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Ras et al.

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(54) **METHOD FOR CONSTRUCTING PERMANENT MAGNET ASSEMBLIES**

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H01F 1/00 (2006.01)

(52) **U.S. Cl.** **29/607; 29/608; 29/609; 29/602.1; 29/467; 428/900; 428/928**

(58) **Field of Classification Search** **29/607, 29/608, 609, 602.1, 603.2, 830, 467, 468; 336/218, 234; 428/900, 928; 277/629**

See application file for complete search history.

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(57) **ABSTRACT**

A method for constructing a permanent magnet assembly by using a non-magnetic frame between individual magnet segments to restrain the movement of the magnet segments. The frame restricts the movement of the magnets during assembly. The frame also provides an effective system for replacing magnets in the existing assembly.

4 Claims, 7 Drawing Sheets

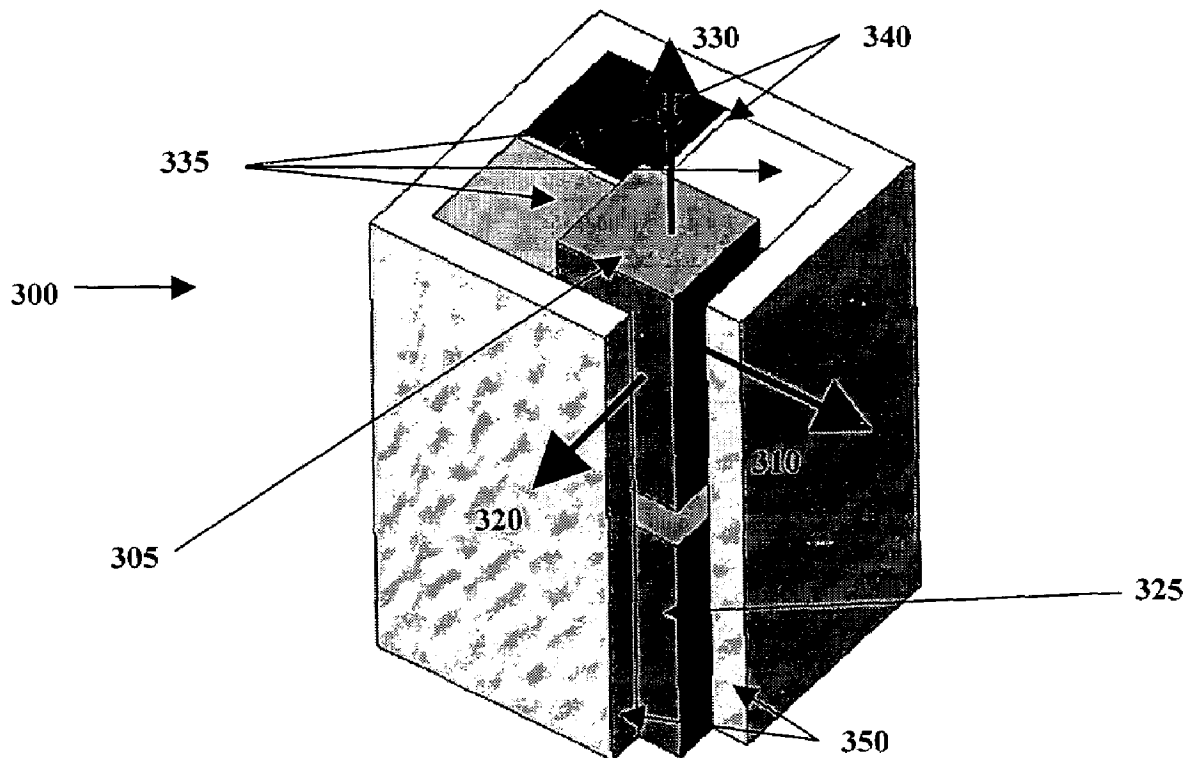


FIG. 1
(PRIOR ART)

