *in vacuo* or surrounded by an inert gas.

No mechanical operation that will put a permanent internal strain on the finished products is to be applied subsequent to the slow cooling.

By the hereindescribed process it is possible to obtain iron with permeabilities up to ten times, and with varying degrees of coercive force and hysteresis losses even as low as one-tenth, that of the best commercial grades of iron known at present. The magnetic properties of the iron products of the above-described process, therefore, are widely different from those of the iron products heretofore known. As measured by the Burrows compensated double bar and yoke method, or by the Ring method, the refined and treated metal may, for instance, have a magnetic permeability, μ, at ordinary temperatures, of at least 13,000 and as high as 70,000 at flux densities, B, between 5,000 and 10,000 gausses and a hysteresis energy loss for $B_{max.} = 10{,}000$ and 15,000 of less than 1,000 and 2,000 and as low as 250 and 575 ergs per cu. cm. of metal per magnetic cycle, respectively. The coercive force for B 15,000 is less than 0.36 and may be as low as 0.085 gilberts per cm.

Pure vacuum fused iron made in accordance with my invention has a specific weight of 7.9 to 8.10 which is up to 1 per cent. higher than that of the purest commercial iron made by any prior methods.

For the attainment of products with higher electrical resistance than is obtainable with the pure iron products it is necessary to alloy the iron with some other material, for example, by adding from 2 to 5 per cent. of aluminum or silicon to the molten bath. I have found that the addition of such amounts of aluminum or silicon can be added to the pure iron without lowering the magnetic quality much, if any, below the figures given in the preceding paragraph. The best results have been obtained with a silicon content of 3 to 4 per cent., as this gives the best combination of high permeability, low hysteresis loss, and high electrical resistance. However, if such additions are made, precautions must be taken not to introduce impurities into the iron beyond the amounts previously specified; and if such impurities are introduced, they must be eliminated. For instance, carbon may be eliminated as already shown by the reaction,

$$C + FeO \rightleftarrows CO + Fe.$$

If such alloys are desired, the iron in its molten state and at a high temperature may be placed in a vacuum tank and the alloying material like silicon or aluminum added to it as needed to keep or maintain the metal in a sufficiently liquid state by the lowering of its melting point to carry on the operation as previously specified. The heat liberated by the addition of these alloying materials will also assist in maintaining the temperature of the metal. Thus in the circumstance outlined it may not be necessary to add any external heat to the iron while *in vacuo*.

For the attainment of products with relatively high permeabilities at high flux densities, alloying elements like silicon or aluminum should not be added to the iron to any large extent (except in so far as such elements may be used as deoxidizing agents) as it is well known that they tend to lower the saturation intensity of the iron.—Cobalt is the only element known at present that raises the saturation intensity of pure iron.—It may furthermore be necessary for the attainment of such product to forge, roll, or otherwise mechanically work the iron.

By this treatment, the vacuum fused iron, as hereinbefore described, will have higher permeabilities at high flux densities than the best commercial grades of iron known at present. The permeability for B=20,000 gausses, for instance, will be at least 100 and that for B=18,000 gausses 250–400.

If, in addition to the high permeabilities at high densities, it is also desired that the products shall have the high permeabilities at low and medium densities previously described, and the low hysteresis loss there mentioned, it is necessary, subsequent to the mechanical working, to anneal the products at temperatures not exceeding 900° C. followed by slow cooling. (Annealing at temperatures exceeding 900° C. will lower the permeabilities for high flux densities.)

By this process, namely, vacuum fusion of a pure grade of iron, decarburization, deoxidation, mechanical working, annealing

and slow cooling as above described, it is possible to obtain products characterized by the following values:

(1) *Permeability.*

For B=5,000–10,000 gausses, the permeability μ=13,000–70,000.

For B=15,000 gausses, the permeability μ=5,000–18,000.

For B=18,000 gausses, the permeability μ=250–400.

For B=20,000 gausses, the permeability μ=at least 100.

(2) *Coercive force.*

For B=15,000 gausses, the coercive force H_c=0.085–0.36 gilberts per centimeter.

(3) *Hysteresis loss.*

For B=10,000 gausses, the hysteresis loss=250–1,000 ergs per cubic centimeter per cycle.

For B=15,000 gausses, the hysteresis loss=575–2,000 ergs per cubic centimeter per cycle.

Commercial grades of iron of a high degree of purity containing as low as 0.01 per cent. carbon are improved to a very large extent magnetically by remelting *in vacuo*.

