Dec. 15, 1959 F. F. KIRCHNER ET AL 2,917,682

MAGNET

Filed July 9, 1956 2 Sheets-Sheet 1

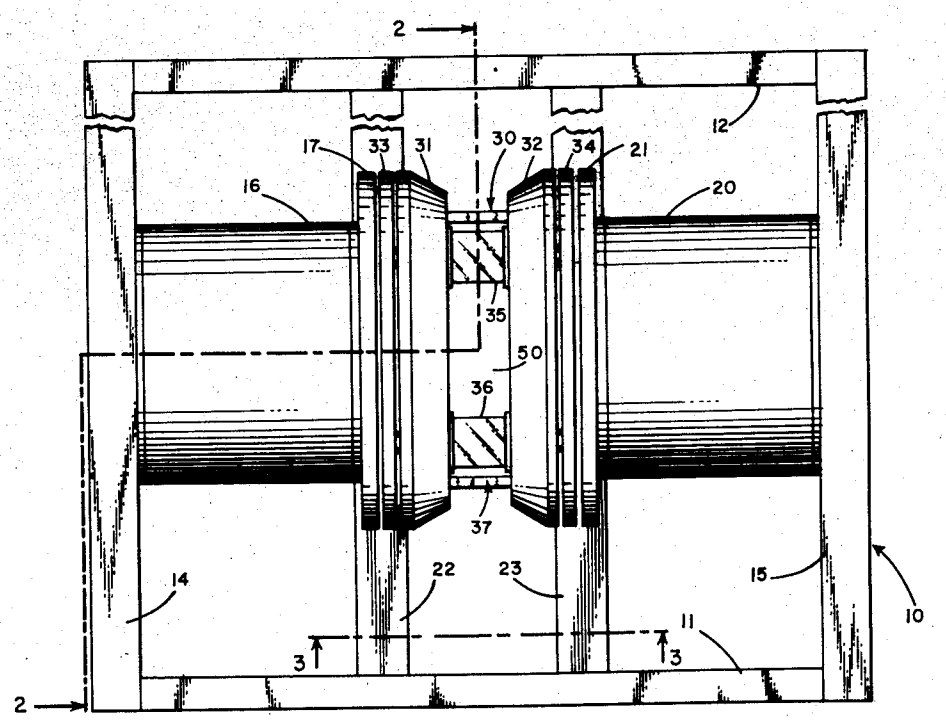


FIG. 1

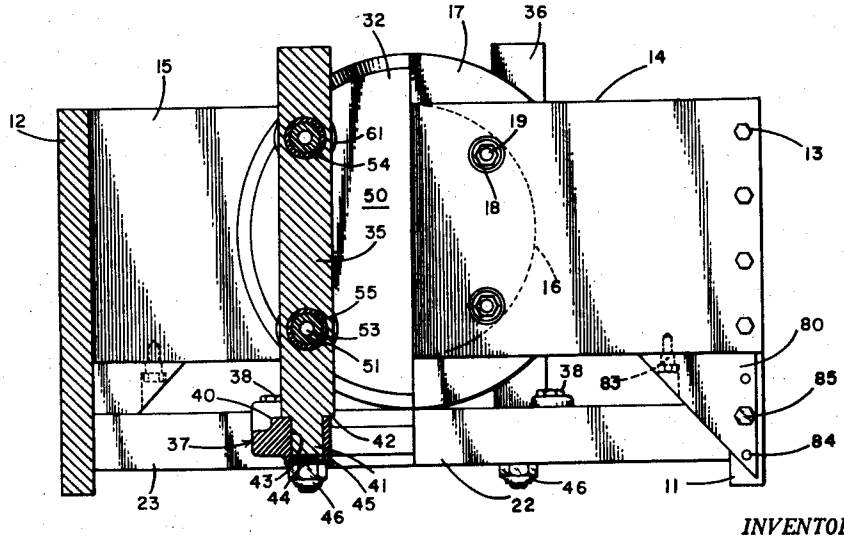


FIG. 2

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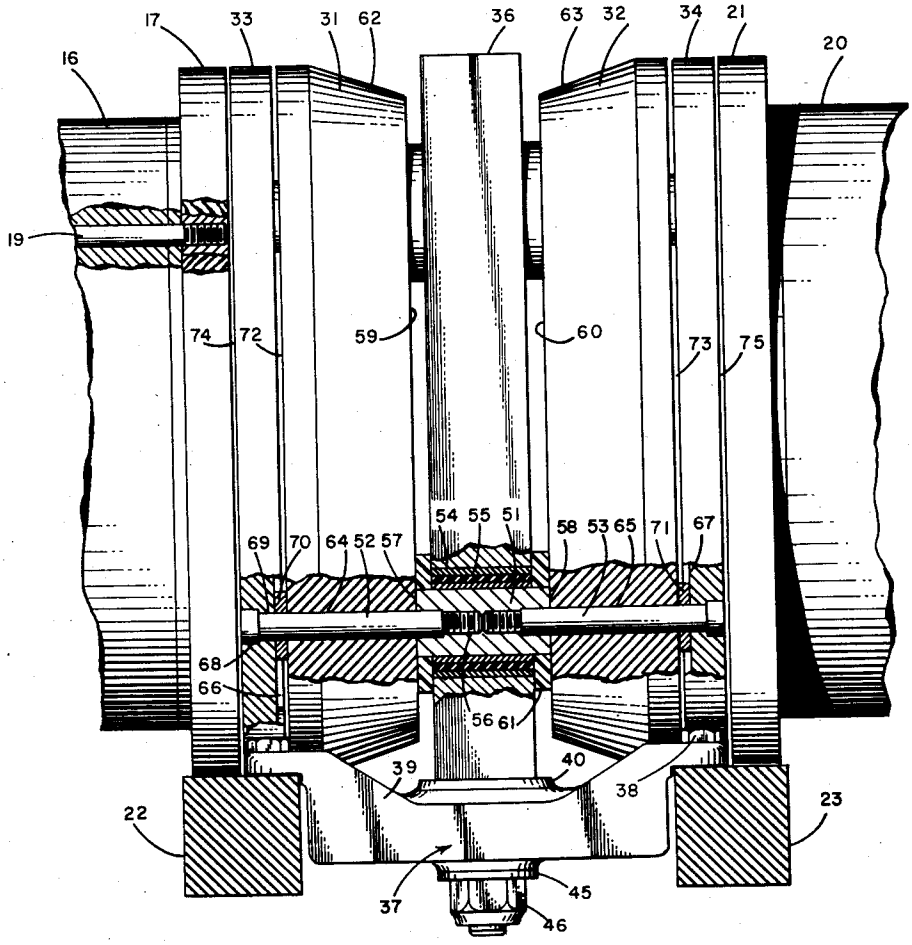


FIG. 3

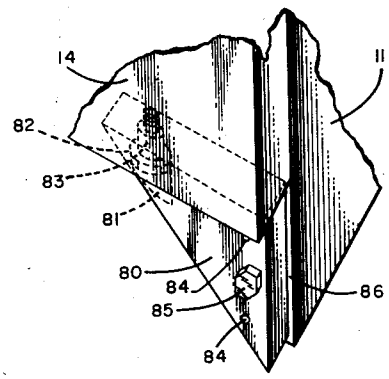


FIG. 4

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MAGNET

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12 Claims. (Cl. 317—200)

The present invention relates to magnets and, more particularly, to a magnet for producing a highly homogeneous magnetic field.

In certain instances requiring the use of a magnet, it is necessary that the magnetic field produced thereby be highly homogeneous. For example, in a magnetic resonance apparatus such as that described by F. Kirchner and L. Jimerson Jr. in application Serial No. 552,403, dated December 12, 1955, the permanent magnet structure which is employed is required to produce a highly homogeneous unidirectional field.

In the design of such a magnet, the design and construction of the pole pieces is of great importance. The surfaces of the pole pieces must be plane and are therefore ordinarily machined with great accuracy. The pole faces must also be as nearly parallel as possible since the relative position of the pole face surfaces has a direct effect on the homogeneity of the field.

It has been customary to produce a homogeneous magnetic field by a magnet apparatus of the type in which each pole piece is fixed independently of the other on a yoke structure. More specifically, the yoke is rectangular and has a permanent magnet core secured to the inside of each end plate. The pole faces are fixed to the opposing inner ends of the magnet cores. It is apparent that any deformation of the yoke, resulting from shock or thermal expansion, for example, changes the relative position of the pole faces. Consequently, frequent checking and adjustment of the parallelism of the pole face surfaces is required and the field is not always homogeneous.

It is therefore an object of this invention to provide a new and improved magnet structure for producing a highly homogeneous magnetic field.

Another object of this invention is to provide a new and improved magnet for producing a highly homogeneous field wherein the relative position of the pole faces is not affected by small deformations of the yoke structure.

Still another object of this invention is to provide a new and improved magnet means for producing a homogeneous magnetic field in which the pole face surfaces are plane and are maintained absolutely parallel to one another.

