July 25, 1939. C. SCHAARWÄCHTER ET AL 2,167,188

SOUND RECORDING AND REPRODUCING ELEMENT, AND MORE PARTICULARLY A PERMANENT MAGNET THEREFOR

Filed Feb. 26, 1937 2 Sheets-Sheet 1

Fig. 1.

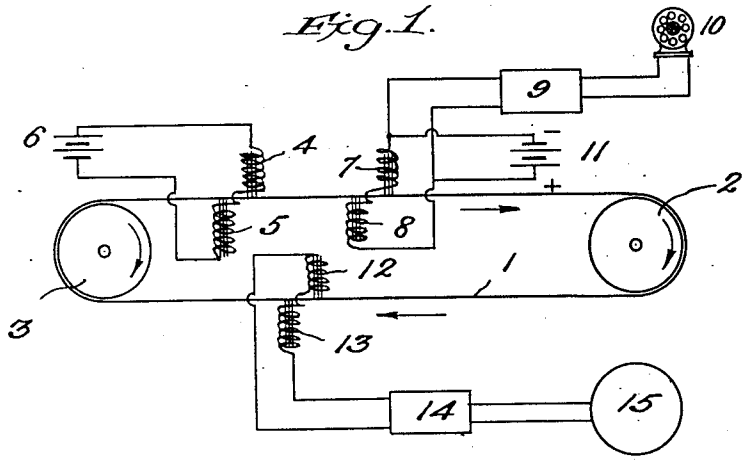
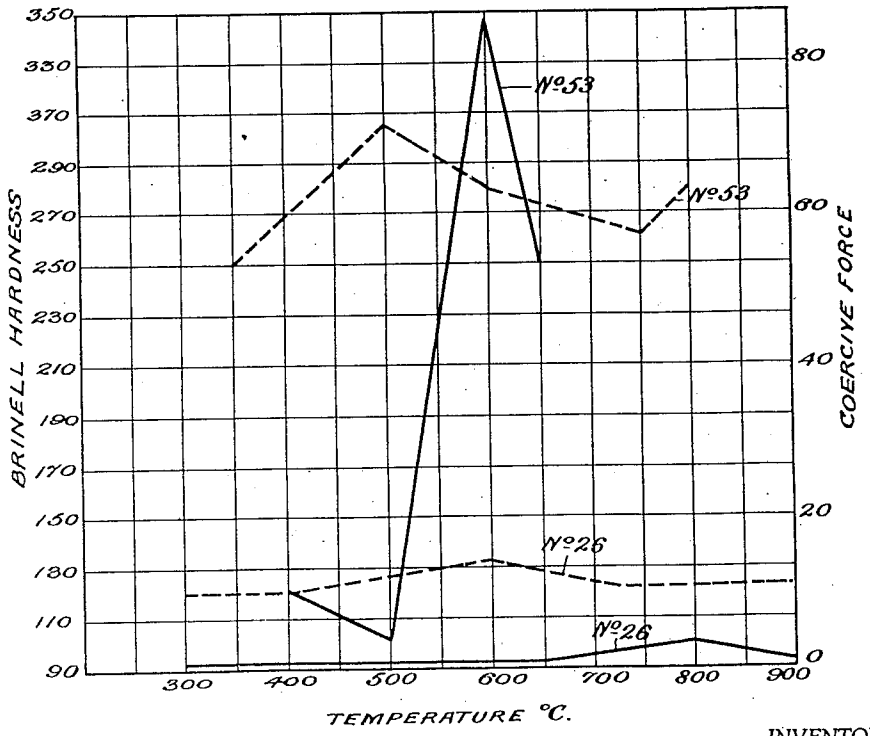



Fig. 2.




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MACHINE ELEMENTS AND MECHANISMS

CROSS REFERENCE

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25

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Filed Feb. 26, 1937 2 Sheets-Sheet 2

Fig. 3.