One phase of the process has been described as including the melting of the iron in the vacuum furnace. It will be understood, however, that the invention contemplates the use of molten metal rendered so by other means than the action of the vacuum furnace, in which circumstance the molten metal would be introduced into this furnace or a vacuum tank and there subjected to the stages of treatment described.

It is also to be understood that the specific apparatus, materials and process steps which have been described herein are intended to illustrate my invention and not to impose restrictions thereon, and that my invention comprises all such modifications and adaptations as fall within the scope of the appended claims.

It is to be understood that in the specification and appended claims the term "vacuum" includes any degree of sub-atmospheric pressure which will produce the effects described above and that the term "annealing" covers heating and slow cooling as described hereinbefore.

Having thus described my invention what I claim as new and desire to secure by Letters Patent is:

1. The method of making a magnetic iron product which consists in melting a low carbon iron *in vacuo* and thereby refining the iron and imparting superior magnetic properties, substantially as described.

2. The method of making a magnetic iron product which consists in subjecting a low carbon iron *in vacuo* to a high degree of heat to thereby melt and refine the iron, and treating the molten iron with a material capable of increasing its electrical resistance, substantially as described.

3. The method of making an iron product having superior magnetic properties which consists in melting and refining a ferrous metal and subjecting the refined molten metal to the action of a vacuum to thereby degasify and further refine the metal, substantially as described.

4. The method of making an iron product having superior magnetic properties which consists in melting and refining a ferrous metal and subjecting the refined molten metal to the action of a vacuum to thereby degasify and further refine the metal and treating the molten metal with a material capable of increasing the electrical resistance of the metal, substantially as described.

5. The method of making an iron product having superior magnetic properties which consists in melting and refining a low carbon iron *in vacuo*, permitting the metal to solidify, and then mechanically working the solidified metal, substantially as described.

6. The method of making an iron product having superior magnetic properties which consists in melting and refining a low carbon iron *in vacuo*, treating the molten iron with a material capable of increasing the electrical resistance thereof, permitting the metal to solidify, and then mechanically working the solidified metal, substantially as described.

7. The method of making an iron product having superior magnetic properties which consists in melting and refining a ferrous metal, subjecting the refined molten metal to the action of a vacuum to thereby degasify and further refine it, permitting the metal to solidify, and then mechanically working the solidified metal, substantially as described.

8. The method of making an iron product having superior magnetic properties which consists in melting and refining a ferrous metal, subjecting the refined metal while in a molten state to the action of a vacuum to thereby degasify and further refine it, treating the molten metal with a material capable of increasing the electrical resistance thereof, permitting the metal to solidify, and then mechanically working the solidified metal, substantially as described.

9. The method of making an iron product having superior magnetic properties which consists in melting and refining a low carbon iron *in vacuo*, permitting the iron to solidify, mechanically working the solidified metal, and then annealing the metal, substantially as described.

10. The method of making an iron product having superior magnetic properties which consists in melting and refining a low carbon iron *in vacuo*, treating the molten

iron with a material capable of increasing the electrical resistance thereof, then permitting the metal to solidify, mechanically working the metal, and then annealing, substantially as described.

11. The method of making an iron product having superior magnetic properties which consists in melting and refining a ferrous metal and subjecting the refined molten metal to the action of a vacuum to thereby degasify and further refine it, permitting the metal to solidify, mechanically working the metal, and then annealing, substantially as described.

12. The method of making an iron product having superior magnetic properties which consists in melting and refining iron, and subjecting the molten metal to the action of a vacuum to thereby degasify and further refine it, treating the refined molten iron with a material capable of increasing the electrical resistance thereof, permitting the metal to solidify, mechanically working the solidified metal, and then annealing, substantially as described.

13. The method of making an iron product having superior magnetic properties which consists in subjecting a refined molten iron in which manganese, sulfur and phosphorus have been reduced to 0.05 per cent, or less when taken in the aggregate, and carbon to 0.02 per cent. or less, to the action of a vacuum and treating the molten iron with a deoxidizing agent to such extent that the product shall contain not over 0.05 per cent. oxygen, substantially as described.

14. The method of making an iron product having superior magnetic properties which consists in subjecting a refined molten iron in which manganese, sulfur, and phosphorus have been reduced to 0.05 per cent. or less when taken in the aggregate, and carbon to 0.02 per cent. or less to the action of a vacuum, and treating the molten iron with a material capable of increasing the electrical resistance thereof, substantially as described.