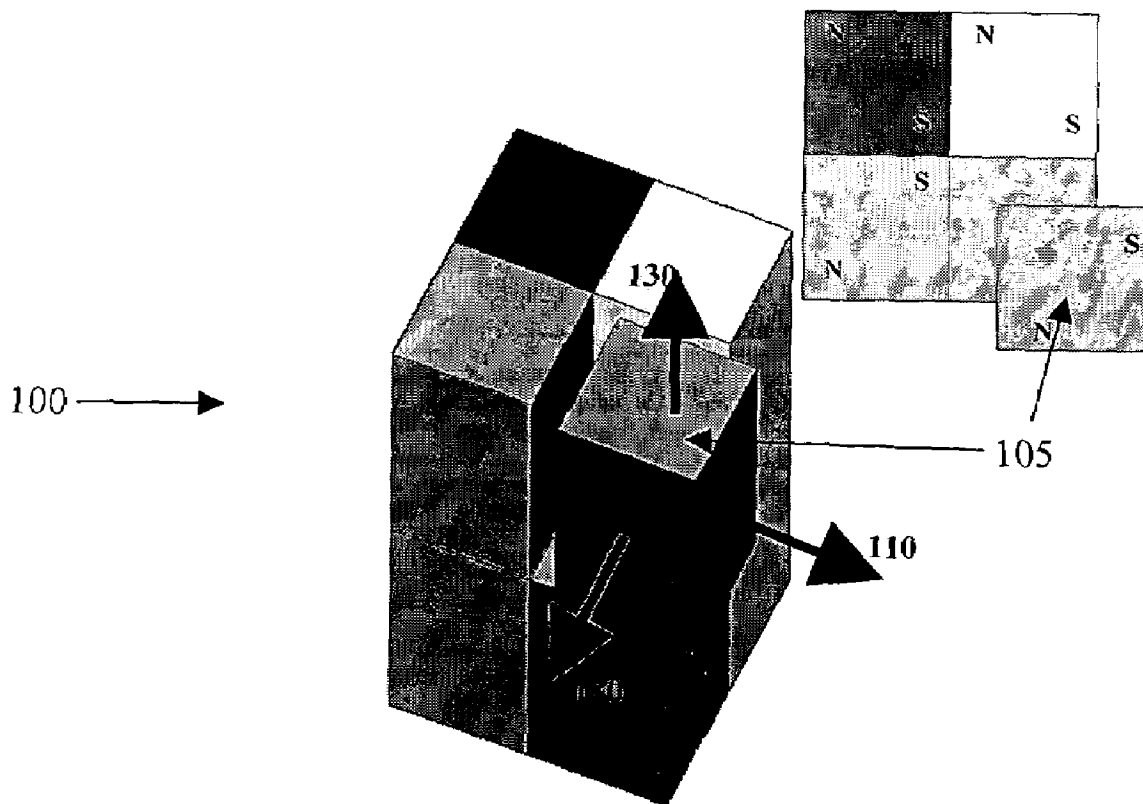


FIG. 2

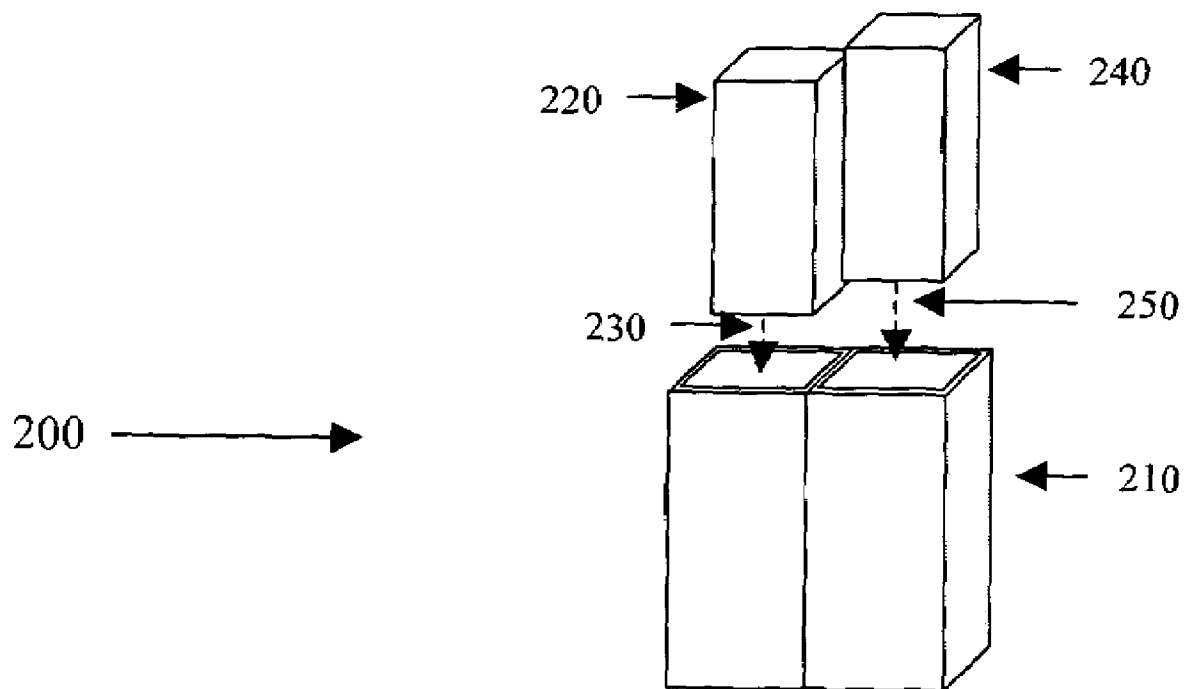


FIG. 3

