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PERMANENT MAGNET OF COPPER-COBALT-NICKEL ALLOY

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Our invention relates to alloys and to methods for manufacturing permanent magnets having a great coercive force and a strong remanent magnetism.

In recent years it has been possible to manufacture with success high-grade permanent magnets of iron-nickel and iron-nickel-cobalt alloys containing aluminum or titanium. The materials are, however, only valuable as regards the magnetic properties. They present certain drawbacks in cases in which other properties are also essential. That is to say, the magnets consisting of such alloys are very difficult to machine; in general, they can only be ground, but cannot be machined by the use of drills and other cutting tools. It is, therefore, necessary that they be given their final form by casting. The alloys have a coarse-grained structure and tend to form flaws and pipes. That is the reason why the same favorable properties are not frequently attained in finished magnets as is possible with magnets free of flaws and pipes obtained in laboratories. The strength and the tenacity of the mentioned alloys are relatively small so that they can be hardly employed for mechanically highly stressed magnets; for instance, for rotating magnet wheels of electric machines or for other magnets, which are subjected when in operation to vigorous or continuous shocks.

Permanent magnets are known which may be machined by drills and cutting tools and which have also a greater strength and tenacity than the above-mentioned alloys containing aluminum and titanium. However, the magnetic properties, particularly the residual magnetism and the coercive force of the known machineable alloys are considerably inferior.

The object of our invention is the provision of alloys and of methods for manufacturing permanent magnets which have excellent magnetic properties and which are as regards the above-mentioned other properties superior to magnets consisting of nickel steels and cobalt-nickel steels containing aluminum and titanium.

According to our invention alloys containing 5 to 70% cobalt, 10 to 50% nickel and 20 to 85% copper are employed in the manufacture of permanent magnets.

Magnets consisting of such alloys have a very great coercive force and a strong residual magnetism. Depending upon the composition of the alloys a coercive force up to about 1,000 oersteds and a residual magnetism up to about 8,000 gauss may be obtained. In some alloys both the coercive force and the residual magnetism present higher values than those hitherto obtained. In this case the properties of the magnets are highly stable as to thermal influences and shocks. Furthermore, they have great strength and tenacity and tend to a considerably smaller extent to form flaws or pipes than is the case with the hitherto known high-grade magnetic alloys. The alloys according to the invention may be easily machined; for instance, by turning, milling, filing, drilling and other cutting operations.

Particularly favorable magnetic properties may be obtained with alloys containing 15 to 35% nickel, 20 to 65% copper and 15 to 65% cobalt.

The alloys according to the invention composed essentially of copper-nickel-cobalt may also contain other constituents. Particularly a portion of the nickel and cobalt content may be replaced by iron. By adding iron to the alloy the residual magnetism is in general increased, the coercive force lowered, and the machineability is improved. It is, therefore, possible with an iron content of about 5 to 10% to obtain also permanent magnets having superior magnetic properties. In exceeding a certain percentage of iron the magnetic power of the alloy, however, decreases. Consequently, the iron content should not exceed 30% of the total weight of the alloy. The alloys may contain other metals, such as manganese or chromium, and also traces of metalloids, such as silicon. The total percentage of the last-mentioned substances should be less than 5%. When using manganese the percentage of this metal should be less than 2%.

The alloys according to the invention have after casting already favorable magnetic properties which may, however, be considerably improved by heat treatment. To this end, heating for some hours at a temperature above 950 degrees centigrade, particularly between about 1,000 degrees centigrade and the melting point, has proved suitable. After annealing the alloys are cooled down. The rapidity with which the cooling is effected in the most favorable manner depends upon the composition of the alloy and upon the fact as to whether a greater coercive force or a

stronger residual magnetism is preferable. It is particularly advantageous to quench the alloys after annealing and to subject them to a further heat treatment at a temperature between 500 and 700 degrees centigrade.

In connection with the following table particulars as to the composition and heat treatment are hereinafter described.

