

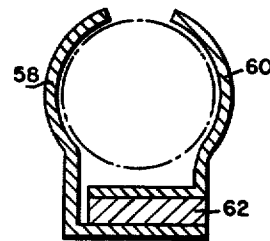
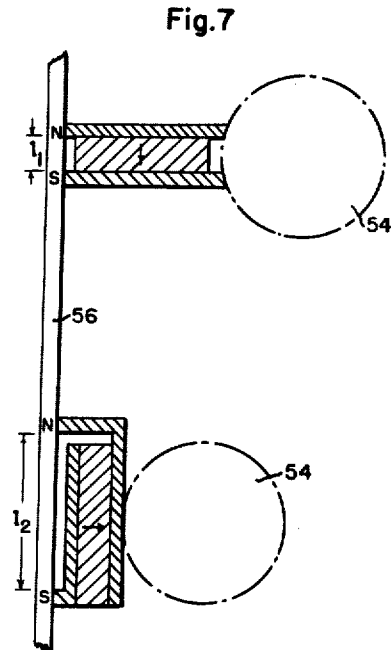
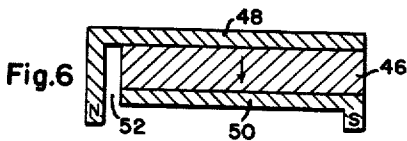
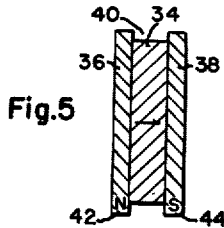
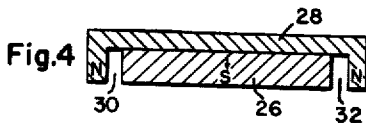
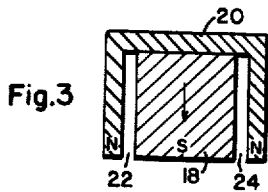
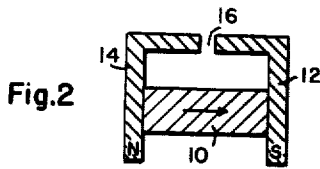
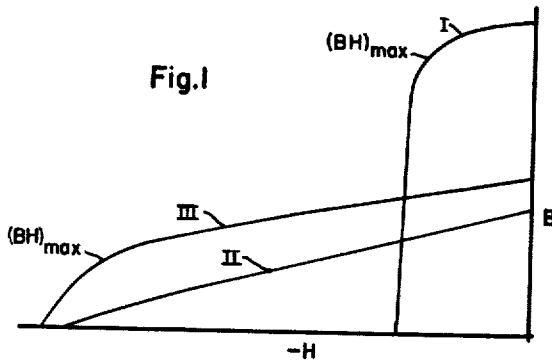
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J. R. HANSEN

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PERMANENT MAGNET ASSEMBLY

Filed Jan. 20, 1958



INVENTOR

John R. Hansen.

BY *J. H. Munnay*
ATTORNEY

1

3,095,525

PERMANENT MAGNET ASSEMBLY

John R. Hansen, New Providence, N.J., assignor to
Crucible Steel Company of America, Pittsburgh, Pa., a
corporation of New Jersey

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This invention relates to a permanent magnet assembly and more particularly to a magnet assembly employing permanent magnetic material having a short length and comparatively large cross sectional area.

Although not limited thereto, the present invention finds particular application with permanent magnetic materials, such as sintered $\text{BaO} \cdot 6\text{Fe}_2\text{O}_3$, which have a very great resistance to demagnetization. Efficient assembly designs for such types of magnetic materials require magnets having a short length and comparatively large cross sectional area, the large cross sectional ends being the poles of the magnet. As will be understood, such large cross sectional poles are required since the flux density of the material is lower than in conventional materials; and, hence, a greater area is required to achieve a given number of flux lines.

In order to utilize a permanent magnet most efficiently, a soft iron shunt path is provided between its poles, the shunt path having an air-gap at one point along its length. With this arrangement, the reluctance of the shunt path will be greater than that through a solid magnetically permeable object which comes into contact with the poles, so that almost all the flux will flow through the object rather than the shunt path while the magnet is in use. In the usual case, the shunt path referred to above takes the form of a pair of low carbon steel bars or pole pieces, each of which is in contact with a respective pole of the magnet and separated by an air-gap designed to give optimum results. The bars also serve to direct the magnetic flux of the magnet to points where it can be most effectively used.