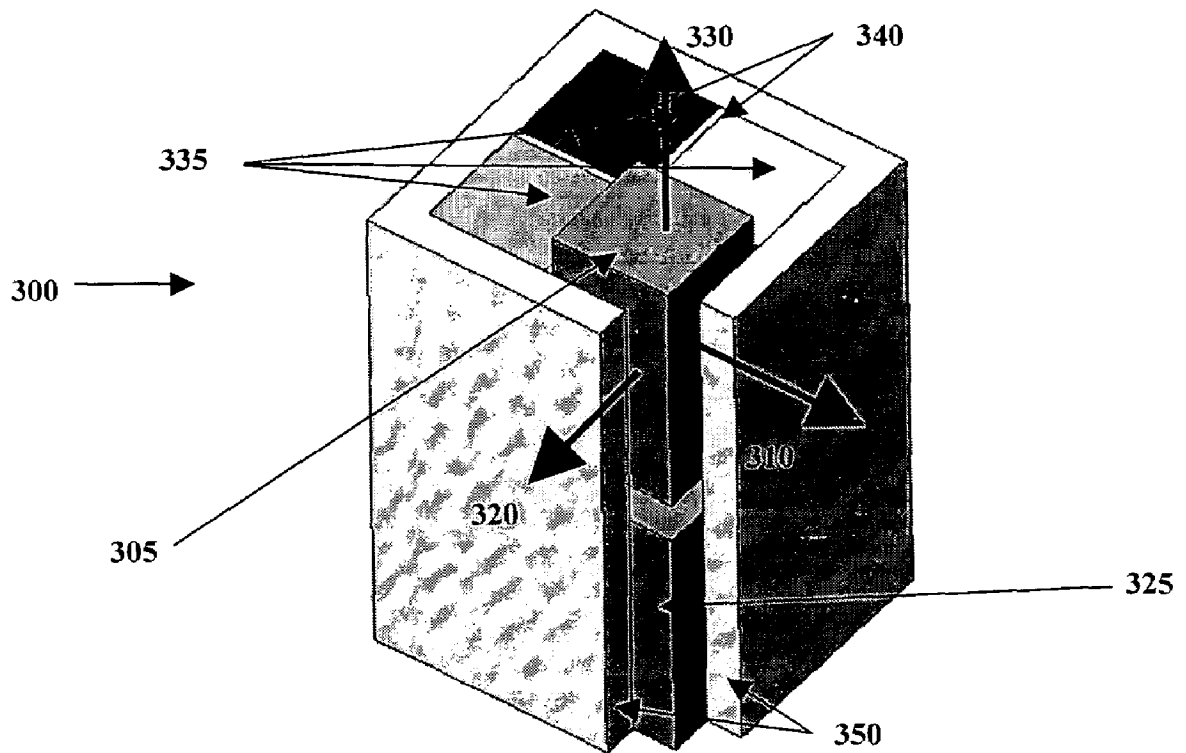


FIG. 4

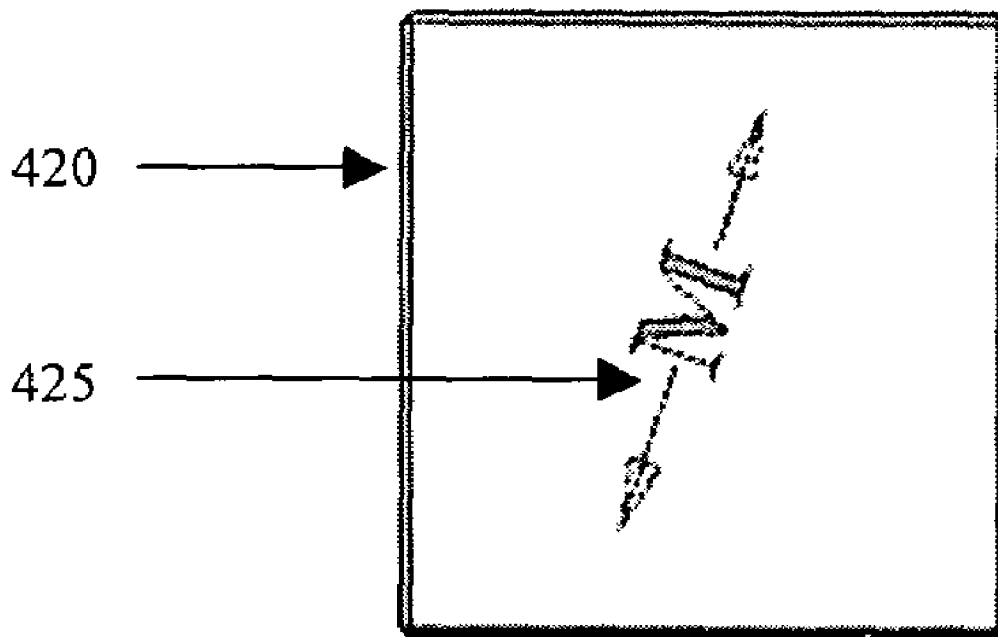
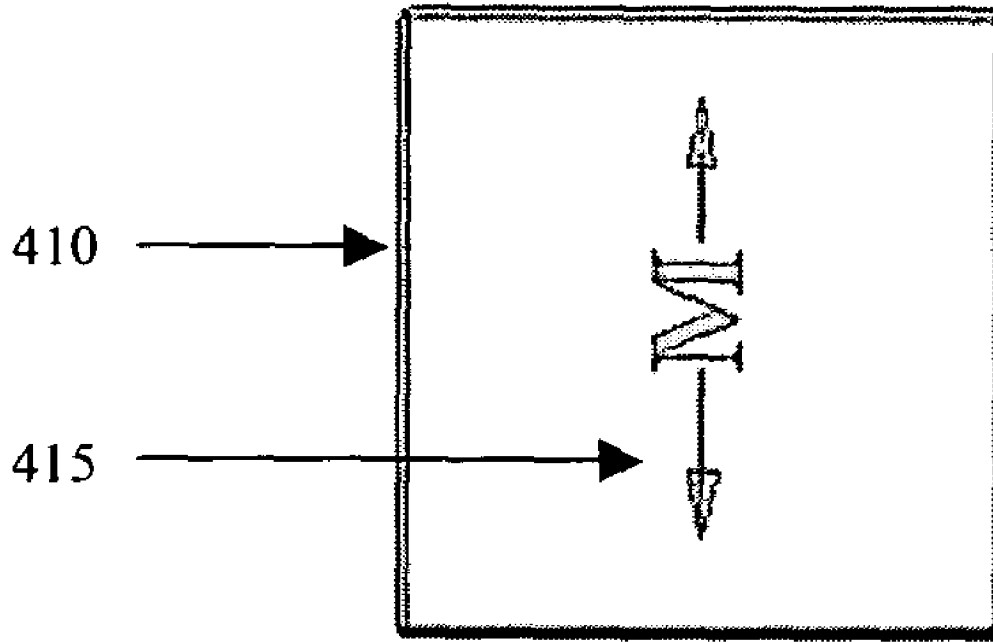


