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Paper No. 23

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BEFORE THE BOARD OF PATENT APPEALS
AND INTERFERENCES

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BOARD OF PATENT APPEALS
AND INTERFERENCES

Ex parte THOMAS A. PERRY
JOHN R. BRADLEY,
THADDEUS SCHROEDER,
and CARLTON D. FUERST

Appeal No. 94-3541
Application 07/789,702¹

ON BRIEF

Before SCHAFER and HARKCOM, Vice Chief Administrative Patent Judges, THOMAS and JERRY SMITH, Administrative Patent Judges.

THOMAS, Administrative Patent Judge.

ON REQUEST FOR RECONSIDERATION

Appellants ask that we reconsider our decision of February 28, 1995, wherein we sustained the rejection of claims

¹ Application for patent filed November 8, 1991. According to applicants, this application is a Division of Application 07/589,359, filed September 28, 1990, now U.S. Patent No. 5,091,021.

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13, 14, 16-20 and 24 under 35 U.S.C. §§ 102/103 over Ara alone and the rejection of claim 15 under 35 U.S.C. 103 over Ara in view of Hattori.

Pages 10 and 11 of our original opinion contain an analysis of Ara from which we concluded at the bottom of page 11 that appellants' "position that the initial state of the common carbon steel in Ara is that it is softly magnetic and does not have permanent magnetic material properties is contrary to the weight of the evidence." Even after conducting a detailed study of the entirety of appellants' request for reconsideration, we adhere to this original view. We do this for two reasons.

First, appellants' reference to Figure 4 of Ara at page 3831 is noted. The discussion of this figure at the bottom of column 1 of this page not only indicates that the peaks shown in this figure indicate the presence of remnant magnetism in the beam-irradiated tracks, the

profiles shown by the dash-dot lines are of the magnetized base specimens. Their slopes and deviations from the zero-gauss line are caused by the magnetizing field which flowed in the direction of the plane of the specimen during magnetization (Fig. 2(a) [sic 3(a)]).

Thus, it appears to us that there is some measure of retained magnetism in the non-irradiated base S35C or 1035 steel after the magnetic field in Ara has been removed. This indicates to us that the so-called ferromagnetic S35C (1035) steel in Ara

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exhibited permanent magnet-type properties of the type required by claim 24 on appeal.

The above-noted portions of Ara seem to confirm our view expressed in the original opinion and controvert appellants' assertion at pages 7 and 8 of the request for reconsideration. We conclude that Ara's teachings would have indicated to the artisan the opposite of what appellants have set forth in footnote 6 at the bottom of page 7 of the request for reconsideration:

If the S35C steel ferrite/pearlite substrate had possessed permanent magnet properties Ara et al could have obtained a remnant magnetic field in it without transforming portions of it to martensite. However, they did not obtain remnant magnetization in the ferrite because it was not capable of retaining magnetic flux even though "ferromagnetic".

The second reason for maintaining our conclusion in the original opinion that the weight of evidence indicated to us that Ara taught to the artisan that the ferromagnetic S35C or common 1035 steel would have indicated to the artisan that it exhibited permanent magnet-type characteristic is confirmed again by reference to the Kirk-Othmer Encyclopedia of Chemical Technology.² The beginning of the second full paragraph at page

² Kirk-Othmer Encyclopedia of Chemical Technology, Third Edition, Vol. 14, 1981, pp. 650-651. Copy attached. This encyclopedia is considered to be a standard reference work and has been noted by us to substantiate facts in the evidentiary showing already made by the examiner and is submitted now in
(continued...)

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651 states that "[l]ow carbon steel for use as soft magnetic material contains <0.10 wt% C." This indicates to us that the percentage weight of carbon in the ferromagnetic S35C or 1035 steel in Ara would have been fairly characterized by the artisan as a hard magnetic material since it contains carbon exceeding 0.10 wt%, that is, in the range from 0.32 to 0.38 percent, as shown in the table at the bottom of column 1 at page 3830 of Ara.

Appellants' submission of the various recently issued U.S. patents referring to various ferromagnetic soft materials as being other than a permanent magnet, as discussed at page 9 of the request for reconsideration, have been noted but do not lead us to conclude that there is any error in our original opinion especially in light of what we have just noted here.

Therefore, the weight of the evidence leads us to the same conclusion as we made at page 11 of our original opinion. Other than the noted U.S. patents, appellants have submitted no objective evidence to lead us to conclude that the ferromagnetic S35C or common 1035 steel in Ara is softly magnetic.

Finally, we again make reference to pages 13 and 14 of our original opinion which relates to the product-by-process

²(...continued)
light of appellants' arguments in the request for reconsideration. In re Boon, 439 F.2d 724, 169 USPQ 231 (CCPA 1971). As such, it is not considered to be a basis of a new ground of rejection.

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limitations set forth in the latter half of claim 24 on appeal. There, among other points raised, we indicated that the manner of making the claimed magnet has not been shown by appellants by appropriate evidence to be a structural feature. We adhere to this conclusion in this decision on reconsideration even in view of appellants' arguments with respect to the process limitations at pages 10-12 of the request for reconsideration.

Even considering the merits of the arguments presented in the request for reconsideration in the above noted pages, it is noted that claim 24 does not require that a phase or structural change occur in the underlying permanent magnet material. The bottom of page 11 of the request for reconsideration indicates that the underlying microstructure remains unchanged. This is also stated at the bottom of page 7 of the specification as filed.

There is also no upper temperature limit claimed and there is no mention of the Curie temperature of the underlying material which appears only according to the disclosed invention to be a threshold or critical temperature. All that the claim requires is that the broadly defined "energy" directed into the unmagnetized substrate "selectively heat a volume in the substrate to lower its coercivity of the surrounding portion of the substrate." Therefore, from the readers' point of view, the reference to the McGraw-Hill Encyclopedia of Science and

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Technology³ at pages 14 and 15 of our original opinion still appears to be appropriate. We made passing mention of this reference for the proposition that it was known in the art to cool a heated permanent magnet material in a magnetic field through the Curie temperature and below.