These and other objects are attained in accordance with the present invention by fixing the pole pieces in a removable cartridge unit adapted to be mounted between a pair of opposing magnet cores. The magnet cores, which may be of the permanent type, are fixed to the end plates of a rectangular yoke having a novel flux adjustment means at its corners. The cartridge units is preassembled independently of the magnet cores and yoke and comprises, basically, two pole pieces having optically finished surfaces arranged on a mounting means in such a manner that the spacing thereof may be regulated within microinches. The mounting means in the preferred embodiment comprises spacer means having accurately finished end surfaces which contact the pole face surfaces.

When mounted between the permanent magnet cores

it is apparent that although the relative position of the cartridge with respect to the magnet cores may change by shock or thermal expansion, the geometry of the main gap does not change. The actual field strength may change with variations of the relative position of the cartridge in the magnet assembly, but the homogeneity of the field is not affected.

These and other features of the invention will be apparent from the following description taken in conjunction with the accompanying drawings in which:

Fig. 1 is a top view of a preferred embodiment of the invention showing the cartridge assembled in the yoke structure;

Fig. 2 is an end view and partial cross section of the apparatus of Fig. 1 taken on line 2—2 of Fig. 1;

Fig. 3 is a side view partially in section of the cartridge of Fig. 1 taken on line 3—3 of Fig. 1; and

Fig. 4 is a perspective view of the corner structure of the yoke.

In Fig. 1 is shown a magnet constructed in accordance with the principles of the present invention and including a yoke **10** for supporting permanent magnet core assemblies. Although the preferred embodiment shows a magnet of the permanent type, the invention is not restricted to this type and may also be applied to electromagnets. Yoke **10** generally comprises parallel side plates **11** and **12** to which are secured, as by fastening means **13**, Fig. 2, a pair of parallel end plates **14** and **15**.

Permanent magnet core assembly **16** includes a modulating winding thereon and is supported between the inside of end plate **14** and a retaining plate **17** of magnetic material disposed at its other end. End plate **14** has a plurality of countersinks **18** in its outer face to accommodate bolt and nut means **19** which pass through plate **14** and magnet core **16** to engage threads in retaining plate **17**, as shown in Fig. 3. Opposing magnet core **20** and retaining plate **21** are identical to core **16** and plate **17** and are similarly fastened to end plate **15**. Retaining plates **17** and **21** are assembled with care so that they are reasonably parallel.

Non-magnetic support bars **22** and **23** have flat upper surfaces and extend between side plates **11** and **12**. The support bars are secured to the side plates by any suitable fastening means, such as dowel and screw means (not shown), which maintain the flat upper surfaces level. Retaining plates **17** and **21** rest on the outer portions of the flat upper surfaces of support bars **22** and **23**, respectively, and derive support therefrom. Support bars **22** and **23** also provide the mounting means for removable cartridge unit **30**.

Cartridge unit **30** generally comprises pole pieces **31**, **32** and equalizer plates **33**, **34** supported by two non-magnetic posts **35** and **36**. Base member **37** carries the posts and is removably fastened to support bars **22** and **23** by bolt means **38**, as shown in Figs. 2 and 3.

Base member **37** of cartridge unit **30** more particularly is made of a non-magnetic material and is generally elongated with upstanding angled arms **39** at the corners thereof which are provided with apertures to receive bolts **38** and have coplanar faces to rest on the flat upper faces of support bars **22**, **23**. At either end of base member **37** are raised flats **40** on which support posts **35** and **36** rest. Posts **35** and **36** have lower portions **41** of reduced cross section to provide shoulders **42** to support the posts on raised flats **40**. Reduced sections **41** pass through apertures **43** in base member **37** and have threaded lower ends **44** to receive washers **45** and nuts **46**.

Pole pieces **31**, **32** are spaced in confronting relation to define a main air gap **50** and are secured to posts **35**, **36** by means of spacers **51** and bolts **52**, **53**. Each post is provided with an upper and a lower cylindrical aperture **54**, each of which receives a spacer **51** and a

bushing 55. Spacer 51 is made of a non-magnetic material which may be easily machined and which retains its dimensions, such as stainless steel or beryllium copper, and has a central aperture 56 threaded at its interior portions to receive on opposite sides the threaded ends of bolts 52 and 53. Spacer 51 extends lengthwise beyond the post, and opposite end surfaces 57 and 58 thereof contact, respectively, pole face surface 59 of pole piece 31 and pole face surface 60 of pole piece 32. Surfaces 59, 60 and 57, 58 are optically finished so as to permit close parallelism of the pole faces to thereby allow the production of a highly homogeneous field.