FIG. 5

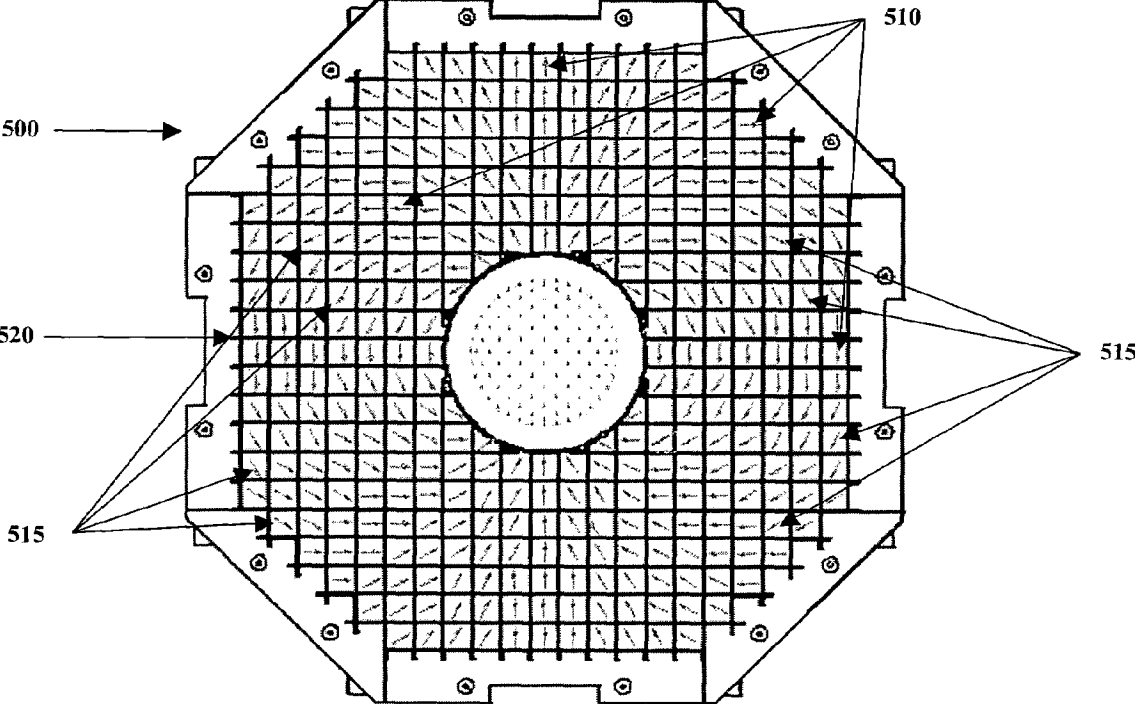


FIG. 6

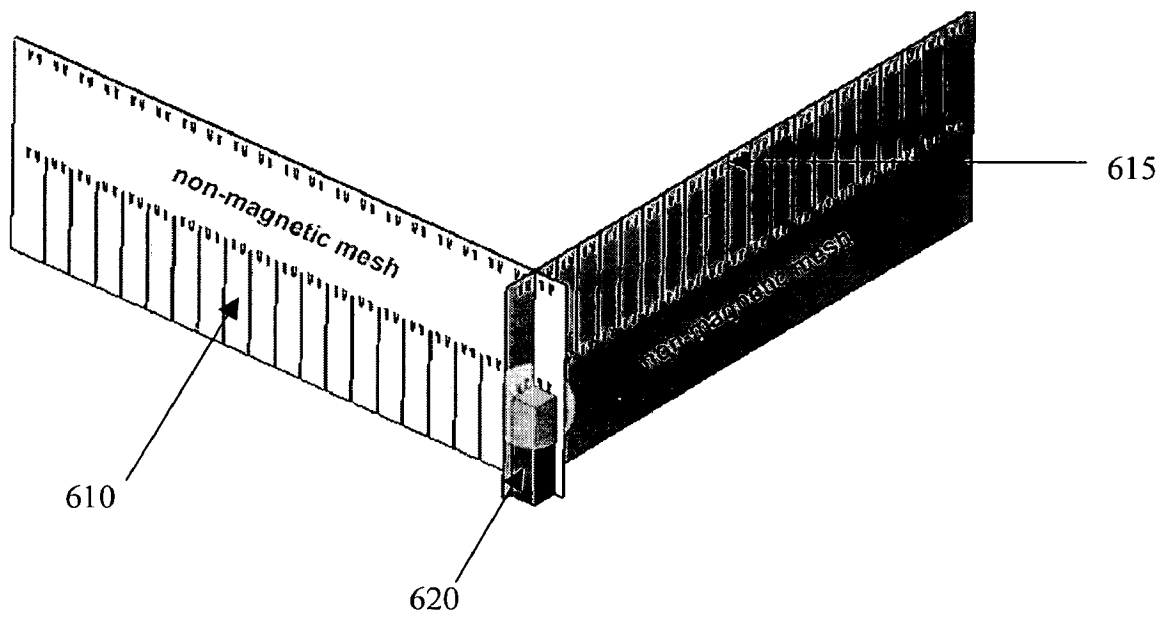
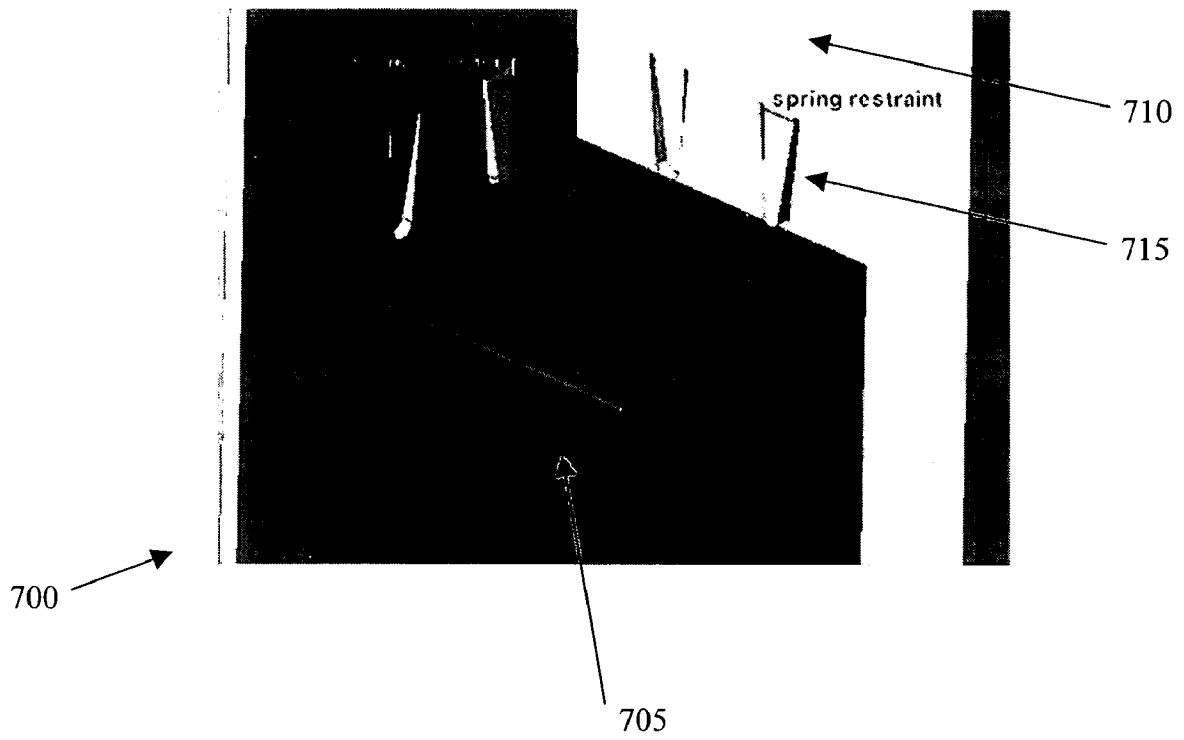


FIG. 7



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METHOD FOR CONSTRUCTING PERMANENT MAGNET ASSEMBLIES

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates generally to magnet assemblies and in particular to a method for constructing a permanent magnet assembly by using a frame to restrain the movement of magnets.

2. Description of the Related Art

Numerous methods exist for construction of magnetic assemblies. The desired configuration and size of the magnetic assembly often dictates the method required for construction of the assembly, due, at least in part, to the large forces inherent in magnetic materials.

Permanent magnet materials function like any other material until magnetized by an external source. Manufacturing operations on permanent magnet materials such as grinding, slicing, etc. are well established, and pose no significant challenges to those equipped with the proper tools. Although charged magnetic materials can be machined, unmagnetized stock is preferred.