In our deliberations with respect to the request for reconsideration we have also become aware of certain portions of the Metals Handbook⁴ issued by the American Society for Metals. At page 599 of this reference it has also been well-known in the art, given the 1948 copyright date of this reference, that the heat treatment for the Alnico 5-type of permanent magnet material indicates that the material was heated to a high temperature and aged for a relatively long length of time. The process of making a permanent magnet out of this material "requires cooling from the solution temperature [a higher temperature] in a magnetic field oriented to conform to the pattern of magnetization desired in the finished magnet."

³ McGraw-Hill Encyclopedia of Science and Technology, Vol. 8 McGraw-Hill, Inc., (1971), pp. 36-37.

⁴ Metals Handbook, American Society for Metals, (1948), pp. 595-599. Copy attached.

As we concluded at page 15 of our original opinion, we also conclude with respect to the Metals Handbook reference that it may well have been obvious to the artisan to have applied this well-known knowledge in the art to the teachings of Ara to form selected strong or relatively stronger magnetic field regions in a hard or permanent magnetic material. We also repeat our additional observation at page 15 of our original opinion that the obviousness of using a higher carbon content steel than Ara's 0.35% would have been apparent to the artisan in view of common knowledge in the art that the 1% carbon steel (Item 1 page 36 of McGraw-Hill Encyclopedia) has been considered a hard magnetic material.⁵

In view of the foregoing, appellants' request for reconsideration is granted to the extent that we have in fact reviewed our findings but is denied as to making any change therein.

⁵ Appellants' make an inapposite reference to dependent claim 15 and the additional reference to Hattori at page 12 of the request for consideration. Inasmuch as appellants have made no arguments to any dependent claim in the brief and reply brief (our original opinion at page 9), no new arguments will be entertained here.

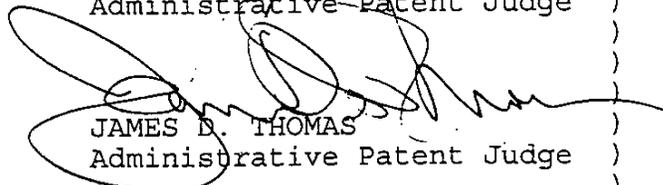
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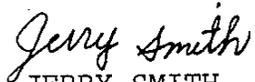
No time period for taking any subsequent action in connection with this appeal may be extended under 37 CFR 1.136(a).

DENIED


RICHARD E. SCHAFEE, Vice
Administrative Patent Judge)


GARY V. HARKCOM, Vice
Administrative Patent Judge)


JAMES D. THOMAS
Administrative Patent Judge)


JERRY SMITH
Administrative Patent Judge)

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coercive-field strength or coercive force or coercivity, the induction is zero. Upon increase of field, the induction follows curve 3, completing the hysteresis loop. Commercial magnetic materials generally are classified into soft magnets, with $H_c \lesssim 10$ A/cm (12.6 Oe), and hard or permanent magnets, with $H_c \gtrsim 100$ A/cm (126 Oe). A number of recent applications make use of semihard magnets, with 10 A/cm $\lesssim H_c \lesssim 100$ A/cm.

For permanent-magnet materials where the coercivity is large, the demagnetization curve, which corresponds to the second quadrant of the hysteresis loop, sometimes is plotted as the polarization $J (= B - \mu_0 H)$ vs H ($B - H$ vs H) to show the intrinsic characteristics of the material. The value of H for which $J = 0$ is the intrinsic coercivity H_{cJ} , whereas the usual coercivity, for which $B = 0$, is denoted by H_{cB} or H_c . For permanent magnets, the value $(BH)_{\max}$, the maximum energy product, is provided. The value $(BH)_{\max}$, indicated in the second quadrant of Figure 1, represents the point of maximum efficiency where a given amount of flux is carried by the smallest amount of material.

For soft magnetic materials, the permeability $\mu = B/H$ represents the slope of the $B - H$ curve. The most often quoted values are the initial permeability μ_i and the maximum permeability μ_m . These correspond to the initial and maximum slopes of the virgin magnetization curve, respectively (Fig. 1). Since the value of μ_i at $B, H = 0$ needs to be extrapolated from measurements at finite H , the value often is quoted in commercial catalogues at specific B or H . The quoted values usually are relative to the free-space value μ_0 .

Other forms of permeability often are quoted as related to specific applications (9). A term closely related to the permeability is the volume susceptibility $\kappa = M/H$ which particularly characterizes diamagnetic and paramagnetic substances. A variety of susceptibilities is given in ref. 5.

When a ferromagnetic or ferrimagnetic substance is heated, the value of saturation polarization J_s decreases with temperature and reaches a zero value at the Curie temperature T_c or Curie point. Above this temperature, the material becomes paramagnetic since the magnetic moments of the atoms are prevented by the thermal agitation from spontaneous alignment. The equivalent temperature for the transition from antiferromagnetism to paramagnetism is the Néel temperature.

Soft Magnetic Materials

Soft magnetic materials are characterized by high permeability and low coercivity. There are six major groups of commercially important soft magnetic materials in use: iron and low carbon steels, iron-silicon alloys, iron-aluminum and iron-aluminum-silicon alloys, nickel-iron alloys, iron-cobalt alloys, and ferrites. In addition, some amorphous soft magnetic alloys appear promising (see Amorphous magnetic materials).

