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PERMANENT MAGNET CONSTRUCTION

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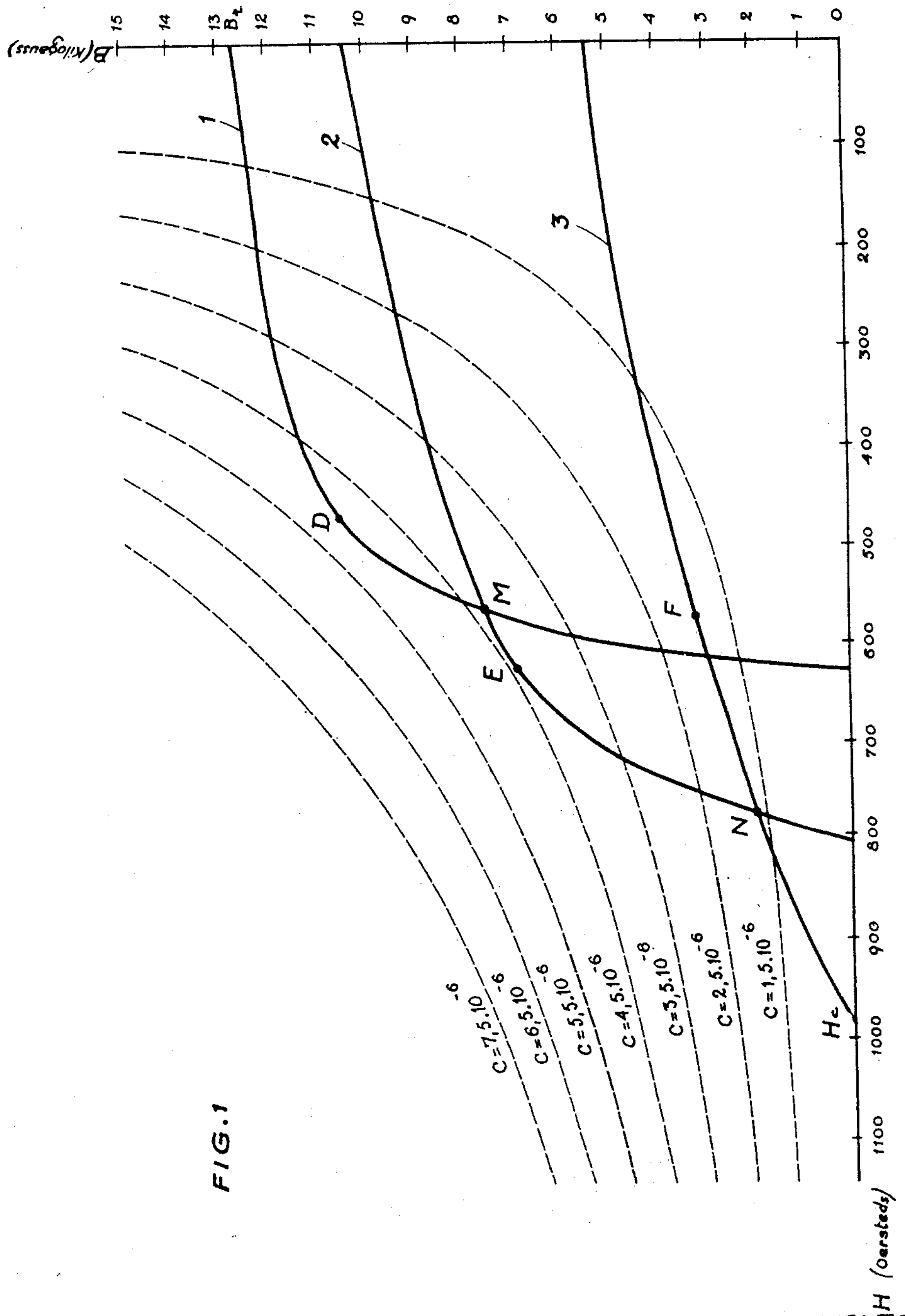