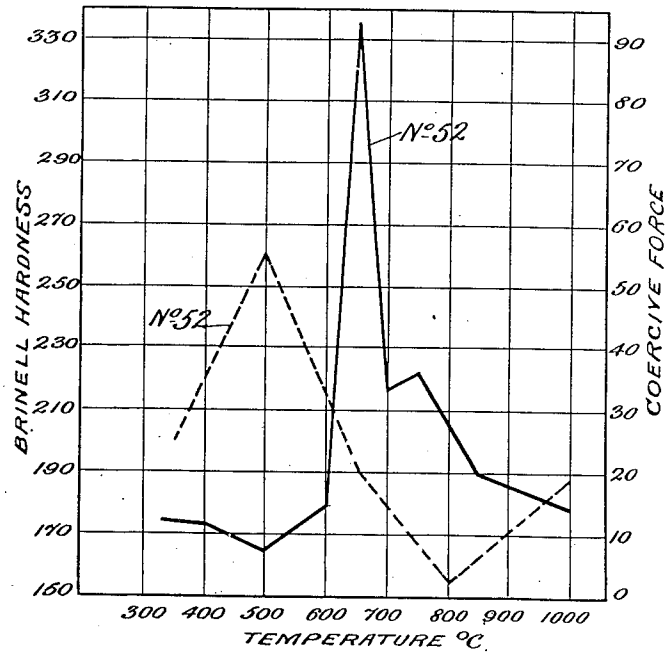
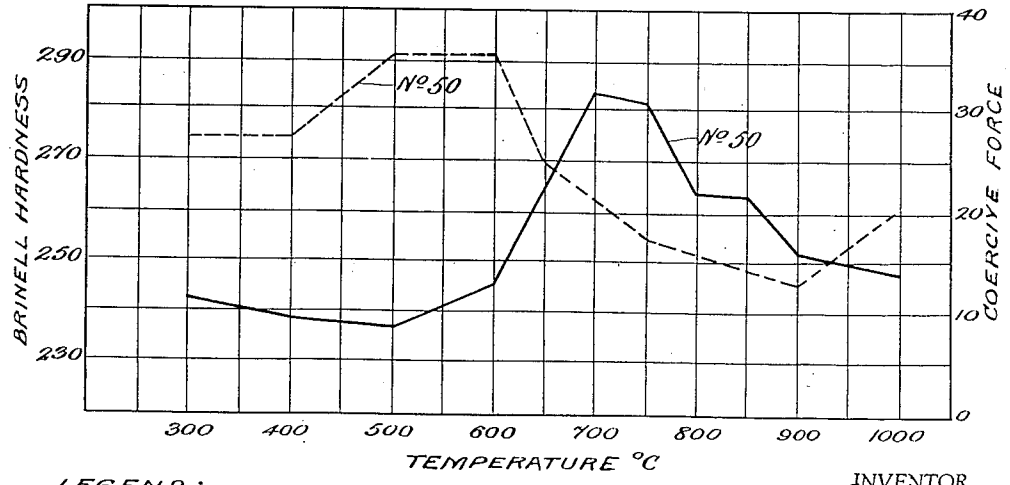



Fig. 4.




LEGEND :-

------ BRINELL HARDNESS

——— COERCIVE POWER

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# UNITED STATES PATENT OFFICE

2,167,188

## SOUND RECORDING AND REPRODUCING ELEMENT, AND MORE PARTICULARLY A PERMANENT MAGNET THEREFOR

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Application February 26, 1937, Serial No. 127,810
In Germany March 2, 1936

12 Claims. (Cl. 274—41.4)

The present invention relates to a sound recording and reproducing element, and more particularly to a permanent magnet therefor.