Iron and Low Carbon Steel. Like all soft magnetic materials, iron and low carbon steel are characterized by high permeability and low coercivity. Research-grade iron (99.99+% pure) generally is obtained by zone refining and electrodeposition from high purity salts; total metallic and nonmetallic impurity levels are as low as 10-20 ppm. Such purity generally is too expensive for commercial use. Commercially pure iron, often referred to as Armco iron or magnetic ingot iron, is 99.9% pure, with the chief impurity being oxygen (0.15 wt %) which is tied up as oxide inclusions and which does

not affect the magnetic properties greatly. Typical magnetic properties of annealed sheet which has been prepared from magnetic ingot iron are shown in Table 1 (10) and Figure 2. The annealing is carried out at about 800°C. The carbon and nitrogen that is dissolved in the lattice at this temperature, however, can precipitate at low temperature, causing magnetic aging which is manifested by a rise in coercivity. Nitrogen, in particular, precipitates slowly at room temperature, but the aging can be hastened by a heat treatment at ca 100°C which stabilizes the material.

Another way of stabilizing the iron is to add elements, eg, titanium and aluminum, to tie up the carbon and nitrogen in stable compounds. This type of iron is known as electromagnet iron and its magnetic properties are shown in Table 1. The magnetic properties of both types of commercially pure iron are nearly equivalent, with electromagnet iron having a somewhat larger resistivity and smaller coercivity. Iron with exceptionally low coercivity and high permeability can be prepared by careful annealing in pure H₂ at temperatures above 1300°C.

Low carbon steel for use as soft magnetic material contains <0.10 wt % C. It is considerably less expensive than the Si-Fe alloys and has reasonably good magnetic properties after decarburization. Therefore, it is widely used in low intermittent duty motors where cost is of primary importance and loss is secondary. Typical magnetic properties of decarburized, low carbon steel sheets are shown in Table 1. Decarburization generally is carried out at ca 800°C in a suitable decarburizing atmosphere, eg, wet hydrogen. The carbon level can be lowered to 0.002–0.005% to decrease coercivity. The presence and distribution of the insoluble carbon influences coercivity. For example, the coercivity of an SAE 1010 steel with a fine lamellar cementite (Fe₃C) structure can be reduced by one half by a spheroidization annealing at 680°C (11).

Commercial low carbon sheet steels for electrical applications are furnished in

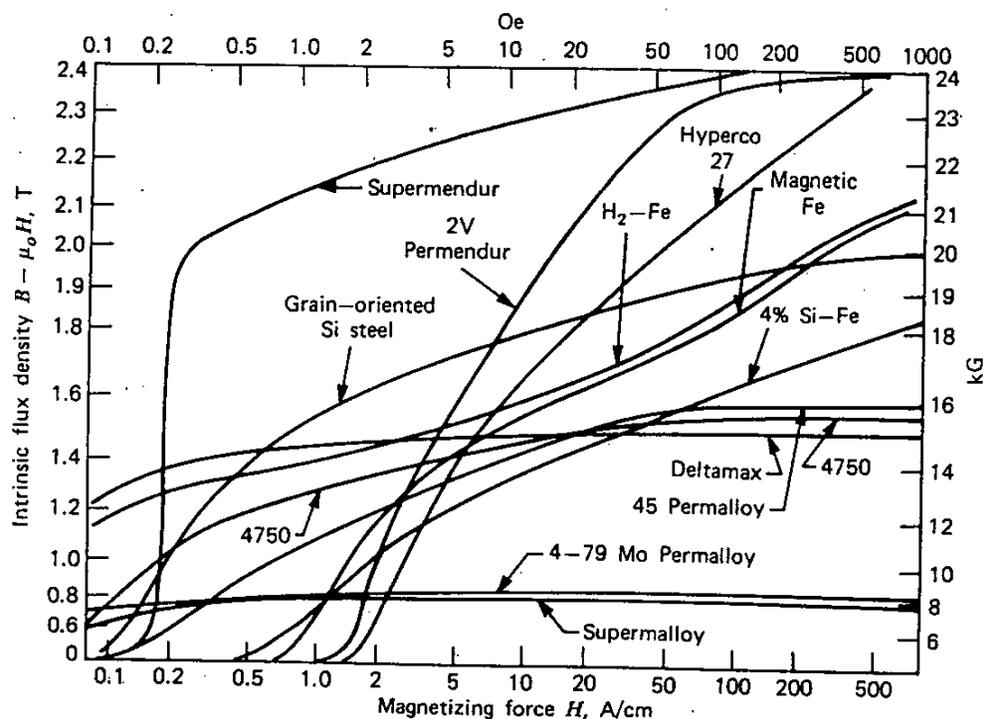


Figure 2. Magnetization curves of some commercial soft magnetic materials.

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By correct proportioning of the parts, it is thus possible to compensate almost entirely for the temperature changes. Alloys for such purposes are essentially of two types:

- 1 The nickel-copper type that contains about 70% Ni, 30% Cu as well as certain admixtures, such as 2% Fe ("Calmalloy"¹¹), or about 1% Mn with or without a small amount of silicon (Westinghouse Alloy). Characteristic curves are shown for these alloys in Fig. 20.
- 2 The nickel-iron type containing 30 to 40% Ni with a small amount of manganese, chromium and silicon. Curves for this type of alloy ("Thermoperm") are shown in Fig. 21.¹² The curves are nearly straight lines all the way from low temperatures up to 60 C, and the temperature coefficients are higher than for the monel type of alloy.

Sintered Compressed Iron Powder.* For many applications in which the magnetic circuit is complicated and would require considerable machining, it is often advantageous to make the parts by pressing iron powder into a mold and sintering the parts thus made, in a reducing atmosphere. In Fig. 22, 23 and 24 are shown the effects of forming pressure, sintering temperature and sintering time, on the magnetic permeability of iron for a constant magnetizing force, as a percentage of the permeability of annealed hot rolled low-carbon steel.