FIG. 1

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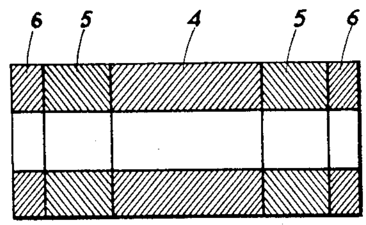

FIG. 2

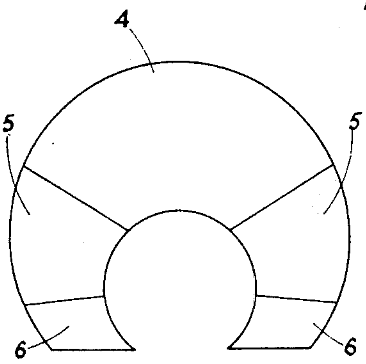

FIG. 3

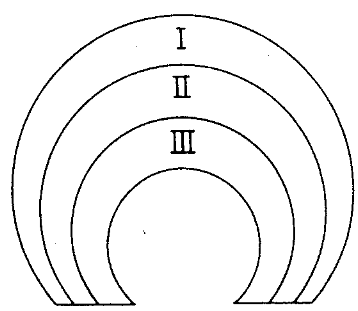

FIG. 4

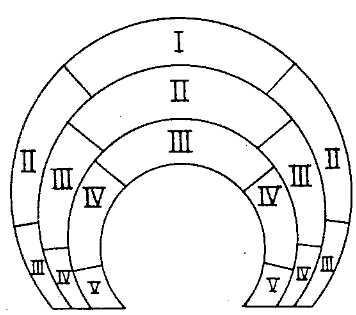

FIG. 5

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PERMANENT MAGNET CONSTRUCTION

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The present invention relates to a permanent magnet construction, and more particularly to a permanent magnet construction made of several pieces or portions of magnet having different magnetic characteristics.

The primary object of the present invention is a permanent magnet which produces, with the same volume, a useful magnetic field which is stronger than the known magnets, or which may be utilized with a smaller volume while retaining the same useful field.

Accordingly, it is an object of the present invention to provide a permanent magnet construction in which the volumetric dimension thereof or actual configuration may be reduced for a given magnetic field strength.

It is another object of the present invention to provide a permanent magnet made of several portions in which the magnetizing field is increased for a given volume thereof.

It is still another object of the present invention to provide a permanent magnet construction made of several magnetic portions or pieces having different materials which are selected and arranged according to a predetermined pattern insofar as the properties thereof are concerned so as to approach as closely as possible optimum operating conditions.

These and other objects, features and advantages of the present invention will become more obvious from the following description when taken in connection with the accompanying drawing, which shows for purposes of illustration only several embodiments in accordance with the present invention and wherein:

Figure 1 is a diagrammatic showing of several characteristic curves of some magnetic materials.

Figure 2 is an axial longitudinal cross-sectional view through a tubular magnet of rectilinear or straight configuration in accordance with the present invention, and

Figures 3, 4 and 5 are plan views of three different embodiments of horseshoe-shaped magnets in accordance with the present invention.

The magnet according to the present invention is characterized by the fact that it is constituted by the assembly of portions or pieces of magnetic materials of different characteristics, the materials having the strongest residual induction or retentivity and the weakest coercive field being utilized in the zones of the magnet where the demagnetizing field is weakest, and vice versa.

Referring now to the drawing, wherein like reference numerals are used throughout the various views to designate like parts, and more particularly to Figure 1, which illustrates the characteristic curves for several magnetic materials, the values of the induction B of the characteristic curves are plotted therein along the ordinate and as a function of the demagnetizing field H which is plotted along the abscissa. Each curve intersects the axis of the ordinate at a point corresponding to the residual induction B_r of the material in question. Furthermore, each curve also intersects the axis of the abscissa at a point corresponding to the coercive field H_c of this same material.