Alloy No.	Per-cent Cu	Per-cent Ni	Per-cent Co	B_r	${}_JH_c$	$B_r \times {}_JH_c \times 10^{-3}$
1	60	20	20	1600	160	2.6
2	60	20	20	2100	930	19.5
3	40	20	40	4960	440	21.9
4	21	20	59	7930	110	8.5
5	30	20	50	6300	300	18.9
6	34	23	43	5340	373	19.9
7	37	25	38	4600	500	23.0
8	37.5	25	37.5	4000	520	20.8
9	45	25	30	3400	710	24.1
10	50	25	25	3300	760	25.4
11	50	30	20	3200	670	21.5
12	32	35	33	4540	460	21.8
13	35	40	25	3480	410	14.3

In this table the second, third and fourth columns contain the percentage of copper, nickel and cobalt, while the fifth column gives the value of the residual magnetism B_r, the sixth column that of the coercive force ${}_JH_c$ and the seventh column contains the product of the value of the fifth and sixth columns multiplied by 10^{-3} (${}_JH_c$ denotes the coercive force for a magnetization $J=0$ as compared to the value ${}_BH_c$=coercive force for an induction $B=0$).

The alloy 1 was investigated directly after chill casting without subsequent heat treatment and gave for B_r a value of 1,600 and for H_c a value of 160. The same alloy was then heated at 1,050 degrees centigrade, then quenched in oil and finally annealed for two hours at 650 degrees centigrade. The values thus obtained are those shown for the alloy No. 2. As will be seen from the above table the coercive force attained the particular high value of 930.

The alloy 3 was heated at a temperature of 1,150 degrees centigrade for five hours, then quenched in oil and finally annealed for four hours at 650 degrees centigrade.

The alloys 4, 5 and 10 were heated at 1,050 degrees centigrade, quenched in oil and then annealed for six hours at 650 degrees centigrade. This treatment gave according to the composition of the alloy particularly favorable values for the coercive force (alloy No. 10) or for the residual magnetism (alloy No. 4). Also some alloys are indicated in the table in which both the coercive force and the remanent magnetism have high values, for instance in the alloys No. 7 and 8.

The alloy 6 was heated for five hours at 1,150 degrees centigrade, quenched in oil and annealed for five hours at 650 degrees centigrade. Alloy 8 was heated for ten hours at 1,100 degrees centigrade, quenched in oil and then annealed for sixteen hours at 650 degrees centigrade. Alloy 9 was heated for ten hours at 1,100 degrees centigrade, quenched in oil and then annealed for thirty-two hours at 600 degrees centigrade.

The alloys 11 and 12 were heated for 10 hours at 1,100 degrees centigrade, quenched in oil and then annealed for sixty hours at 600 degrees centigrade. The alloy 13 was heated for five hours at 1,150 degrees centigrade, quenched in oil and then annealed for four hours at 650 degrees centigrade.

In heat treating alloys the time required for heating or annealing is, as a rule, the shorter, the higher the temperature at which the heat treatment is effected. If the alloys are annealed after heating and cooling or quenching—which is the case with the majority of the above-mentioned examples—the magnetic hardness (coercive force) increases considerably, for instance, up to 100 times and over the value obtained without annealing the alloys, whereas the mechanical hardness varies substantially to a lesser extent, generally only about from 5 to 10%. In the alloys indicated in the above table a mechanical hardness of 160 to 200 Brinell units was measured after casting, heating and quenching. After annealing, the hardness amounted to 180 to 200 Brinell units. This slight increase in mechanical hardness with increasing coercive force results in a further advantage of the alloy as compared to the permanent magnets hitherto known of great coercive force and residual magnetism. That is to say, the alloys according to the invention may be machined and given their final form not only prior to the heat treatment but also the magnetic properties may be at first improved by a heat treatment and the alloys may be then finally machined. In the case of martensitic magnet steels such a method of manufacture is not possible. With such steels the hardening can only be effected after the machining. In this case the magnets, particularly in the case of complicated forms, are liable to shrink or change their shape. This is avoided according to the invention.

The alloys according to the invention have great magnetic stability as manifested by low values of the reversible permeability μr. The reversible permeability is the permeability which corresponds to the intersection of the magnetization curve with the ordinate ($H=0$) after the material has been demagnetized from positive H values down to negative values and remagnetized up to the value $H=0$. This reversible permeability is a measure for the degree of stability of a permanent magnet against demagnetizing influences. As example the following further particulars are given as to the alloys 8 and 9. The composition and heat treatment of both alloys have been already mentioned above. In the alloy No. 8 BH_{max}=591,000. With an induction B=2,400 the reversible permeability μr=3.8. With B=3,200 μr=3.6. The values for μr are, therefore, very small. In the alloy No. 9 BH_{max}=690,000. With an induction B=2,000 μr=2.9 and with B=2,600 μr=2.8. The particular low values of the reversible permeability which in part lie below the values hitherto attained with high-grade magnetic alloys show that the magnetic stability for comparatively high values of the residual magnetism is extremely great. The magnets are, therefore, highly insensitive to the influence of demagnetizing fields.