From these curves it appears that a pressure of 80 tons per sq in., combined with a sintering temperature of 1200 C for 3 hr, yields magnetic properties equal to or better than those of annealed hot rolled low-carbon steel or wrought iron.

Summary. As a summary, Fig. 25 shows B - H curves for materials considered in this article, and Table VI shows applications in electrical apparatus and instruments, with the required or desired magnetic and electrical properties and the corresponding alloy that will serve best.

* P. R. Kalischer, Westinghouse Res. Lab., unpublished report

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Permanent Magnet Materials

By K. L. SCOTT*

TWO TYPES of permanent magnet material are in wide use today; namely, the magnet steels, which contain carbon as a hardening constituent, and the more recently developed magnet alloys, which are virtually free from carbon. A third type, composed of metallic oxides, has a limited field of use. Particularly great progress has been made since about 1925 in the development and improvement of the carbon-free type of material. In the present article the first type will be referred to as magnet steels and the second type as magnet alloys; the oxide magnets will receive little discussion.

Theoretical Discussion. In order to understand the relative importance and usefulness of each type of material, a brief summary of the fundamental theory of permanent magnets will be given. In Fig. 1 are shown a typical hysteresis loop and magnetization curve for a permanent magnet alloy. The variables are magnetizing force H , in oersteds [0.1 (4π) times the ampere turns per centimeter], as abscissas, and magnetic flux density or induction B , in gauss (so-called "lines of force" per square centimeter) as ordinates. Starting with an unmagnetized specimen, if increasing values of H are applied (as by gradually increasing the electric current in a coil or wire wound on the specimen) the corresponding values of magnetic flux produced in the specimen will be as shown by the familiar S-shaped magnetization curve, also called the "normal induction curve". If the values of H are gradually decreased from the highest applied value, H_{max} , to zero, and then increased in the negative direction to a negative H_{max} (accomplished by reversing the current in the magnetizing winding), the value of B will change from a positive B_{max} to a negative B_{max} along the left-hand curve of the hysteresis loop. If this process is repeated,

starting with a negative H_{max} , the right-hand side of the hysteresis loop will be traced. If the value of magnetizing force is reduced from H_{max} to zero (as by opening the circuit of the magnetizing winding) the value of B will drop from B_{max} to the intersection of the hysteresis loop with the B axis. The value of B at the point of intersection is called the "residual induction", designated B_r . If sufficient negative magnetizing force is applied now to reduce the value of B from B_r exactly to zero, the value of negative H required will be as shown by the intersection of the hysteresis loop with the H axis. This particular value of H is called the "coercive force", designated H_c . This quantity affords a measure of the resistance of a material to demagnetization.

It is appropriate to distinguish here between the total induction B and the intrinsic induction B_i , which is that part of the total induction B caused by the presence of the magnetic material. B_i is equal to $B - H$, and is numerically equal to B only when $H = 0$, as shown in Fig. 2, in which hysteresis loops based on B and B_i are shown for the same cycle of magnetization. It is to be noted that the values of B_r are the same for both loops, but the value of coercive force for the B_i loop, designated H_{ci} , is greater than the value of H_c . The difference is significant for the magnet alloys that have high values of coercive force, since in some instances H_{ci} affords a more accurate measure of the permanence of a magnet (that is, its resistance to demagnetization) than H_c .

The descending branch of the hysteresis loop between the points B_r and H_c is most important in the theory of permanent magnets. It is known as the "demagnetization curve". If the product of the coordinates B and H of this curve is plotted against corresponding values of B , a new curve is obtained, as shown in Fig. 3. The maximum value of the product $B \times H$ —designated $(BH)_{max}$ —as obtained

* Western Electric Company, Chicago

from this curve, is proportional to the maximum amount of magnetic energy that a magnet of the given material can support in an air gap, per unit volume of the magnet. Hence, the most efficient design for a magnet will be one that works the magnet at the flux density corresponding to the $(BH)_{max}$ point of the material.

Since the value of $(BH)_{max}$ is proportional to the maximum obtainable air-gap energy per unit volume of a magnet, $(BH)_{max}$ constitutes the best criterion of the magnetic quality of a permanent magnet material. The co-ordinates of the $(BH)_{max}$ point can be located to a close approximation by the intersection of the diagonal of the rectangle that has sides OB_r and OH_c , with the demagnetization curve, as shown in Fig. 3. The $(BH)_{max}$ point can also be located quite well by the point of tangency on the demagnetization curve, of a straight line parallel to a line through B_r and H_c . However, this method will

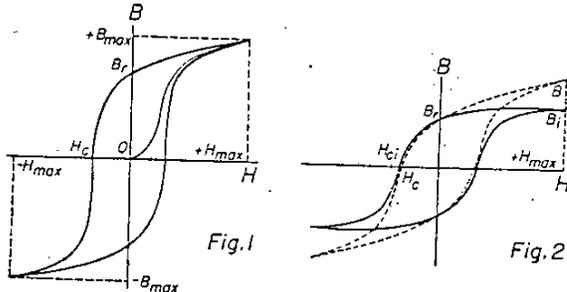


Fig. 1 Typical hysteresis loop of permanent magnet alloy
Fig. 2 Hysteresis loops showing relation of intrinsic or ferric induction B_i and total induction B

not work for materials with characteristics such as are illustrated in Fig. 8. For the magnet steels and some of the magnet alloys, the product $B_r \times H_c$ is directly proportional to $(BH)_{max}$ and hence gives an approximate indication of magnet quality. The co-ordinates B and H of the $(BH)_{max}$ point are equal respectively to approximately $0.65B_r$ and $0.65H_c$. Hence the values of B_r and H_c for these materials, are useful as inspection criteria and also indicate approximately the proper working flux density for purposes of design.