The curve **1** is the characteristic curve of the so-called material "Ticonal 600" of which the approximate composition is as follows:

Twenty-four parts of cobalt,
Fourteen parts of nickel,
Eight parts of aluminum, and
Three parts of copper,

the parts being given in percentages of weight, the rest of the percentage being iron.

The characteristic curve **2** corresponds to the so-called material "Ticonal 800" of which the approximate composition is as follows:

Twenty-four parts of cobalt,
Fifteen parts of nickel,
Eighteen parts of aluminum,
Three parts of copper, and
1.25 parts of titanium,

all parts being given as percentages of the weight, the rest being iron.

Curve number **3** corresponds to the so-called material "Alnico 12" of which the approximate composition is as follows:

Thirty-five parts of cobalt,
Eighteen parts of nickel,
Six parts of aluminum, and
Eight parts of titanium

all parts being given as percentages of the weight, the rest being iron.

The curves, by going from curve **1** to curve **3** are more and more flattened and elongated so that a point of intersection M exists between curves **1** and **2** and a point of intersection N between curves **2** and **3**.

It is known already that the useful field of a permanent magnet is proportional, on the one hand, to its volume, and, on the other, to the product BH, wherein B designates the induction at a given point, and H the demagnetizing field at that point, these two points being linked by the curve B—H of the material used, and the product BH being taken as average value for all the points of the magnet.

For a given useful field, the volume of the magnet will therefore be the more reduced the greater the product BH. With a given volume, the useful field is, therefore, proportional to the product BH. This clearly indicates the interest to find an appropriate means to realize a magnet with a value BH which is as high as possible.

A family of hyperbolas representing the expression $BH=c$, with the constant c increasing as one goes away from the origin of the coordinate system is plotted in dash lines in Figure 1. If it is supposed that the particular magnet has a uniform material, and with the hypothesis that the demagnetizing field is constant throughout the entire magnet, it is easy to locate with the aid of these hyperbolas a point on the B—H curve corresponding to the maximum of the product BH. This point is situated at D, E and F respectively for the materials **1**, **2** and **3**.

By succeeding in providing a magnet having a uniform material in such a manner that it operates with the values of B and H corresponding to the points D, E or F respectively, it would appear that those conditions have been realized under which the average value of BH is equal to the maximum value of this product for a given material, and in which, consequently, the magnet is of optimum construction.

However, both theory and actual experience have clearly demonstrated that the hypothesis advanced hereinabove is not accurate. Even in the case of a straight magnet, the demagnetizing field does not remain constant along the entire length of the magnetic bar but, by reason of an unequal distribution of the fictitious magnetic masses, is minimum at the center of the bar and maximum at the extremities thereof. The variation is even more pronounced in the case of a curved magnet, owing to the difference of length between the interior fiber and the external fiber of the contour. It follows therefrom that even if one succeeds to operate within a zone of the magnet having a value of H corresponding to the maximum of BH along the magnetizing curve, or reasonably adjacent to this maximum, there exist other zones in which the deviation with respect to the maximum becomes quite considerable. As a result thereof, the average value of BH is, therefore, considerably less than the realizable maximum with the given material, and the magnet can no longer be considered as being constructed to the apparent best possibilities of the available techniques and knowledge of the art.

The present invention provides means which permit to obviate the shortcomings of the prior art, to bridge the gap between theoretical optimum and practical realization, and to improve these conditions. The magnet in accordance with the present invention is no longer constructed of a homogeneous magnetic material throughout but is subdivided into different zones. Each of these zones is formed by a different magnetic material in such a manner as to utilize a material which has a residual induction which is stronger and a coercive field which is weaker in the zones in which the demagnetizing field is the weakest, and vice versa.

The magnet according to the present invention is thus constituted by an assembly of several pieces or portions of magnetic material of different characteristics, these pieces being assembled, for example, by bonding or adhesion between straightened surfaces with a resinous material such as the material known, for example, under the name of "Araldite" or by any other known means.