Bushing 55 comprises two co-axial non-magnetic sleeves having a molded rubber sleeve in between and isolates spacers 51 from stresses occurring in the mounting means therefor. Washers 61 may also be composed of rubber and fit around the extended end portions of spacer 51 and are in contact with pole pieces 31 and 32 so as to constrain them axially.

Pole pieces 31 and 32 are of magnetic material, of course, and are circular and have bevelled inner edges 62 and 63. Apertures 64 and 65 in the respective pole pieces permit passage of the shanks of bolts 52, 53, respectively.

Equalizer plates 33, 34 are of the same diameter as the pole pieces and have shallow recesses 66, 67, respectively, in the surfaces adjacent the pole pieces, whereby these plates are generally cup-shaped. This shape results in a reduced air gap at the rims and is adopted to provide extra flux at the rims to make up for the amount of flux leakage from the pole pieces in the region of bevelled edges 62, 63, thereby producing a more homogeneous field at the center of the main gap. Each equalizer plate is preferably made of a material having a high permeability and has a countersink 68 and an aperture 69 to receive the head and shank of bolt 52 or 53. Washers 70 and 71 of non-magnetic material are inserted between adjacent pole pieces and equalizer plates and create air gaps 72 and 73.

Each air gap and its respective equalizer plate serves to equalize or make uniform the magnetic flux from permanent magnet cores 16, 20 and their associated retainer plates 17, 21. Retainer plates 17 and 21 are of the same diameter as plates 33 and 34 in order to extend the field of the magnet to the dimensions of the cartridge unit. When the cartridge unit 30 is assembled on support bars 22 and 23, additional air gaps 74 and 75 are created between the respective pairs of plates 17, 33 and 21, 34. Because of the action of the equalizer plates 33 and 34, considerable misalignment of the cartridge assembly 30 is permissible.

It is desirable to have an adjustment for the strength of the magnetic field produced by the permanent magnet cores which is accessible without moving the main members of the device. The means for providing this adjustment is illustrated in Figs. 2 and 4. As shown, end plates 14, 15 of yoke 10 are of lesser height than side plates 11, 12 and should then be thicker to provide the same cross-sectional area for the flux as plates 11 and 12. If the end plates are narrower than the side plates, a minor saturation occurs in the corner region because of the high flux density resulting from the flux passing from the narrow end plates to the wider side plates. This saturation reduces the flux in the main gap between the pole pieces. To control the degree of saturation, auxiliary shunt paths for the corners of the yoke are provided by triangular adjusting plates 80 mounted in each corner.

Each adjusting plate 80 has a right angle corner which fits in the corner of the yoke. One side of triangular adjusting plate 80 extends inwardly along the lower edge of end plate 14 or 15 in engagement therewith and the other side extends downwardly along the endwise edge of side plate 11 or 12 with a variable spacing therefrom. For pivotally mounting each adjusting plate, each has a countersunk aperture 81 extending vertically through its inner end and providing a shoulder 82 for engagement by a pivot stud 83 received by the aperture 81 and threaded into the lower edge of the overlying end plate. Pivot stud 83 maintains the top edge of adjusting plate 80 in engagement with the lower edge of the end plate and permits pivotal adjustment of the outwardly directed portions of plate 80 so as to provide a variable air gap 86 between the edge of side plate 11 and plate 80. A plurality of set screws 84 extend through each plate 80 and contact the edge of side plate 11 or 12. A locking bolt 85 also extends through plate 80 and is threaded in the side plate. Initially, locking bolt 85 is tightened to maintain contact between plates 80 and 11 or 12. After magnetization, the flux adjustment is made by backing out locking bolt 85 and adjusting set screws 84 to give the desired width of air gap 86. Locking bolt 85 is then tightened against plate 80 to fix the air gap dimensions.

In assembling the device, cartridge unit 30 is adjusted before securing it to the yoke. There are four bolts 52 for aligning pole face surface 59 and, similarly, four bolts 53 for aligning pole face surface 60. Substantially absolute parallelism of optically finished pole face surfaces 59 and 60 can be obtained since contacting spacer surfaces 57 and 58 are also optically finished. If desired, spacer end surfaces 57, 58 may be machined rough and bolts 52, 53 then may be tightened the desired amount to produce parallelism of pole face surfaces 59, 60. Also, spacers 51 may be sliced on opposite sides parallel to the end surfaces to provide a spring action permitting alignment of pole face surfaces 59, 60 when bolts 52, 53 are tightened.