It has been shown also that the flux density of a fully magnetized bar magnet, designated B_{rem} , depends on the length L and equivalent diameter D in the manner shown in Fig. 4. This curve holds for most permanent magnet materials, but applies strictly only to straight bars. However, the curve will also apply quite well to magnets of other shapes, unless the ends of the magnets are relatively close together, or are brought effectively close together by iron pole pieces. The preceding simplifications are not permissible for magnet alloys such as Alnico 5, for which the demagnetization curve is more concave towards the origin. Thus the product of $B_r \times H_c$ is not a good criterion of quality for Alnico 5. In general, magnet design should be based on actual demagnetization curves and actual values of the energy product.

Testing of Magnet Materials and Magnets. Most manufacturers and large users of permanent magnet steels or alloys, test the materials for magnetic quality by measuring B_r and H_c , and $(BH)_{max}$. After suitable heat treatment, straight bars of cast or rolled material are tested in some form of permeameter. For methods and equipment for making these tests, see ASTM Method A34-46.

Most users of magnets also make a flux test on the finished magnets. This test can be made most accurately with a search coil and a flux meter of the galvanometer type. Greater speed and sufficient accuracy for commercial purposes can be obtained in many instances by using a flux meter of the d-c meter type, in which the test magnet furnishes the field to deflect the moving coil of the meter; or by adapting an a-c meter of the iron vane type. Some have used voltage measurements from air-core coils rotating in the field or air gaps of strong magnets.

Aging of Magnet Materials and Magnets. The magnetic properties of the permanent magnet steels are not stable

with time; the residual induction and coercive force of most of them begin to change spontaneously as soon as the steels are hardened, and continue to change for an indefinite time. The rate of change is greatest immediately after hardening, and decreases rapidly so that in a few days the rate is low. The rate and amount of change differ for different kinds of steel and are not uniform for any given kind of steel. The direction of the change is always for the residual induction to increase and the coercive force to decrease. Because of this instability it is good practice for a user of magnet steel, buying under specifications of magnetic properties, to allow an aging period between the hardening and testing of test bars.

Because of the nature of magnet alloys and the kind of heat treatment employed for them, such aging phenomena are much less pronounced in the magnet alloys and are negligible for most purposes.

The state of magnetization of magnetized steel magnets is also subject to a peculiar instability. It is observed that magnets magnetized immediately or soon after hardening, but not subjected to adverse fields, will suffer a spontaneous decrease in flux, beginning immediately after magnetizing. The rate of loss of flux is greatest immediately after magnetization, and decreases rapidly with time, so that after several days the flux has reached an approximately stable value. If the magnet is remagnetized, the same phenomenon is repeated, but less flux is lost than the first time. The phenomenon, however, is only temporary, and disappears when sufficient time has elapsed after hardening, so that if a magnet is magnetized after standing at room temperature for about four weeks after hardening, the subsequent spontaneous loss in flux will be negligible. This phenomenon appears to be present in the magnet alloys only to a negligible extent, if at all.

The loss of flux that occurs in magnets because of external demagnetizing influences is also commonly but improperly referred to as "aging". External demagnetizing influences include mechanical shock, heat, and adverse magnetic fields, including a-c fields and the fields of other

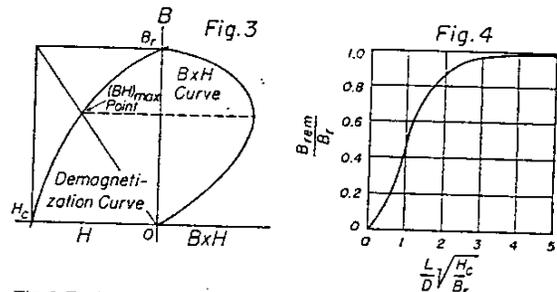


Fig. 3 Typical demagnetization curve of permanent magnet alloy
Fig. 4 Relation between magnetic properties and dimensions of straight bar magnets

magnets. In general, if a magnet is weakened by any one of the above means and not remagnetized, it will not be further weakened by a repetition of the same treatment, and will suffer only a slight loss in flux from the application of any other treatment that would have weakened it originally by about the same amount. In the process inspection of magnets after hardening, some users follow the magnetizing operation by a partial demagnetization or aging before testing, for the purpose of eliminating magnets that are improperly heat treated or made of defective material. If a stabilizing treatment is required, as for magnets to be used in measuring instruments, the material may be stored for a long time, subjected to heat (as by immersion in boiling water) or partially demagnetized by an a-c or d-c field after final magnetization.

Methods of Magnetizing Magnets. The problem of magnetizing permanent magnets has become increasingly difficult with the advent of materials that have coercive forces in the range of 500 oersteds and higher. The magnetizing field required for magnetizing a magnet fully is from four to five times the coercive force of the material, ranging from 250 amp-turns per cm for the chromium and tungsten steels to 2500 amp-turns per cm for some of