Magnetic materials are frequently altered by machining operations to shape the materials and to adjust the magnetic field characteristics of the materials. The altered, unmagnetized, magnetic materials may be assembled and then magnetized to full saturation, to minimize the exposure of assembly personnel to potentially dangerous forces that would otherwise exist if assembling magnetized materials. Although it is preferred that all magnets be charged after assembly, the sheer size and, more importantly, orientation of magnetic materials in some assemblies require personnel to work with fully magnetized materials. The associated dangers are significant and compounded as the size of the magnetized materials increases.

Magnetic assemblies may involve permanent magnets positioned in a manner that counters the natural alignment tendencies of the magnets, creating very large torques and forces that may lead to self-destruction if not properly restrained, during the assembly process.

Adhesives are currently the main fastening mechanism in the majority of magnetic assemblies. During the assembly process, external restraints are placed on the magnet being loaded into the assembly. These restraints are typically 3-axis ball screw driven linear slides. Adhesive is placed on the contact surfaces of the target magnet, which is then placed into its location in the assembly and held there until the adhesive has set.

Magnets being installed in magnet assemblies often experience three orthogonal forces. These forces generally differ in magnitude making it difficult to maintain the magnet's physical orientation as it is being assembled. Increased magnet sizes or certain assemblies can create forces that can approach hundreds or thousands of pounds and make hand assembly difficult, dangerous, or even impossible. As stated above a mechanical means of assembling such structures is required. Such means can become prohibitively large and costly. Furthermore, once the adhesive is set and the mechanical restraints removed, the loads imparted on the target magnet are fully absorbed by the adhesive. Although this has proven to be an acceptable method of assembly, broken or faulty bond lines may exist causing magnets to come loose.

Once a magnet assembly is completed, an exoskeleton of metal is often placed around the unit to act as the last line of defense against any failed bond line.

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Nonetheless, at times during the assembly process the adhesive is the only fastening mechanism used to constrain the vast amounts of energy stored in the unit.

Magnets may be improperly oriented or defectively attached during construction of the assembly. Repair of magnets assembled in incorrect orientations can be difficult as well as dangerous. Attempting to separate faulty magnets may also sacrifice the integrity of any other bond lines or damage any other magnets in the system.

BRIEF SUMMARY OF THE INVENTION

A method for constructing permanent magnet assemblies utilizes a frame that houses and restricts movement of magnets being added to the assembly. The frame may be between any or all adjacent magnets or magnet blocks in an assembly. The frame is particularly useful in assemblies where the magnetic orientations differ between adjacent magnets. In another aspect, the frame may form an interlocking mesh to aid in constructing permanent magnet assemblies.

In another aspect the frame may contain deformations that structurally hold the magnets in place.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The embodiments of the invention are illustrated by way of example and not limitation in the accompanying figures, in which:

FIG. 1 provides a three dimensional view depicting three orthogonal forces acting on a magnet being added to a permanent magnet assembly.

FIG. 2 provides a view of two magnets and a frame for receiving them in the assembly process to create a magnetic assembly, in one embodiment of the invention.

FIG. 3 provides a view of a magnet assembly consisting of a frame and more than two magnets, in one embodiment of the invention.

FIG. 4 depicts two different magnetic polar orientations.

FIG. 5 depicts a magnet assembly consisting of a frame, and magnets oriented in polar directions in a manner to complete a magnetic circuit.

FIG. 6 provides a cut-away view of the frame in a magnet assembly, showing an interlocking mesh embodiment for the frame.

FIG. 7 provides a view of a deformation in the frame acting as a restraint to a magnet inserted into the frame.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 illustrates potentially three orthogonal forces acting on an example magnet **105** being placed near a magnet assembly **100** and depicts a typical situation encountered during construction of the magnet assembly. The three orthogonal forces **110**, **120** and **130** are a representation of the forces that may act on magnet **105** in a certain position relative to the magnet assembly **100**. These forces change with respect to the magnet's orientation and/or the orientation of other magnets in the assembly. For example, any of the represented orthogonal forces may be zero. The magnet assembly may consist of magnets with magnetic polar orientations at right angles or any other non-aligned magnetic polar orientation thus increasing or decreasing the orthogonal forces acting on magnet **105**.

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An embodiment **200** of the invention is described with reference to FIG. 2. Two permanent magnet blocks, **220** and **240**, are shown being inserted into a non-magnetic frame **210**. The permanent magnet blocks **220** and **240** may each comprise one or more magnets. The magnets in any embodi-

ment may be comprised of iron, nickel, cobalt, or rare earth materials such as neodymium and samarium, or combinations or derivatives thereof, such as neodymium iron boron. These and other high coercivity materials (with an intrinsic coercivity greater than the flux density provided by the magnetic structure) may be used. The frame **210** in any embodiment may consist of any non-magnetic material or even a marginally magnetizable ferromagnetic material.

The magnets illustrated in FIG. 2 are square. However, other magnet shapes that achieve true tessellation are equally applicable to the invention. For example, triangle-, hexagonal- and octagonal-shaped magnets may be used.

In any embodiment of the invention, the magnets may differ in magnetic polar orientation. An embodiment consists of the frame **210** having a wall adjacent sufficient sides of the magnets such that the frame restricts movement of each magnet in at least one direction. Such a frame facilitates construction of a magnet assembly, and permanent magnet assemblies in particular, as described below.