Certain permanent magnetic materials require that the magnet have a short length and relatively large cross sectional area. In such cases, conventional shunt path arrangements are undesirable since they result in inability to adhere to curved surfaces, excessive length resulting in a high center of gravity, and poor spreading of leakage flux when used on thin ferromagnetic materials that become saturated.

It is an object of this invention to provide a new and improved permanent magnet assembly.

More specifically, it is an object of this invention to provide a permanent magnet construction employing a thin flat magnet which has a very great resistance to demagnetization.

Another object of the invention is to provide a novel magnetic shunt path configuration for use with permanent magnetic materials.

The above and other objects and features of the invention will become apparent from the following detailed description, taken in connection with the accompanying drawings which form a part of this specification and in which:

FIGURE 1 is a graph illustrating the demagnetization curves of a conventional anisotropic aluminum-nickel-cobalt-copper-iron base permanent magnetic material and

2

the highly coercive permanent magnetic materials with which the present invention is particularly adapted;

FIGS. 2 and 3 are sectional views illustrating the prior art construction of permanent magnets utilizing conventional anisotropic aluminum-nickel-cobalt-copper-iron base permanent magnetic material;

FIGS. 4 and 5 are sectional views of permanent magnets employing the highly coercive permanent magnetic material of the present invention, but constructed in accordance with the teachings of the prior art;

FIG. 6 is a sectional view of a permanent magnet constructed in accordance with the teachings of the present invention and adapted for use in adherence applications;

FIG. 7 is a view illustrating one use of the present invention; and

FIG. 8 is a view illustrating an application of the present invention in a motor armature assembly.

Referring to FIG. 1, the demagnetization curves of various types of permanent magnets are shown. Curve I is representative of the family of permanent magnets having an aluminum-nickel-cobalt-copper-iron base composition; whereas, curves II and III are representative of the highly coercive permanent magnetic material of the present invention. The magnetic material represented by curves II and III may consist, for example, of non-cubic crystals of a material selected from a group consisting of $\text{MO} \cdot 6\text{Fe}_2\text{O}_3$, where M is at least one of the metals selected from the group consisting of barium, strontium and lead. In the graph, the quantity B represents flux density or lines of flux per square centimeter of magnet cross sectional area and is measured in gauss. The quantity -H represents the applied demagnetizing force on the magnetic material and is measured in oersteds per centimeter of length.

It can be seen that in the aluminum-nickel-cobalt-copper-iron family of permanent magnets, the flux density remains constant at a high value and then drops off suddenly at a relatively low demagnetizing force. The magnetic materials utilized in the present invention, on the other hand, do not have as great a maximum value of flux density, but resist demagnetization much better than the group represented by curve I. In this respect, it takes a greater demagnetizing force to reduce the maximum value of flux density to, say, one-half of its original value than it did in the case of the aluminum-nickel-cobalt-copper-iron group. Since the flux density of permanent magnetic materials having demagnetization curve II is much less than those having curve I, it follows that the pole faces of magnets in the former group must have a greater area than those in the latter. That is, the pole faces of permanent magnets having a relatively low flux density for a given magnetizing force must be larger than those having a larger flux density for the same magnetizing force in order to produce the same number of flux lines.

Referring to FIGS. 2 and 3, typical assemblies are shown for permanent magnetic materials characterized by demagnetization curve I of FIG. 1. In FIG. 2, the assembly comprises a bar 10 of permanent magnetic material magnetized in the direction of the arrow. Two pieces 12 and 14 of soft, low carbon steel are affixed to the north and south poles of the bar 10, the soft steel pieces being L-shaped and separated by a shunt gap 16. The ends of the bars removed from gap 16 project from the body of bar 10 and serve to direct the magnetic flux from the bar to points where it can be effectively used. In the assem-

bly of FIG. 2, and in all of the assemblies hereinafter described, the pieces 12 and 14 may be attached to bar 10 by rivets, bolts, adhesives, plastics or any other suitable fastening means.