Permanent Magnet Materials

Table I. Commercial Types of Magnet Steels

Type of Steel	Nominal Composition, (a) percentage					Mo	Nominal Magnetic Properties ^(b)		Hardening Temperature, deg Fahr.	Quenching Medium
	C	Mn	Cr	W	Co		B _r , gauss	H _c , oersteds		
W	0.70	0.30	0.20	5.50	...	...	10,000	43	1450	Water
W-Cr	0.70	0.30	0.50	6.00	...	...	10,000	43	1450	Oil
Co	0.90	0.35	4.75	1.25	...	...	9,000	58	1500	Water, Oil
Co-Cr	0.90	0.35	3.50 to 4.00	1.00	...	...	9,000	58	1500	Oil
Co-W	0.90	0.35	4.00	1.00	...	...	9,000	58	1500	Oil
Cr-Mn	0.50	0.40	2.25	...	...	...	10,000	43	1450	Water
Cr	0.90	0.20 to 0.80	3.00 to 4.00	...	...	...	9,000	58	1500	Oil
Cr	0.95	0.35	6.00	...	...	...	9,000	58	1500	Oil
Cr	1.00	0.35	4.00	...	...	...	9,000	58	1500	Oil
Cr-Mo	1.00	0.35	4.00	...	...	...	9,000	58	1500	Oil
W	0.70	0.30	0.20	5.50	...	...	10,000	65	1550	Water
W-Cr	0.70	0.30	0.50	6.00	...	...	10,000	65	1550	Oil
Co	0.90	0.35	4.75	1.25	...	...	9,000	70	1600	Oil
Co	0.90	0.35	3.50 to 5.75	1.25	35.00 to 41.00	...	9,000	70	1600	Oil
Co-Cr	0.90	0.35	3.50 to 5.75	1.25	18.00	...	9,000	70	1600	Oil
Co-Cr	0.95	0.30	3.00 to 3.00	8.75	17.00	...	9,000	70	1600	Oil
Co-W	0.95	0.30	3.00 to 3.00	8.75	17.00	...	9,000	70	1600	Oil

(a) Limits usually 0.30% Si max, 0.03% P and S max, 0.50% Ni max
 (b) Values for previously annealed materials usually 5 to 10% lower in H_c
 (c) Heat treatment: 2100 F, cool in air; 1850 F, cool in air.

the magnet alloys, such as Alnico 4. Most magnets made of steels and alloys that have low coercive force, can be fully magnetized by means of large electromagnets. Some magnets that have high coercive force and favorable shapes, can also be magnetized by the same means; but magnets of more intricate shapes or greater length may require the use of a magnetizing winding of very heavy wire carrying large currents. Water-cooled copper tubing carrying hundreds or thousands of amperes has been used for some applications. Banks of heavy-duty rectifiers or low-voltage high-current d-c generators, such as plating generators, are suitable sources of current. Short-duration heavy current pulses from half-cycle welders, or large banks of condensers have also been employed successfully. The advantage of these methods over the use of electro-magnets is that the required high field strengths can be obtained readily and at the same time the direction of the field can be made to conform to the desired path of flux through the magnet, by suitable shaping of the winding. Where the current flow is of short duration, a lighter and more easily manipulated winding may be used.

Magnet Steels. The types of magnet steel produced commercially in the United States are classified by their manufacturers as follows: carbon-manganese, chromium, chromium-molybdenum, tungsten, chromium-tungsten, and various grades of cobalt steel, including cobalt-chromium and cobalt-tungsten. The chromium steels are made in grades ranging from nominal 1 to 6% Cr; the tungsten steels range from 5 to 8% W; and the cobalt steels contain from 3 to 38% Co, with chromium from 2 to 10%, and a fraction of 1% Mo in certain steels. Some tungsten steels contain enough chromium to make them oil-hardening. Otherwise the tungsten steels, the 2% Cr steel and the carbon-manganese steels are water-hardening, and all the rest are oil-hardening. It is noteworthy that the 1% Cr steel has the best magnetic properties when quenched in oil; but water, some water solution, or a light oil is recommended for the 2% Cr steel. Data concerning the various types of magnet steel are shown in Table I. Only those types reported by various American manufacturers are included, and the data serve to summarize information furnished by the manufacturers.

Manufacture of Magnet Steel. In general, the methods of melting, rolling and fabricating magnet steels are similar to those used for tool steels of similar composition. Exceptions arise from the fact that mechanical properties are of secondary importance and practices that would be harmful to the magnetic properties must be avoided as much as possible. This means that the thermal history of the steel should be as brief as can be. Rolling or forging should be accomplished with a minimum amount of reheating, and overheating should be avoided. The steel should not be annealed unless necessary for machining operations, and the anneal should be as light as is consistent with machinability.

If the magnetic properties are impaired by overannealing or overheating, it is possible to restore a good measure of the loss by a normalizing treatment, quickly heating and cooling the material from a temperature well above the transformation range. Normalizing temperatures in

use range from 1700 to 2300 F for 5% W steel, and from 1700 to 2000 F for chromium steel.

Melting and Rolling. Magnet steels are almost always melted in electric furnaces, either arc or induction. Hot Forming. In many instances, the shapes of permanent magnets are such as to require hot forming. This may be done satisfactorily at temperatures between 1400 and 1800 F. Higher temperatures are detrimental to the quality of the steel. A medium temperature is preferable and the heating and forming should be done as quickly as possible. Magnets are usually air-cooled after forming. Sometimes magnets are hardened by quenching immediately after the forming operation; thus one heating operation may be eliminated. This practice requires better than ordinary control of the forming temperature.

Annealing. Great emphasis should be placed on the desirability of designing magnets so that they do not require annealing for machining operations. When the need is unavoidable, or when cold forming or blanking is the chosen fabricating process, as light an anneal as possible should be used, because annealing always impairs the magnetic properties of a magnet steel. However, grades of steel that are air-hardening must be annealed if the magnets are to be machined. If hot forming is not required or if the machining can be done before forming, the material can be annealed at the mill. Magnet steel should be heated to the annealing temperature quickly, held at temperature only long enough to be heated through, and cooled just slowly enough to avoid air-hardening. Cooling from 1000 F to room temperature may always be done in the open air.