Heretofore various proposals have been made in the sound reproducing and recording art to utilize metallic strips, wires, and other elements for recording sound and subsequently reproducing. Among the outstanding applications of these proposals may be mentioned devices for recording and reproducing dictation, phonographic records, automatic telephone call receiving systems, and talking motion pictures. The investigators in this art were searching for a metallic permanent magnet which could be made in commercial quantities on an industrial basis and which possessed requisite properties including ductility, workability and uniformity. During the early development in this art, attempts were made to use steel wires, but it was soon found out that certain disadvantages were found which made it impractical for successful commercial operations. In more recent years proposals have been made to use cobalt steel, but cobalt steel likewise has shortcomings, including non-uniformity, high cost, and the like. Endeavors have been made to provide the art with better, more uniform and cheaper permanent magnets which were composed of a metal or alloy which could be manufactured on a commercial basis and which possessed the unusual combination of properties required in this art. Thus, Swiss Patent No. 127,077 describes a magnet which is soft and which does not retain any subsequent amount of residual magnetism. As is known, a soft magnet can be magnetized with a relatively low magnetizing force, but immediately loses its magnetism when the magnetizing force is discontinued. Other patents and publications including United States Patents Nos. 1,803,353, 1,805,049, 1,853,575, and 1,992,325, describe alloys some of which may possess properties which may have made them useful as soft magnets, but none of these alloys per se would have been useful as permanent magnets for sound recording and reproducing systems. Although various attempts and proposals have been made, none, as far as is known, has successfully and fully solved the problem and provided the art with a completely satisfactory permanent magnet for sound recording and reproducing purposes.

We have discovered a permanent magnet which has special utility for use as a sound recording and reproducing element. It has been found that special iron, nickel, copper alloys having critical narrow ranges when subjected to a special heat-treatment and subsequent magnetizing treatment produce surprisingly new permanent magnets, possessing a relatively high coercive force. It has been found that the high coercive force is due to two dominant critical factors. The first factor is the extremely high supersaturation of the alpha iron crystals with nickel and copper, due to their presence in critical percentages and due to the special heat-treatment. The second factor is the production by a special re-heating operation to produce a fine dispersion of sub-microscopic segregations of mixed crystals composed substantially entirely of copper and nickel. The unusually fine dispersion which is obtained is probably due to a phenomenon known as "lockerstellen" or of loose spots in the crystal lattice. The phenomenon of lockerstellen is due to the transformation of gamma iron crystals to alpha iron crystals at temperature below that of recrystallization of the present special alloy.

It is an object of the invention to provide an improved sound recording and reproducing apparatus especially one provided with a novel uniform alloy steel strip or wire or element which is an efficient permanent magnet and which records sound accurately and which effectively reproduces the recorded sound even after considerable periods of time.

A further object of the invention is the provision of a process for producing permanent magnets made from special alloy steels containing critical percentages of copper and of nickel.

It is also within the contemplation of the invention to provide a process of producing permanent magnets from special alloy steels which are subjected to special heat treatment for the improvement of properties especially the coercive force and residual magnetism and the subsequent magnetization by treatment with a magnetizing force.

Other objects and advantages of the invention will become apparent from the following description taken in conjunction with the accompanying drawings in which—

Fig. 1 is a diagrammatic view of the improved sound recording and reproducing apparatus;

Fig. 2 depicts a graph illustrating the Brinell hardness and the coercive force of the present special alloys in a soft and in a hard condition after heating to various temperatures in comparison with a steel alloy not possessing the critical composition of the present permanent magnet;

Fig. 3 is a graph illustrating another embodiment of the present permanent magnet and

showing the extraordinarily high forces which can be produced; and

Fig. 4 is another view similar to Fig. 3 of still another embodiment of the new permanent magnet.

Referring more particularly to Fig. 1, the reference character 1 is a steel band which is tensioned between a pair of rollers 2 and 3 and which is adapted to be moved at a substantially constant rate of speed. Coils 4 and 5 are energized by means of a source of direct current 6 which effects a uniform magnetization of band 1 throughout its full length. Coils 7 and 8 are connected with an amplifier 9, which amplifies the sound currents produced by a microphone 10 which is exposed to the effect of the sound oscillations to be recorded. Generally speaking, it is preferred to provide a preliminary magnetization of the recording coils by means of a weak electric current derived from a source 11. Coils 12 and 13 are connected with a second amplifier 14 which amplifies the incoming weak electrical currents and introduces them into a loud speaker 15.