As it is well known, the path provided by the upper portions of pieces 12 and 14 and the shunt gap 16 is necessary to utilize the magnet most efficiently. It is, of course, necessary that the length of gap 16 be greater than the sum total of the gaps between the magnet poles and a magnetically permeable object while the magnet is in use. In magnet assemblies for static applications the length, cross section, and volume of permanent magnets characterized by demagnetization curves I and III can be determined by the following equations:

$$(1) \quad Am = FBgAg/Bm$$

$$(2) \quad Lm = fBgLg/Hm$$

$$(3) \quad Vm = \frac{FfBg^2Vg}{BmHm}$$

where, for example, from FIG. 2

Am is the cross sectional area of magnet 10;

Lm is the length of magnet 10;

F and f are leakage constants determined by the characteristics of the magnetic circuit;

Bg is the flux density in the shunt gap 16;

Ag is the area of shunt gap 16;

Bm is the flux density of magnet 10;

Hm is the magnetizing force of magnet 10;

Vm is the volume of magnet 10; and

Vg is the volume of shunt gap 16.

It is evident from Equation 3 above that the volume of magnetic material in magnet 10 needed to supply the flux density Bg to the shunt gap 16 is inversely proportional to the product of B and H of the magnet at its operating point, and that this value will be a minimum when the product is a maximum. Furthermore, in order to operate at this point, the length of gap 16 must fall within a critical range. In view of the foregoing, the Bm and Hm of the magnet 10 will correspond to B and H of demagnetization curve I at its maximum energy product (BH) max.

It is also evident from Equations 1 and 2 that a magnet material having a characteristic demagnetization curve III will have a relatively large cross section and short length as compared to a magnet with properties shown by curve I.

In the case of a permanent magnet having essentially the straight line demagnetization curve II, the shunt gap length may be designed so as to be appreciably greater than the sum total of the gaps between the magnet poles and a magnetically permeable object while the magnet is in use. This is permitted since recovery on use is effected very nearly along the demagnetization curve. This characteristic type of recovery also permits designing magnets with a shorter length, i.e., below the (BH) max. point of curve II.

Referring again to FIG. 2, the assembly shown may be used to hold on to either flat or curved surfaces. It is also adapted to firmly hold on to thin ferromagnetic materials that become saturated due to the spreading out of the leakage flux. In FIG. 3, the assembly includes a bar 18 magnetized in the direction of the arrow. In this case, however, the shunt path for the magnetic flux comprises a C-shaped soft iron member 20 which is separated from the core 18 by air gaps 22 and 24. In this case, the air gaps 22 and 24 serve the same function as gap 16 in FIG. 2 and are designed in accordance with the first and second equations outlined above to give maximum flux density across the air gaps 22 and 24 for a minimum volume of magnetic material. Although the assembly of FIG. 3 is suitable for use as a holding device on flat sur-

faces where intimate contact with a ferromagnetic body is achieved, it is totally inadequate for curved surfaces.

As was stated above, efficient assembly designs for magnetic assemblies employing permanent magnets having the magnetization curve II or III require magnets having a short length and comparatively large cross sectional area. If the permanent magnets having a short length and large cross sectional area are constructed in accordance with the previous designs illustrated in FIGS. 2 and 3, the arrangement shown in FIGS. 4 and 5 will result. The arrangement of FIG. 4 corresponds to that shown in FIG. 3 and comprises a bar 26 of magnetic material, magnetized in the direction of the arrow, and provided with a C-shaped soft steel member 28 to provide a shunt path. As was the case in FIG. 3, the member 28 is separated from the bar 26 by air gaps 30 and 32. The difficulty with this assembly, however, is that it is satisfactory for adherence to flat surfaces only where intimate contact is realized.

In FIG. 5, the assembly shown corresponds to that of FIG. 2. Here, the flat bar 34 is magnetized in the direction of the arrow and is provided with two low carbon, soft steel members 36 and 38. The air gap between members 36 and 38 is provided at 40, and the poles of the magnet are at 42 and 44. Although this assembly is suitable for holding to both flat surfaces and curved surfaces having a small radius, it is impractical for most applications due to its height, high center of gravity, and poor spreading of leakage flux when used on thin ferromagnetic materials that become saturated.

Since the conventional magnet designs of FIGS. 4 and 5 are unsuitable in many applications for permanent magnetic materials having a demagnetization curve represented by curve II or III of FIG. 1, the present invention shown in FIG. 6 was devised. In this case, a thin flat member 46 of permanent magnetic material is again magnetized in the direction of the arrow. In this case, however, the two soft iron members 48 and 50 are L-shaped in cross section. One leg of the cross section of member 50 extends across one pole face of bar 46, and its other leg extends outwardly from the pole face of the magnet adjacent to one edge. The other member 48 likewise has its one leg extending across the opposite pole face of member 46. In this case, however, the remaining leg of member 48 extends over the edge of member 46 in a direction parallel to the outwardly extending leg of member 50. An air gap 52 is left between the left extremity of member 50 and the downwardly extended leg of member 48, this air gap 52 serving the same function as air gap 16 in FIG. 2.