Hardening. The recommended hardening temperatures are listed in Table I. The optimum hardening temperature is usually the one that gives the highest value of (BH)_{max} or of the product B_r × H_c. However some magnets are not proportioned for maximum efficiency and require higher values of B_r or H_c, than are associated with the maximum value of (BH)_{max} or the product B_r × H_c, because high values of B_r are best for long or slender magnets and high values of H_c for short thick magnets. Oil-quenching results in higher values of H_c and lower values of B_r, than water-quenching. A much greater amount of warping, cracking and breaking results from water-quenching. For this reason oil-hardening steels are gradually re-tempering water-hardening steels for most applications. Magnets should not be held at the hardening temperature longer than is necessary for the solution of carbides. A prolonged soak at the quenching temperature is usually detrimental to the magnetic properties of magnet steels.

Grinding. Hardened magnets should be ground very carefully in order to avoid grinding cracks, which sometimes develop hours after the grinding operation. Wet grinding, light cuts, and careful selection of the abrasive wheel are the best safeguards against grinding cracks. In general, a grinding practice that is suitable for tool steel will be suitable for magnet steel.

Magnet Steel Castings. Cobalt steel magnets of more or less intricate shapes have frequently been produced by casting. The properties of cast cobalt steel do not differ greatly from those of forged or rolled steel, although the

Table II. Nominal Properties of Carbon-Free Permanent Magnet Alloys

Magnet Material	Chemical Composition	Form	H_{max} , oersteds	B_{max} , gauss	Residual B_r	Coercive Force H_c	External Energy $(B_a H_a)_{max}$	Weight, lb per cu in.	Mechanical Properties	Commercial Methods of Fabrication
Comol Remalloy	12 Co, 17 Mo, rest Fe	Bar Cast	1000	15,200	10,000	225	1,100,000	0.295	Hard, relatively strong, but brittle	Cast, hot forge, machine, punch (thin sections)
Alnico 1	12 Al, 20 Ni, 5 Co, rest Fe	Cast	2000	12,350	7,100	400	1,300,000	0.249	Hard, brittle	Cast, grind
Alnico 2 (cast)	10 Al, 17 Ni, 12.5 Co, 8 Cu, rest Fe	Cast	2000	12,600	7,200	540	1,600,000	0.256	Hard, brittle	Cast, grind
Alnico 2 (sintered)	10 Al, 17 Ni, 12.5 Co, 6 Cu, rest Fe	Sintered	2000	12,000	6,900	520	1,430,000	0.245	Hard	Sinter, grind
Alnico 3	12 Al, 25 Ni, rest Fe	Cast	2000	12,000	6,700	450	1,380,000	0.249	Hard, brittle	Cast, grind
Alnico 4	12 Al, 28 Ni, 5 Co, rest Fe	Cast	3000	11,850	5,200	700	1,300,000	0.253	Hard, brittle	Cast, grind
Alnico 5	8 Al, 14 Ni, 24 Co, 3 Cu, rest Fe	Cast	2000	15,700	12,000	575	5,000,000	0.264	Hard, brittle	Cast, grind
Alnico 12	35 Co, 18 Ni, 6 Al, 8 Ti, rest Fe	Cast	3000	12,800	5,800	950	1,750,000	0.260	Hard, brittle	Cast, grind
Cunife	60 Cu, 20 Ni, 20 Fe	Wire	2400	8,400	5,400	550	1,550,000	0.311	Ductile, malleable	Cold roll, machine, punch
Cunico	50 Cu, 21 Ni, 29 Co	Strip Rod Wire Cast	3200	8,000	3,400	710	850,000	0.300	Ductile, malleable	Cast, cold roll, machine, punch
Vectolite	30 Fe ₂ O ₃ , 44 Fe ₃ O ₄ , 26 Co ₃ O ₄	Pressed pieces	3000	4,800	1,600	900	500,000	0.100	Low strength, brittle	Sinter, grind
Silmanal	86.75 Ag, 8.8 Mn, 4.45 Al	Rod Strip Sheet	20,000	20,830 (a) $B_r = 830$	550	H_{c1} (a) 6000	85,000	0.325	Workable	Machine, punch, cold roll

(a) B_r and H_{c1} values are on the basis of intrinsic induction.
Data from the General Electric Company, including demagnetization curves

coercive force is usually higher and the residual induction lower. The same annealing and hardening practices are recommended. The cast material is ordinarily more brittle than the forged. Casting the other magnet steels affords no appreciable advantage.

Miscellaneous. The magnetic properties of magnet steels have not been correlated reliably with the microstructure. In general, a fine, silky fracture is associated with good material. Of course decarburization should be avoided. After hardening, heating above 212 F is detrimental to the magnetic properties. Serious impairment begins to take place between 300 and 400 F. Defective magnets may frequently be reclaimed by rehardening. For immersing magnets during water-quenching, there is no standard method that will minimize warpage or breakage. In handling magnets that must be formed to size just before the

these alloys. Furthermore, materials are commercially available that have far greater coercive force and residual induction values than any of the magnet steels, and other such alloys are being developed. The following materials of this class are known or are in use at the present time

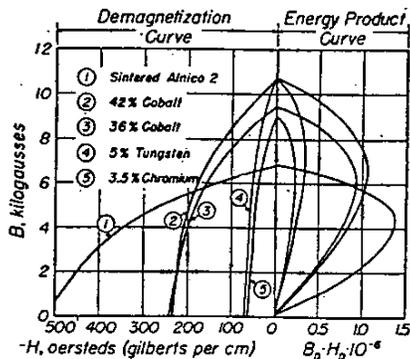


Fig. 5 Demagnetization curves and energy product curves of various magnet materials

quench, the tongs should make as little contact as possible with the magnets to avoid cooling them too much by contact with cold metal before the quench.