The frame **210** in FIG. 2 has receiving slots for magnet blocks **220** and **240**. Magnet block **220**, for example, is first inserted at **230** into the receiving slot of the frame **210**. In this example, the frame **210** prevents movement of magnet block **220** in the direction in which the magnet is being inserted or from which the magnet may be removed. In one embodiment frame **210** may allow more than one dimension of movement for magnet block **220** but may still restrict movement by the magnet block **220** in at least one direction.

In FIG. 2, the magnet block **220** may be inserted at **250** into frame **210**, for example, once the first magnet block **220** has been inserted into the frame **210** or concurrently therewith, according to various manufacturing methods. The magnet blocks **220** and **240** may have different polar orientations, which may cause the magnets to misalign, absent a frame, thus making construction of magnetic assembly **200** difficult. The frame **210** restricts the movement for each magnet block **220** and **240** in at least one direction thus aiding the construction of magnetic assemblies. In one embodiment, the frame **210** restricts the movement of each magnet block **220** and **240** to one axis of direction.

In FIG. 2 the magnet blocks **220** and **240** may be attached to the frame **210** by mechanical or adhesive ways. Adhesive may be applied to the surfaces of the magnet blocks **220** and **240** to connect to frame **210**, and the magnet blocks may be held in place mechanically until the adhesive sets, at which time the mechanical restraints may be removed. Alternatively, the frame could receive the adhesive or it may be applied to both the frame and the surfaces of the magnet blocks. Upon the adhesive setting, the mechanical restraints may be removed and the magnet blocks **220** and **240** remain in the frame due to the set adhesive.

In another embodiment, the frame may be configured to handle any number of magnet blocks in creating a magnet assembly, such as described below for FIG. 3 and FIG. 5.

An embodiment **300** of the invention is now described with reference to FIG. 3. A magnet assembly is illustrated having a magnet block **305** being added to the assembly, magnet blocks **325** and **335**, already added to the assembly, a frame **340** into which the magnets are inserted, and including an outer portion of the frame **345** that acts as an exoskeleton to bind the magnet blocks together. The figure illustrates the potential forces **310**, **320** and **330** acting on the

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magnet **305** being added to the assembly **300**, depending on the magnetic polar orientation of other magnets in the assembly. FIG. 3 provides a sectional view **350** to illustrate a magnet block **325**. In practice, the exoskeleton **345** encloses the assembly. The embodiment **300** in FIG. 3 has receiving slots for all magnet blocks, including magnet blocks **305** and **325**. FIG. 3 shows magnet block **305** being inserted into the receiving slot of the frame **340**, over top of the already inserted magnet block **325**. The frame **340** prevents movement of magnet block **305** in any but one direction. In one embodiment frame **340** may allow more than one dimension of movement of a magnet block including magnet block **305**.

In FIG. 3 the magnet blocks may be attached to the frame **340** by mechanical or adhesive ways. Adhesive may be applied to the surfaces of the magnet blocks to connect the magnet blocks to frame **340**. The magnet blocks may be held in place mechanically until the adhesive sets, at which time the mechanical restraints may be removed. Upon the adhesive setting, the mechanical restraints may be removed but the magnet blocks remain assembled in the frame due to the set adhesive.

The frame **340** may have a deformation, such as the spring restraint depicted in embodiment **700** in FIG. 7 and described below, which locks the magnet blocks into place once placed in the frame **340**. The deformation may be an indentation or simply a semi cut portion of the frame **340** operating as a spring such that once the magnet block has been pressed past it, the magnet force acting on the block cannot overcome the locking mechanism. It would be understood by one of skill in the art that many types of mechanical restraint either as a deformation in the frame material or attached to the frame material may be used by itself or in combination with the adhesive to keep the magnet blocks in the frame **340** and thus maintain the magnet assembly **300**.

FIG. 4 depicts magnet blocks **410** and **420** with different magnetic orientations. Magnet **410** has an orientation **415** that is perpendicular to the face of magnet **410**, whereas magnet **420** has an orientation **425** that is aligned at an acute angle to the face of magnet **420**. In FIG. 4 the acute angle is 30 degrees, therefore, the orientations of magnets **410** and **420** differ by 30 degrees. The 30 degree difference in magnetic orientations is particularly efficient for generally square magnet blocks since 12 orientations can occur based upon only the two magnet blocks **410** and **420**, as depicted in FIG. 5. However, it is appreciated that other angles of magnetic orientation with respect to a face of a magnet is also possible without departing from the spirit of the invention. The different orientations allow magnet blocks to be inserted into a frame in a manner that facilitates creating a magnetic circuit among the assembled magnetic blocks. In other words magnet blocks can be placed in a closed loop manner consisting of placing the north polar end of one magnet block adjacent the south polar end of another magnet block, and furthermore by having an offset angle between magnetic field orientations for at least some of the adjacent magnet blocks, as depicted in FIG. 5.

Magnet blocks may consist of smaller or even larger offset angles than the 30 degrees shown in FIG. 4. Referring to FIG. 5, as the angle offsetting magnetic field orientations for adjacent magnet blocks is decreased the resulting magnetic field strength of a magnet assembly increases. It would be understood by one of skill in the art to vary the offset angle of magnetic field orientations to other than 30 degrees as depicted in FIG. 4.