From the preceding description, the operation of the magnetic sound recording and reproducing system will be readily understood by those skilled in the art. Special alloy steel band 1 is passed at a uniform speed of say about 1.5 meters per second, between the two recording coils 7 and 8 which are arranged opposite to each other and are displaced with respect to each other by about 0.25 to about 0.50 mm. The two coils are connected in series and constitute the so-called recording head which is lightly pressed by means of a spring against the moving band 1. The sound waves received by the microphone are converted into electrical oscillations and are amplified by the amplifier. The band passing through the recording head is thus magnetized in accordance with these electrical oscillations. When it is desired to reproduce the sound recorded on the band, a second system of coils 12 and 13, the so-called reproducing head is subjected to the effect of the magnetic field produced by the band whereby an alternating electro-motive force will be induced in the reproducing coils 12 and 13. This alternating electro-motive force may be amplified by a suitable amplifier and the amplified currents are introduced into a loud speaker 15 or some other sound producing means whereby the original sound oscillations recorded on the band will be reproduced.

In order to obtain reproduction substantially free from distortion and thereby effect substantially perfect reproduction of the original sound, a pre-magnetizing head constituted of coils 4 and 5 is arranged in proximity to the band 1. This premagnetizing head causes strong and uniform magnetization of the band up to practically the maximum magnetism. By means of the unusually strong residual magnetism in the band and by means of employing a suitable negative biasing voltage in the recording coil, it is possible to so adjust the alternating magnetic field that the recording is carried out upon the most favorable and linear part of the hysteresis curve as those skilled in the art will readily appreciate.

According to the present invention the novel sound recording and reproducing element and permanent magnet therefor is made of a special ductile alloy steel consisting of about 70% to about 87% of iron, about 10% to about 20% of nickel and the balance substantially copper and constituted of alpha iron crystals super-saturated with copper and nickel and having a gamma-alpha transformation at a temperature below the re-crystallization temperature of said alloy and having an alpha-gamma transformation at a temperature higher than said gamma-alpha transformation temperature. The band may have in practice a cross-section of about 0.08 x 3 mms. Instead of the band, it is possible to use wire with about 0.22 mm. diameter. For best results the invention contemplates as a new article of manufacture, a sound recording and reproducing element elongated by working and made of a permanent magnet, comprising a ductile alloy consisting of about 70% to about 87% of iron, about 10% to about 20% of nickel and the balance substantially copper and constituted of alpha iron matrix supersaturated with copper and nickel and containing a fine dispersion of submicroscopic segregation of mixed crystals composed substantially of copper and nickel.

The present special alloy steels may be mechanically treated in the homogenized soft condition to an unusually high degree. Actual tests have demonstrated that the special steel alloys may be rolled to strip or drawn to wires and show between the new critical composition limits surprisingly high permanent or residual magnetism.

It was discovered that special steel alloys whose critical limits are about 70% to about 87% iron, about 3 to about 20% copper, and about 10 to about 20% nickel acquire unexpected permanent magnetic qualities after a special treatment involving heating and subsequent magnetization. These special steels consist of iron as a base and two additional critical metals present in critical percentages. The one metal is copper which is in part not miscible with the iron and the second is nickel which forms not only mixed crystals in all proportions with iron, but also forms a solid solution with the copper which supersaturates the alpha iron upon a special heat treatment. The nickel also effects a temperature hysteresis of the gamma alpha transformation which hysteresis increases with increasing amounts of iron.

From a theoretical point of view the binary iron-copper system shows that the gamma iron has a greater solubility for the copper than the alpha iron. In the event that nickel is present, more copper and nickel would be dissolved in the gamma iron than in the alpha iron. With alloy steels having compositions outside of the present critical ranges, the transformation of gamma iron into alpha iron occurs at higher temperatures at which a change of the places of the atoms in the lattice structure is effected. A part of the copper iron and of the nickel would then precipitate and cause objectionable segregation which is undesired. These detrimental segregations would coagulate into larger particles and would be incapable of effecting the improvement of the coercive power as contemplated by the present invention. If, on the other hand, the gamma-alpha transformation occurs as in the present invention at temperatures below the re-crystallization temperatures of the special steel alloys, say, for instance, at temperatures below 300° C., then there will be obtained highly supersaturated crystal lattices of alpha iron due to the freezing of the atom movements.

It was discovered that within these fields the coercive power and residual magnetism after homogenising, quenching and heating the alloys to a temperature up to somewhat above those used for precipitating hardening are rather high.