It is apparent that the assembly of FIG. 6 can be readily used as a holding device on curved ferromagnetic surfaces, whereas the assembly of FIG. 4 cannot. Furthermore, it has a low center of gravity which permits better magnetic adherence to inclined surfaces, particularly in the vertical plane, than the assembly of FIG. 5. This feature is shown in FIG. 7, where the assemblies of FIGS. 5 and 6 are employed to hold a circular member 54 to a vertical ferromagnetic member 56. In the case of the assembly of FIG. 5, a relatively long cantilever arm extends between members 54 and 56; and, since the length l_1 between the poles of the magnet is much shorter than the cantilever arm, the adherence of the magnet must be many times the weight of member 54. When the assembly of the present invention is used, however, the cantilever arm is much shorter and the length l_2 between the poles much larger, so that a magnet having a smaller adherence force is required for a given weight of member 54.

Still another advantage of the present invention resides in the fact that it has better magnetic adherence to thin ferromagnetic curved surfaces than either of the assemblies of FIGS. 4 and 5, since the leakage flux spreads out over a larger area; and intimate contact is not required between the poles.

If the permanent magnet construction of FIG. 6 em-

5

plays magnetic material having the characteristic demagnetization curve III of FIG. 1, the length of gap 52 may be designed in accordance with the equations:

$$Am = FBgAg/Bm$$

$$Lm = fBgLg/Hm$$

in order to operate at its maximum energy product (BH max.) or above this point, depending upon the particular environmental conditions under which the assembly must operate. Optimum efficiency is obtained when using the magnetic material of curve III by magnetizing the member 46 after assembly. If the assembly of FIG. 6 employs permanent magnetic material having demagnetization curve II, however, the length of gap 52 is not critical since recovery is effected essentially along the slope of the demagnetization curve. That is, since the curve II is substantially a straight line, the product of B and H is essentially constant at all points along the curve; and the length of the gap may vary without affecting performance provided it is not less than the sum total of the gaps between the magnet poles and a magnetically permeable object while the magnet is in use. Furthermore the member 46 may be magnetized before assembly when employing material having the demagnetization curve II.

The novel assembly of FIG. 6 can also be used in other applications such as polarized relays, magnetos, tachometers, generators, motors, and the like. In this respect, the narrow width of the invention makes it particularly desirable in a magneto flywheel or rotor.

The assembly of FIG. 8 employs permanent magnetic material characterized by curve II or III of FIG. 1, and is similar in construction to that of FIG. 6. In this case, however, the members 58 and 60 are extended and used as a motor armature. The short width of the magnet 62 makes the arrangement especially adaptable to compact designs.

Although the invention has been shown in connection with a certain specific embodiment, it will be readily apparent to those skilled in the art that various changes in form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention.

I claim as my invention:

1. A magnetic circuit having at least one air gap therein comprising a permanent magnet in the form of a rectangular parallelepiped having a short length and large cross sectional area, said magnet being magnetized along an axis parallel to said short length and having poles on its opposite large cross sectional area surfaces, first and second ferromagnetic parts each having an L-shaped cross section with one leg of the cross section abutting a respective pole surface of said magnet, the other leg of the cross section of said first ferromagnetic part being substantially shorter than its said one leg and extending outwardly from an edge of its associated pole surface, and the other leg of the cross section of said second ferromagnetic part being substantially shorter than its said one leg and extending along an opposite side of the permanent magnet which is parallel to said short length, said other leg of the second ferromagnetic part being spaced from said last-mentioned side and said first ferromagnetic part to form an air gap therebetween and being equal in length to the outwardly extended perpendicular distance from the permanent magnet surface abutted by said one leg of the second ferromagnetic part to the terminus of said other leg of the first ferromagnetic part, thereby defining contacts for effecting adherence to a metallic surface.