Figure 2 represents for purposes of illustration only a longitudinal cross-sectional view of a tubular rectilinear magnet in conformity with the present invention. The magnet of Figure 2 comprises a center section or portion **4** made of "Ticonal 600" which has the characteristics corresponding to curve **1** of Figure 1. Adjacent the center section of portion **4** are disposed on each side thereof two symmetrical sections or portions **5** made of "Ticonal 800," the characteristics of which are indicated by curve **2** of Figure 1. Finally, adjacent the outer faces of the two symmetrical portions or sections **5** are two symmetrical end sections or portions **6** made of Alnico 12, the characteristics of which correspond to those of curve **3** of Figure 1. The length of each magnet section or portion **4**, **5** and **6** is determined by the condition that the plane of separation between the sections or portions **4** and **5** be positioned at the place where the demagnetizing field corresponds to that of the point M of Figure 1, and that the plane of separation between the sections or portions **5** and **6** be positioned at the place where the demagnetizing field corresponds to the value at point N of Figure 1.

The operating points of all the zones of the magnet of Figure 2 are thereby constituted along the contour of a curve connecting points H_cNEMDB_r of Figure 1. One may readily ascertain that for this contour indicated hereinabove which results from a construction according to Figure 2 the average value of the product BH is clearly greater than in the case where the operating points are found on a single characteristic curve **1**, **2** or **3** which proves the improved results obtained by means of the present invention.

Figure 3 represents an application of the structure of Figure 2 in case of a curved magnet which has the shape of a horseshoe. The same reference numerals designate again the same or corresponding elements as in Figure 2, and the same description is applicable with the supplementary remark that the planes of separation between the pieces **4**, **5** and **6** are no longer planes which are parallel among each other but instead generally planes perpendicular to the lines of force in the magnet.

As already indicated hereinabove, in curvilinear magnets, the heterogeneity of distribution of the demagnetizing field is even further accentuated due to the inequality of the length of the fibers along the interior contour and exterior contour of the magnet. It may therefore be useful to utilize different materials for zones separated, not by planes perpendicular to the lines of force as in Figure 3, but by surfaces parallel to these lines. Such an arrangement is shown in Figure 4 which shows a horseshoe-shaped magnet constituted by an assembly of three pieces I, II and III, each of horseshoe shape, and of which the materials used have characteristics of which the reciprocal relations are of the type of the curves **1**, **2** and **3** of Figure 1. The pieces I, II and III need not be placed in intimate contact, on the contrary, they may be electrically insulated from each other along the surfaces parallel to the lines of force, the insulation being assured either by air or, for example, by a bonding layer utilized for the assembly thereof.

Figure 5 represents a combination of the arrangements of Figures 3 and 4. In the embodiment of Figure 5, five different materials are used which are designated respectively by reference numerals I, II, III, IV and V, and which have successively more and more flattened and elongated characteristics, each pair of characteristic curves intersecting each other as is the case with each pair **1**, **2** or **2**, **3** of Figure 1. The hard ferrites may be utilized as materials having a weakest residual induction and the strongest coercitive field. The various constituent pieces of the magnet are limited by surfaces which are either normal or parallel to the lines of force of the body of the magnet. It is also understood that an insulation may be provided between the pieces along the separating surfaces which are parallel to the lines of force but not along the surfaces normal or perpendicular thereto.

The magnets described hereinabove may be magnetized by winding a coil over the assembled body of the magnet and to pass therethrough current pulses of such an intensity that all of the magnets attain saturation. It is known that this method of magnetization causes eddy currents within the material, and under these conditions the electrical insulation of the magnet pieces, mentioned hereinabove, provides a convenient means to effectively reduce these currents.