The special heat-treatment of the present steel

alloys is, according to the principles of the present invention, the following novel combination of operations. At first, it is necessary to homogenize the alloys by annealing them at a temperature within the homogenization limits. That is at temperatures above 900° C., say, for instance, at a temperature of about 1000° C. After this annealing, the alloys are quenched in order to preserve the homogenized structure at lower temperatures. After the quenching, the alloys may be worked, say rolled or drawn, etc., and the alloys are re-heated to a temperature within the irreversible region extending from the gamma-alpha transformation temperature to the alpha-gamma transformation temperature. This reheating is preferably conducted at a temperature above those temperatures heretofore employed for conventional hardening. If reference is made to Fig. 3, this special relation will be clearly appreciated. It was found that by only using the foregoing reheating operation the highest coercive forces could be produced in the present steel alloys. The most useful temperature is just below the upper temperature limit of the irreversible transformation field, that is about 650° C.

Furthermore, there will be developed a phenomenon known as "gitterlockerstellen" during the gamma-alpha transformation. By then increasing the temperature, a segregation in the form of a very fine dispersion of sub-microscopic particles composed substantially of nickel, iron and copper will progress at the loose spots of the lattice structure.

There are accordingly two dominant and critical factors which make it possible to obtain a high coercive force in the present special steel alloys. One of these factors is the extremely high over-saturation of the alpha iron crystals in consequence of homogenising and quenching these alloys having the gamma-alpha transformation at relatively low temperatures. The other or second factor is the segregation caused by reheating in a very fine form of the submicroscopic nickel-copper crystals due to the "lockerstellen". The copper content, therefore, has to be maintained between the critical percentages of about 3 to about 20%, the iron content from about 70% to about 87%, and the nickel content from about 10% to about 20%.

For the purpose of giving those skilled in the art a better understanding of the invention, the following illustrative examples are given. In Fig. 2 are shown the qualities of two alloys, numbered 53 and 26 after the same heat treatment. The compositions of these alloys are as follows:

| | Iron | Nickel | Copper |
|---|---|---|---|
| | *Percent* | *Percent* | *Percent* |
| No. 53 | 75 | 20 | 5 |
| No. 26 | 60 | 25 | 15 |

Alloy No. 53 has a composition according to the invention, whilst alloy No. 26 has a composition beyond the critical limits contemplated by the invention. Alloy No. 26 has only a maximum of coercive power of about 3.0 oersteds. The alloy 53 has a remarkable coercive power up to 85 oersteds. The maximum coercive power of alloy 53 is reached after heating to 600° C., whilst the maximum coercive power of alloy 26 is reached only at 800° C.

In addition, the quality index, [B×H] max./8π, within the irreversible field increases with increasing nickel content, and somewhat with increasing copper content. The diagrams depicted in Figs. 2 to 4 show the maximum coercive power for various nickel contents. The composition of the alloys is the following:

| | Fe | Ni | Cu | $H_c$max. |
|---|---|---|---|---|
| | *Percent* | *Percent* | *Percent* | *Oersteds* |
| No. 50 | 85 | 10 | 5 | 32 |
| No. 52 | 80 | 15 | 5 | 93 |
| No. 53 | 75 | 20 | 5 | 85 |

A further illustrative example is the alloy containing 75% iron, 15% of nickel, and 10% of copper. This alloy, after the above-mentioned heat-treatment has 200 oersteds, 6000 gauss, an energy [B×H] max. of 533,000; and a quality index [B×H] max./8π of 21500. The alloy containing 77.5% iron, 15% of nickel, 7.5% of copper, has 150 oersteds; an energy of 400,000; and a quality index of 16,000. This alloy may be easily and readily worked hot and cold.

An illustrative example for the production of sound recording and reproducing wires is the following: The alloy with 75% iron, 20% nickel, and 5% copper is melted and hot-rolled down to about 6 mms. wire in the usual manner. Then it was pickled and cold drawn to 2.2 mms. Now the wire was annealed in an annealing furnace, at a temperature of about 900° C. to 1000° C. in a hydrogen atmosphere. The wire then was cold drawn to 1.2 mms. and annealed again in the foregoing manner. The wire was cold drawn to the finer diameter of 0.22 mm. Now, in order to give it the magnetic hardening, the wire was slowly heated in an annealing furnace for about 25 seconds at 515° C. The thus-treated wire had the following qualities: tensile strength of 152 kilograms/mm.$^2$; elongation of 0.5 to 1%, coercive power of 60 oersteds; and a residual magnetism of 6000 gauss.