An embodiment **500** of the invention is described with reference to FIG. 5, depicting a top view of a magnetic

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assembly comprising magnet blocks **510** and **515** inserted into a frame **520**, with the magnet blocks **510** and **515** oriented such that they complete a magnetic circuit. Each arrow depicted in the 12 different orientations of magnet blocks **510** and **515** represents the magnetic polar orientation of that particular magnet block once it is inserted into the assembly. As stated above, by utilizing only the magnet blocks **410** and **420** as depicted in FIG. 4, the embodiment **500** may be constructed with magnets having 12 different magnetic polar orientations. The embodiment **500** utilizes the different magnetic polar orientations to complete a magnetic circuit and therefore increases the magnetic field strength of the magnet assembly. Other embodiments such as **500** may be constructed utilizing magnetic polar orientations differing by other than 30 degrees.

FIG. 6 illustrates a cut-away view of the frame and a magnet block **620** in the assembly in FIG. 5. In one embodiment the frame consists of a first portion **610** that interlocks with a second portion **615** much in the nature that cardboard separators in cardboard boxes interlock. In one embodiment the portions **610** and **615** are comprised of a non-magnetic material. It would be understood by one of skill in the art for the frame portions to alternately be slightly magnetic such as any ferromagnetic material.

The cut-away view depicted in FIG. 6 is accomplished by adjoining the first portion **610** with the second portion **615** such that they form a frame. The frame generally wraps around the magnet, but the cut-away view in FIG. 6 represents the magnet block being surrounded by the frame on only 2 sides. FIG. 6 further depicts a spring restraint locking mechanism further defined below in embodiment **700**. The interlocking mesh allows for simplified construction of the frame that can be utilized in construction of a magnet assembly, as described above. FIG. 6 illustrates that magnet block **620** can be restrained in the frame below the spring restraint locking mechanism. Furthermore, the locking mechanism allows an additional magnet block to be placed on top of magnet block **620**.

An embodiment **700** of the invention is described with reference to FIG. 7. The embodiment **700** shows a magnet block **705**, a frame **710** and a spring restraint **715** in the frame **710**. The spring restraint **715** is a structure on the frame that acts to keep the magnet block **705** in place once it has been situated. The spring restraint may likewise be any deformation in the frame **710** material or may actually be an addition to the frame so long as the structure allows the magnet block **705** to be placed into the receiving portion of the frame in a manner that physically restricts extraction of the magnet block **705** from the frame **710**. In FIG. 7 the magnet block **705** is inserted into the frame **710**. Upon insertion of the magnet block **705** into the frame **710**, the spring restraint **715**, or other similar locking structure or deformation of the frame material **710**, physically restrains extraction of the magnet block **705** from the frame **710**.

The embodiment **700** may be utilized in frame **340** to lock the magnet blocks **305**, **325** or **335** into place once placed in

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the frame **340**. The deformation may be an indentation or simply a semi cut portion of the frame **340** operating as a spring such that once the magnet block has been pressed past it, the magnet force acting on the block cannot overcome the locking mechanism. It would be understood by one of skill in the art that many types of mechanical restraint either as a deformation in the frame material or attached to the frame material may be used by itself or in combination with the adhesive to keep the magnet blocks **305** and **325** in the frame **340** and thus maintain the magnet assembly **300**. The embodiment **700** may work with any other frame dimension, such as depicted in FIG. 2 or FIG. 5.

What is claimed is:

1. A method of building a permanent magnet assembly, comprising:

mechanically restraining a plurality of permanent magnet blocks so as to prevent the plurality of permanent magnet blocks from moving with respect to one another;

mechanically restraining a first permanent magnet block not in the plurality of permanent magnet blocks from moving in either a first direction relative to the plurality of permanent magnet blocks or in a second direction relative to the plurality of permanent magnet blocks, wherein mechanically restraining the first permanent magnet block from moving in the first direction comprises restraining the first permanent magnet block using a nonmagnetic frame, the first and second directions defining a plane, the first permanent magnet block having a first magnetic orientation;

moving the restrained first permanent magnet block with respect to the restrained plurality of permanent magnet blocks, the moving in a third direction not parallel to the plane, the moving to put the first permanent magnet block into a position proximate to the restrained plurality of permanent magnet blocks so as to form a desired angle between the first magnetic orientation and a magnetic orientation of one of the plurality of permanent magnet blocks;

further restraining the restrained first permanent magnet block in the position, including deforming the nonmagnetic frame.

2. The method of claim 1 wherein mechanically restraining the plurality of permanent magnet blocks comprises restraining at least some of the plurality of permanent magnet blocks using the nonmagnetic frame.

3. The method of claim 1 wherein the first magnetic orientation of the first permanent magnet block and the magnetic orientation of the one of the plurality of permanent magnet blocks differ.

4. The method of claim 3 wherein the desired angle between the first magnetic orientations of the first permanent magnet block and the magnetic orientation of the one of the plurality of permanent magnet blocks is 30 degrees.

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