2. A magnetic circuit adapted to attach to an article of manufacture to adhere to a metallic surface while attached to said article of manufacture, said magnetic circuit having at least one air gap therein comprising a flat permanent magnet having a short length and large cross sectional area, said magnet being magnetized along an axis parallel to said short length and having poles on its opposite large cross sectional area surfaces, said magnet

6

consisting essentially of non-cubic crystals of a material from the group consisting of $MO.6Fe_2O_3$, M being at least one of the metals selected from the group consisting of barium, strontium and lead, first and second ferromagnetic parts each having a first portion abutting a respective pole surface of said permanent magnet and a second portion substantially shorter than its said first portion, said first ferromagnetic part having a second portion which extends outwardly from its associated pole surface, and said second ferromagnetic part having a second portion which extends over the edge of its associated pole surface and adjacent an opposite side of said permanent magnet whereby the extremities of said second portions are each adjacent the same one of said pole surfaces and constitute contact points for adherence to a metallic surface, said second portion of the second ferromagnetic part being equal in length to the sum of said short length of the permanent magnet, the thickness of said first portion of the first ferromagnetic part, and the length of said second portion of the first ferromagnetic part.

3. A magnetic circuit adapted to attach to an article of manufacture and to adhere to a metallic surface while attached to said article of manufacture, said magnetic circuit having at least one air gap therein comprising a flat permanent magnet having a substantially smaller dimension in one direction than dimensions at right angles thereto whereby the magnet has a short length and large cross sectional area, said magnet being magnetized along an axis parallel to the direction of the smaller dimension of said magnet and having poles on its opposite large cross sectional area surfaces, first and second ferromagnetic parts each having an L-shaped cross section with one leg of each cross section abutting the entirety of a respective pole surface of the permanent magnet, the other leg of the cross section of said first ferromagnetic part being substantially shorter than and integral with its said one leg and extending outwardly from its associated pole surface in a direction substantially parallel to the direction of the smaller dimension of said magnet, and the other leg of the cross section of said second ferromagnetic part being substantially shorter than and integral with its said one leg and extending parallel to said other leg of the first part and adjacent an opposite side of the permanent magnet which extends along the direction of the smaller dimension of said magnet, said other leg of the second part being spaced from said last-mentioned side and said first part to form an air gap therebetween and said other legs of said first and second ferromagnetic parts terminating at points lying in a plane perpendicular to the smaller dimension of said magnet thereby defining contact points for adherence to a metallic surface.

4. A magnetic circuit having at least one air gap therein comprising

a flat permanent magnet having a short length and large cross sectional area, said magnet being magnetized along an axis parallel to said short length and having poles on its opposite large cross sectional area faces, first and second ferromagnetic parts each having a first portion which abuts a respective pole surface of said magnet,

said first ferromagnetic part having a second portion which extends outwardly from an edge of its associated pole surface and perpendicular to said pole surface for a distance substantially less than the length of said first portion of the first ferromagnetic part and thence substantially semicircularly outwardly, said second ferromagnetic part having a second portion which extends over an edge of its associated pole surface adjacent to an opposite side of said magnet and perpendicular to said associated pole surface, said second portion of said second ferromagnetic part extending for a distance equal to the sum of

(a) said short length of said magnet,

(b) the thickness of said first portion of said first ferromagnetic part, and

(c) the length of said second portion of said

7

first ferromagnetic part which extends perpendicularly outwardly from an edge of its associated pole surface

and thence substantially semicircularly outwardly, said substantially semicircular portions of said second portions of said first and second ferromagnetic parts being concave inwardly of each other and adapted to be employed as pole pieces of a direct-current motor,

said second portion of said second ferromagnetic part extending in the direction of said second portion of said first ferromagnetic part and being spaced from said last-mentioned side of said magnet and said first portion of said first ferromagnetic part to form an air gap therebetween.

5. An article of manufacture comprising, in combination, a flat permanent magnet having a substantially smaller dimension in one direction than dimensions at right angles thereto whereby the magnet has a short length and large cross sectional area, said magnet being magnetized along an axis parallel to the direction of the smaller dimension of said magnet and having poles on its opposite large cross sectional area surfaces, a first integral L-shaped

8

ferromagnetic member having one leg affixed to one of said large cross sectional area surfaces and a substantially shorter other leg extending outwardly from said one surface, and a second integral L-shaped ferromagnetic member having one leg affixed to the other of said large cross sectional area surfaces and a substantially shorter other leg extending over an opposite edge of said magnet and parallel to said other leg of said first ferromagnetic member, said one leg of the first ferromagnetic member being spaced from said other leg of the second ferromagnetic member to provide an air gap therebetween whereby the extremities of said other legs are both adjacent one of the large cross sectional area surfaces of said magnet and are adapted to effect adherence of said article of manufacture to a metallic surface.

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