The special heat treatment consists in successive re-heatings at slightly increased temperatures followed each time by quenching in water. Thus, for instance, the material was heated one-half hour to 500° C., quenched in water, and then re-heated another half-hour at 650° C. With this process, the highest magnetic effects may be obtained.

Cobalt may be substituted for iron to some extent. The percentage of cobalt should not be higher than about 20%, so that iron is always present to more than 50%.

The nickel may be substituted in part or fully by manganese, platinum, or palladium, and the copper may be substituted by gold. All these substitutes have practically the same effect on the structure of the iron and, therefore, on the magnetic qualities as nickel, or copper, respectively.

Small amounts of additional auxiliary metals, as, for instance, aluminum up to 3%, vanadium, chromium, or molybdenum up to 10%, may be present without materially changing the aforesaid qualities and results.

It is claimed:

1. As a new article of manufacture an elongated sound recording and reproducing element having a worked structure and capable of being permanently magnetized, comprising a ductile alloy consisting of about 70% to about 87% of iron, about 10% to about 20% of nickel and the balance substantially copper and constituted of alpha iron crystals super-saturated with copper and nickel and having a gamma-alpha transformation at a temperature below the recrystal-

lization temperature of said alloy and having an alpha-gamma transformation at a temperature higher than said gamma-alpha transformation temperature.

2. As a new article of manufacture, an elongated sound recording and reproducing element having a worked structure and capable of being permanently magnetized, comprising a ductile alloy consisting of about 70% to about 87% of iron, about 10% to about 20% of nickel and the balance substantially copper and constituted of alpha iron matrix super-saturated with copper and nickel and containing a fine dispersion of sub-microscopic segregations of mixed crystals composed substantially of copper and nickel.

3. As a new article of manufacture, an elongated sound recording and reproducing element having a worked structure and capable of being permanently magnetized, comprising a ductile alloy consisting of about 70% to about 87% of iron, about 10% to about 20% of nickel and the balance substantially copper and constituted of alpha iron crystals super-saturated with copper and nickel and having a gamma-alpha transformation at a temperature below the recrystallization temperature of said alloy and having an alpha-gamma transformation at a temperature higher than said gamma-alpha transformation temperature, said alloy having been subjected to heat-treatment involving heating to a temperature aboout 900° C., quenching the thus heated alloy and re-heating the quenched alloy to a temperature of about 500 to 650° C..

4. As a new article of manufacture, an elongated sound recording and reproducing element having a worked structure and capable of being permanently magnetized, comprising a ductile alloy consisting of about 70% to about 87% of iron, about 10% to about 20% of nickel and the balance substantially copper and constituted of alpha iron matrix super-saturated with copper and nickel and containing a fine dispersion of sub-microscopic segregations of mixed crystals composed substantially of copper and nickel, said alloy having been subjected to heat-treatment involving heating to a temperature above about 900° C., quenching the thus heated alloy, cold-working said quenched alloy, and re-heating the quenched alloy to a temperature of about 500 to 650° C.

5. As a new article of manufacture, an elongated sound recording and reproducing element having a worked structure and capable of being permanently magnetized, comprising a ductile alloy consisting of about 75% iron, about 20% nickel, and about 5% copper and constituted of alpha iron crystals super-saturated with copper and nickel and having a gamma-alpha transformation at a temperature below the recrystallization temperature of said alloy and having an alpha-gamma transformation at a temperature higher than said gamma-alpha transformation temperature.

6. As a new article of manufacture, an elongated sound recording and reproducing element having a worked structure and capable of being permanently magnetized, comprising a ductile alloy consisting of about 78% iron, about 16% nickel, and about 0.5% copper and 0.5% manganese and constituted of alpha iron crystals super-saturated with copper and nickel and having a gamma-alpha transformation at a temperature below the recrystallization temperature of said alloy and having an alpha-gamma transformation at a temperature higher than said gamma-alpha transformation temperature.