Magnet Alloys. The range of possibilities for the design of permanent magnets has been extended greatly by the introduction of alloys that are substantially free from carbon. The magnetic properties of any of the permanent magnet steels can be substantially duplicated by some of

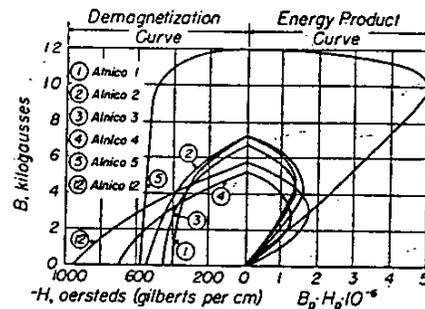


Fig. 6 Demagnetization curves and energy product curves of various magnet alloys

(but not all are commercially available): an alloy of iron, cobalt and molybdenum, known as Remalloy or Comol; various alloys of iron, nickel, aluminum and one or more other elements—cobalt, copper and titanium—with the common name of Alnico, plus an Arabic or Roman numeral to designate the grade; a series of alloys of copper and nickel with iron or cobalt or both, bearing the derived names of Cunife or Cunico; an alloy of platinum, manganese and aluminum known as Silmanal; an alloy of platinum and cobalt that has extremely high coercive force; an alloy of cobalt, iron and vanadium called Vicalloy; and a mixture of iron and cobalt oxides called Vectolite (Table II).

Remalloy or Comol has magnetic properties slightly better than 36% Co steel. Magnets are produced from hot rolled or hot forged bars, or may be cast. The metal may be hot formed at or near 2000 F. The range of hot forming temperatures is rather narrow. After a solution heat treatment between 2200 and 2400 F, followed by an oil quench, the alloy is readily machinable but rather brittle. Magnetic properties are developed by reheating for approximately 90 min at about 1250 F after the solution heat treatment.

The Alnico alloys cannot be worked hot or cold. Magnets are produced by casting and grinding. Drilling, tapping and such processes can be performed only with the aid of soft inserts in the castings. Heat treatment consists of a solution treatment between 1900 and 2100 F, air-cooling, and then aging for approximately an hour at about 1100 to 1300 F. Small magnets may require a slower rate of air cooling and heavy ones may require accelerated cooling in an air blast to develop the desired properties. Rapid cooling favors high values of B , and slow cooling, high values of H_c . The heat treatment for Alnico 5 is an exception in that the solution temperature is about 2400 F and the aging treatment consists of holding for 4 to 10 hr at 1000 to 1150 F. Alnico 5, which is highly directional

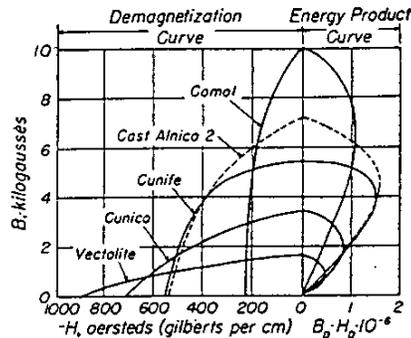


Fig. 7 Demagnetization curves and energy product curves of various magnet alloys

magnetically, requires cooling from the solution temperature in a magnetic field oriented to conform to the pattern of magnetization desired in the finished magnet. Suppliers of Alnico magnets customarily furnish them ground to size, heat treated and magnetized.

Cunife, Cunico and Silmanal are ductile alloys that can be produced in a wide variety of designs by forming, drawing, punching or machining. Cunife is directional and should be magnetized in the direction of cold working. In sheet form this alloy has properties considerably below those of other wrought forms.

Vectolite and sintered Alnico magnets are made from powdered oxides or metals pressed in a die to approximately the final shape and size, and sintered. Both can be ground to final size if very close tolerances are desired, but Vectolite is mechanically weak and is preferably sintered to final size. Vectolite is an electrical nonconductor. Sintered Alnico is fine-grained and stronger mechanically than cast Alnico. The chief advantage of sintered Alnico lies in the production of small sizes and intricate shapes.

Vicalloy is a ductile material with magnetic properties somewhat better than Comol or 36% Co steel. The chief use of Vicalloy has been in magnetic recorder tape.

Comol or Remalloy, Vicalloy, and the platinum-cobalt alloy are not commercially available at present (1947).

Curves of demagnetization and energy product for the magnet alloys are shown in Fig. 5, 6, 7 and 8.

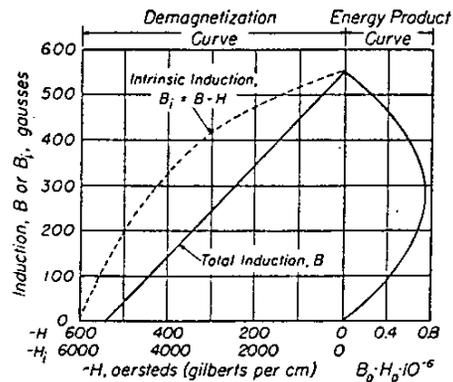


Fig. 8 Demagnetization curves of intrinsic induction and total induction and energy product curve for Silmanal

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Iron-Nickel Alloys

By J. W. SANDS*

IRON and nickel are soluble in all proportions in the molten state and form solid solutions during solidification. At room temperature the alloys may be either ferritic or austenitic in structure, depending on the nickel content and, in some instances, on the thermal history of the sample. Additions of carbon also affect the phase relationships. Nickel lowers progressively the temperature of the gamma-to-alpha transformation in iron, imparts a considerable hysteresis in the temperature of the occurrence of this

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transformation during heating and cooling, and introduces a considerable spread between the temperatures of the beginning and end of transformation. The lowering of the transformation range is so pronounced that when the nickel content is about 34%, the transformation cannot be reached, even at the temperature of liquid hydrogen (20 C above absolute zero). Hence, all the alloys containing more than this amount of nickel are austenitic (face-centered cubic) under all conditions.

Alloys of lower nickel content may be either ferritic or austenitic or a mixture of both, depending on the thermal