While we have shown and described various embodiments in accordance with the present invention, it is understood that the invention is not limited to the illustrated embodiments, in particular neither to the number of different materials used in a magnet nor to the numerical values attached to the particular characteristics of these materials nor to the shape of the magnet. Instead, the present invention is applicable in its wider, more general aspect to all the permanent magnets in which one seeks to approach the optima operating conditions for each particular zone determined by the maximum of the product BH, and, therefore, encompasses all the composite magnets which utilize the arrangements indicated hereinabove. Thus, the present invention is susceptible of many changes and modifications within the spirit and scope of the present invention, and we intend to cover all such changes and modifications as encompassed by the appended claims.

We claim:

1. A magnet structure comprising several magnet portions, juxtaposed in a fixed relationship to form a whole working as a single magnet, said portions being made of permanent magnet materials having different coercive forces and retentivities, said materials being so disposed that, while the whole magnet structure naturally comprises zones of different demagnetizing forces, portions which have relatively high and low coercive forces are

placed in zones of relatively high and low demagnetizing forces respectively, the length of the different magnet portions being such that every two neighboring portions are in contact in a plane at which the demagnetizing force H and the magnetic induction B have values substantially corresponding to those of the intersection point of the curves B versus H of the materials of said two portions whereby for a given magnet volume the total magnetizing energy is considerably increased.

2. A magnet structure as claimed in claim 1, wherein said magnet structure includes two extreme portions made of a first material, two intermediate portions made of a second material, and a central portion made of a third material, the first, second and third materials having relatively high, intermediate and low coercive forces, respectively.

3. A magnet structure as claimed in claim 2, wherein said portions form a long bar.

4. A magnet structure as claimed in claim 2, wherein said portions are essentially U-shaped.

5. A magnet structure as claimed in claim 1, wherein said magnet structure is essentially U-shaped and includes three portions of different materials extending along the entire length of the U, the outer portion, which is the longest, being of high coercive force material and the inner portion, which is the shortest, being of low coercive force material, while the intermediate portion has a medium coercive force.

6. A magnet structure as claimed in claim 1, wherein the magnet structure is of essentially U-shape and includes a plurality of portions made of different materials from one end of the U to the other and from the outer side of the U to the inner side thereof.

7. A magnet structure composed of several magnet pieces forming a single magnetic structure, said pieces being made of permanent magnetic materials having different coercive forces and remanent inductions, and the length of the different magnet pieces and their disposition being such that at every two neighboring surfaces the demagnetizing force H and the magnetic induction B have values substantially corresponding to those of the intersection point of the curves B versus H of the materials of said two portions whereby the total effective product BH approaches maximum throughout the magnet, B being the induction of the magnet and H the demagnetizing field.

8. A magnet structure according to claim 7, wherein said materials are so chosen that each particular material has a remanent induction which is stronger and a coercive field which is weaker in the zones in which the demagnetizing field is weakest.

9. A magnet structure composed of several pieces, said pieces being made of permanent magnetic materials having different coercive forces and retentivities, said magnet being provided with zones of different demagnetizing forces, and the length of the different magnet pieces and their disposition being such that at every two neighboring portions thereof the demagnetizing force H and the magnetic induction B have values substantially corresponding to those of the intersection point of the curves B versus H of the materials of said two portions whereby the effective average product of BH approaches maximum throughout the magnet, B being the induction of the magnet and H the demagnetizing field, in such a manner that the coercive forces are matched to said zones of demagnetizing forces.

10. A magnet structure according to claim 9, wherein said pieces are joined in planes forming an angle with the lines of force.

11. A magnet structure according to claim 10, wherein said angle is 90°.

12. A magnet structure according to claim 9, wherein said pieces are joined in planes essentially parallel to the lines of force.

13. A magnet structure according to claim 12, further comprising insulating bonding means for joining said pieces in said planes.

14. A magnet structure according to claim 9, wherein said pieces are joined in at least one plane forming an angle with respect to the lines of force and at least in one plane essentially parallel to the lines of force.

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