7. As a new article of manufacture, a worked permanent magnet made of an alloy consisting of about 70% to about 87% iron, about 10% to about 20% nickel and the balance substantially copper with minor impurities and constituted of alpha iron crystals super-saturated with copper and nickel and having an alpha-gamma transformation at a temperature substantially above 300° C., said alloy having a substantially permanent coercive force of more than about 30 oersteds, and having been subjected to heat-treatment involving heating to a temperature about 900° C., quenching the thus heated alloy and re-heating the quenched alloy to a temperature of about 500 to 650° C.

8. As a new article of manufacture, a worked permanent magnet made of an alloy consisting of about 70% to about 87% iron, about 10% to about 20% nickel and the balance substantially copper with minor impurities and constituted of alpha iron crystals super-saturated with copper and nickel and having an alpha-gamma transformation at a temperature substantially above 300° C., said alloy having been subjected to heat-treatment involving heating to a temperature above about 900° C., quenching the thus heated alloy and re-heating the quenched alloy to a temperature of about 500 to 650° C., and said alloy having a substantially permanent coercive force of more than about 30 oersteds.

9. As a new article of manufacture, a worked permanent magnet made of an alloy consisting of about 70% to about 87% iron, about 10% to about 20% nickel and the balance substantially copper with minor impurities and constituted of alpha iron crystals super-saturated with copper and nickel and having an alpha-gamma transformation at a temperature substantially above 300° C., said alloy having been subjected to heat-treatment involving heating said alloy to repeated heatings above the temperature of recrystallization but not higher than the alpha-gamma transformation temperature, said repeated heatings increasing in temperature, quenching the alloy after each heating, cold-working said quenched alloy, and re-heating the quenched alloy to a temperature of about 500 to 650° C., and said alloy having a substantially permanent coercive force of more than about 30 Oersteds.

10. The process of producing an easily workable permanent magnet made of an alloy consisting of about 70% to about 87% of iron, about 10% to about 20% of nickel, and the balance substantially copper, and having a high hysteresis of the gamma-alpha transformation which comprises heating said alloy to a temperature higher than about 900° C., quenching the thus heated alloy whereby a uniform structure constituted of alpha iron crystals super-saturated with copper and nickel is produced, reheating said quenched alloy to a temperature between the alpha-gamma transformation temperature and the gamma-alpha transformation temperature, and subsequently subjecting the thus heat-treated alloy to a magnetizing force whereby a permanent magnet is produced having a coercive force of at least 30 oersteds.

11. The process of producing an easily workable permanent magnet made of an alloy consisting of about 70% to about 87% of iron, about 10% to about 20% of nickel, and the balance substantially copper, and having a high hysteresis of the

gamma-alpha transformation which comprises heating said alloy to a temperature higher than about 900° C., quenching the thus heated alloy whereby a uniform structure constituted of alpha iron crystals super-saturated with copper and nickel is produced, subjecting the quenched alloy to repeated reheating at successively increasing temperatures higher than the gamma-alpha transformation temperature to below the alpha-gamma transformation temperature, quenching the re-heated alloy after each re-heating, and subsequently subjecting the thus heat-treated alloy to a magnetizing force whereby a permanent magnet is produced having a coercive force of at least 30 oersteds.

12. The process of producing an easily workable permanent magnet made of an alloy consisting of about 70% to about 87% of iron, about 10% to about 20% of nickel, and the balance substantially copper, and having a high hysteresis of the gamma-alpha transformation which comprises heating said alloy to a temperature higher than about 900° C., quenching the thus heated alloy whereby a uniform structure constituted of alpha-iron crystals super-saturated with copper and nickel is produced, cold-working said quenched alloy, subjecting the quenched alloy to repeated re-heating at successively increasing temperatures higher than the gamma-alpha transformation temperature to below the alpha-gamma transformation temperature, quenching the re-heated alloy after each re-heating, and subsequently subjecting the thus heat-treated alloy to a magnetizing force whereby a permanent magnet is produced having a coercive force of at least 30 oersteds.

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