Magnets according to the invention have, further, great thermal stability. This is due to the fact that the alloys while not having a martensitic character have a high Curie-point (700 to 900 degrees centigrade). The magnetic properties are, consequently, rather insensitive to thermal influences; heatings over 500 degrees centigrade will not impair the magnetic properties. Owing to the stable structure the alloys are further extremely insensitive to shocks.

For some purposes in electrical engineering it is essential that the magnets present the strongest possible residual magnetism rather than the highest values of the coercive force. In this connection the invention provides a method of man-

ufacturing alloys hitherto unknown which while having a strong residual magnetism are easily machineable. For such special cases alloys are preferably employed which have the following compositions: 20 to 35% copper, 10 to 35% nickel and over 35% cobalt. By adding iron the residual magnetism may be increased.

For other purposes in electrical engineering it is, however, more important to attain high values of the coercive force, in which case also a good machineability and strength are required. For such special cases alloys having the following compositions are particularly suitable: 40 to 65% copper, 15 to 30% nickel and less than 35% cobalt.

Magnets according to the invention may be advantageously employed in electricity meters, moving coil galvanometers, oscillographs, polarized relays, motors, generators, tachometers, magnetos and other inductors, electromagnetic and electrodynamic telephones, loudspeakers and microphones, magnetic couplings for measuring and controlling purposes, rotary magnets for signal transmitters employed in signalling systems, blow-out coils and magnetic compasses.

An important sphere of application is magnet wheels for electric machines and apparatus, further magnets for signalling systems, for instance, magnets for railways or other fields of application in which great resistance to shocks is important.

While the known aluminum-nickel-iron-, particularly nickel-iron-titanium-, iron-cobalt-molybdenum-, iron cobalt-tungsten- and similar alloys for permanent magnets have a cubic centered lattice, the alloys according to the invention have a face centered lattice.

We claim as our invention:

1. A permanent magnet formed of an alloy consisting substantially of 15–65% cobalt, 15–35% nickel, and 20–65% copper, and characterized by a coercive force above 100 oersted and a remanence above 1,000 gauss.

2. A permanent magnet formed of an alloy containing 5–70% cobalt, 10–50% nickel, the remainder substantially copper, characterized by a coercive force above 100 oersted and a remanence above 1,000 gauss.

3. A permanent magnet comprising 5–70% cobalt, 10–50% nickel, at least 20% copper, the remainder consisting of from traces to 5% of a metal of the chromium group and a small amount of impurities, said magnet being magnetized to have a coercive force above 100 oersted.

4. A permanent magnet composed essentially of 20–65% copper and a remainder of cobalt and nickel, the percentages of cobalt and nickel having a mutual proportion between ½ and ⅔, said magnet being magnetized so as to have a coercive force above 100 oersted.

5. A permanent magnet containing at most 85% copper, and a remainder consisting substantially of at least 5% cobalt and at least 10% nickel, the copper content forming a higher percentage than each of the metals cobalt and nickel, and the percentages of cobalt and nickel having a mutual proportion between ½ and ⅔, said magnet being magnetized so as to have a coercive force above 100 oersted.

6. A permanent magnet formed of an alloy comprising as essential ingredients 20–35% cobalt, 15–30% nickel, and 40–65% copper, characterized by a coercive force of above 100 oersted and a remanence above 1,000 gauss.

7. A permanent magnet formed of a machineable alloy consisting substantially of 15–65% cobalt, 15–35% nickel, 15–65% copper, minor additions and usual impurities, and having enhanced magnetic properties produced by a heating and quenching treatment and being magnetized to a coercive force above 100 oersted.

8. A permanent magnet comprising 15–35% nickel, 20–65% copper, the balance consisting substantially of cobalt and comprising from traces to 2% manganese, said magnet being magnetized to have a coercive force above 100 oersted.

9. A permanent magnet formed of an alloy containing 20–85% copper, and a remainder consisting substantially all of ferromagnetic metals comprising 5–70% cobalt and 10–50% nickel, and being magnetized up to a coercive force above 100 oersted and a remanence above 1,000 gauss.

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