15. The improved method of making an iron product having superior magnetic properties, which consists in subjecting a refined molten iron in which manganese, sulfur, and phosphorus have been reduced to 0.05 per cent. or less when taken in the aggregate, and carbon to 0.02 per cent. or less to the action of a vacuum, treating the molten iron with a deoxidizing agent to such extent that the product shall contain not over 0.05 per cent. oxygen, permitting the iron to solidify, and then mechanically working the solidified metal, substantially as described.

16. The method of making an iron product of superior magnetic properties which consists in subjecting a refined molten iron in which manganese, sulfur, and phosphorus have been reduced to not over 0.05 per cent. when taken in the aggregate, and carbon to not over 0.02 per cent. to the action of a vacuum, and treating the molten iron with a material capable of increasing the electrical resistance thereof, permitting the metal to solidify, and mechanically working the solidified metal, substantially as described.

17. The improved method of making an iron product having superior magnetic properties which consists in subjecting a refined molten iron in which manganese, sulfur and phosphorus have been reduced to not over 0.05 per cent. when taken in the aggregate, and carbon to not over 0.02 per cent. to the action of a vacuum, treating the molten iron with a deoxidizing agent to such extent that the product shall contain not over 0.05 per cent. oxygen, permitting the iron to solidify, mechanically working the solidified metal, and then annealing, substantially as described.

18. The method of making an iron product of superior magnetic properties which consists in subjecting a refined molten iron in which manganese, sulfur, and phosphorous have been reduced to not over 0.05 per cent. when taken in the aggregate, and carbon to not over 0.02 per cent. to the action of a vacuum, and treating the molten iron with a material capable of increasing the electrical resistance thereof, permitting the metal to solidify, mechanically working the solidified metal, and then annealing, substantially as described.

19. The method of making a magnetic iron product having superior magnetic properties which consists in melting a low carbon iron *in vacuo* and thereby refining the iron and then slowly cooling the product, substantially as described.

20. A magnetic metallic body, crystalline in structure, containing at least 90 per cent. iron and having intercrystalline impurity forming elements aggregating less than 0.15 per cent. and characterized by a magnetic permeability of 13,000–70,000 at a flux density between 5,000 and 10,000 gausses; substantially as described.

21. A magnetic metallic body, crystalline in structure, containing at least 90 per cent. iron and having intercrystalline impurity forming elements aggregating less than 0.15 per cent. and characterized by a hysteresis energy loss for maximum inductions of 10,000 and 15,000 gausses of 250–1000 and 575–2000 ergs per cubic centimeter of metal per magnetic cycle respectively, substantially as described.

22. A magnetic metallic body, crystalline in structure, containing at least 90 per cent. iron and having intercrystalline impurity forming elements aggregating less than 0.15 per cent. and characterized by a coercive

force for a maximum induction of 15000 gausses of 0.085–0.350 gilberts per centimeter; substantially as described.

23. A magnetic metallic body, crystalline in structure, containing at least 99.80 per cent. iron, having intercrystalline impurity forming elements aggregating not over 0.15 per cent. having specific weight of at least 7.9 and having a magnetic permeability of 13,000 to 70,000 at a flux density of between 5,000 and 10,000 gausses; substantially as described.

24. A magnetic metallic body, crystalline in structure, containing at least 90 per cent. iron, the remainder being chiefly silicon or aluminum, and having intercrystalline impurity forming elements aggregating less than 0.15 per cent, and characterized by a magnetic permeability of 13,000–70,000 at a flux density between 5,000 and 10,000 gausses; substantially as described.

25. A magnetic metallic body, crystalline in structure, containing at least 90 per cent. iron, the remainder being chiefly silicon or aluminum, and having intercrystalline impurity forming elements aggregating less than 0.15 per cent. and characterized by a hysteresis energy loss for maximum inductions of 10,000 and 15,000 gausses of 250–1000 and 575–2000 ergs per cubic centimeter of metal per magnetic cycle respectively; substantially as described.

26. A magnetic metallic body, crystalline in structure, containing at least 90 per cent. iron, the remainder being chiefly silicon or aluminum, and having intercrystalline impurity forming elements aggregating less than 0.15 per cent. and characterized by a coercive force for a maximum induction of 15,000 gausses of 0.085–0.350 gilberts per centimeter; substantially as described.

TRYGVE D. YENSEN.

Witnesses:
LILLIAN R. CROMWELL,
MILTON T. MILLER.