Having been adjusted, cartridge unit 30 is secured to support bars 22 and 23 by means of bolts 38. As shown in Figs. 1 and 3, the fit of the cartridge unit between retainer plates 17 and 21 is such that only small air gaps exist between the removable cartridge and the permanent magnet core assembly.

Flux adjusting plates 80 are maintained flush against their adjacent side plates when the device is magnetized. Thereafter they may be adjusted by means of set screws 84 and locking bolt 85 so as to increase the air gap and thus decrease the flux in the main gap to the desired amount. In one unit built in accordance with the principles herein set forth, a field in the main gap of 2,000 gauss is desired and the adjusting plates 80 permit adjustment of the field to within $\pm 0.1\%$. This adjustment compensates for the tolerance with which the permanent magnet assemblies are magnetized.

The magnet of the present invention produces a highly homogeneous magnetic field in the main air gap. Because the pole pieces are fixed relative to each other independently of the yoke and the permanent magnet cores, deformation of yoke 10 due to shock or thermal expansion, for instance, does not affect the geometry of the main gap. Deformation of the yoke does change the relative position of cartridge unit 30 with respect to the permament magnet cores and the yoke, but this does not affect homogeneity of the field in the main gap, although it may change the field strength. Continuous adjustment of field strength may be made by means of windings on the magnet cores, if desired.

Thermal expansion of cartridge unit 30 likewise does not appreciably affect the homogeneity of the field. Expansion is limited to the short length of spacers 51 and is substantially uniform for all four spacers. Therefore, while the main air gap lengthens, the pole face surfaces 59, 60 are maintained parallel. If desired, of course, the cartridge unit may be maintained at constant temperature by any suitable means. Also, the design of the present device permits the permanent placement of insulating material between the magnet core retaining plates 17, 21 and cartridge unit 30.

Various changes and modifications may be made in the embodiment described without departing from the principles set forth, and the invention is intended to in-

clude all such modifications and equivalents as fall within the scope of the appended claims.

We claim:

1. A magnet for producing a highly homogeneous field comprising, in combination, magnetic yoke means, opposing magnet core assemblies mounted on said yoke means, a pair of pole pieces, and non-magnetic means for mounting said pole pieces in spaced gap-forming relation with respect to each other removably on said yoke means between said magnet core assemblies in aligned spaced relation thereto.

2. A magnet for producing a highly homogeneous field comprising, in combination, a rectangular magnetic yoke having end plates and side plates, non-magnetic support means extending between said side plates, a pair of opposing magnet core assemblies each supported by one of said end plates and said support means, and a cartridge unit containing a pair of pole pieces spaced to form a main gap and removably mounted on said support means between said magnet core assemblies in aligned spaced relation thereto.

3. A magnet for producing a highly homogeneous magnetic field comprising, in combination, a magnetic yoke having opposing end plates and side plates, two opposing magnet core assemblies each mounted on one of said end plates, a pair of pole pieces, and non-magnetic means for removably supporting said pole pieces in spaced gap-forming relation on said yoke between said opposing magnet core assemblies independently thereof and in aligned spaced relation thereto.

4. The apparatus of claim 3 including at least one adjustable magnetic plate having a portion thereof pivoted to one of said yoke plates and having another portion thereof adjustably spaced from an adjacent one of said yoke plates to vary the flux produced between said pole pieces.

5. The apparatus of claim 3 including adjustable means to vary the flux produced between said pole pieces, said adjustable means comprising a triangular magnetic plate for each corner of said yoke, pivot means securing one side of each triangular plate to one of said end plates, and fastening means securing the other side of each triangular plate at an adjustable distance from an adjacent side plate, thereby creating a variable air gap.

6. Apparatus for producing a highly homogeneous magnetic field including, in combination, opposing permanent magnet core assemblies supported by a magnetic yoke means, and a removable cartridge supported by said yoke means between said magnet core assemblies in aligned spaced relation thereto, said cartridge comprising a pair of pole pieces having optically finished pole face surfaces, and non-magnetic mounting means maintaining said pole face surfaces in fixed parallelism.

7. The apparatus of claim 6 wherein said mounting means includes a non-magnetic base member, two upstanding non-magnetic posts secured to opposite ends of said base member, and non-magnetic spacer members supported by said posts, said pole pieces being secured to opposite end surfaces of said spacer members.

8. Magnet apparatus for producing a highly homogeneous magnetic field which comprises, in combination, a magnetic yoke means having end plates and side plates, a pair of opposing permanent magnet means each secured to an end plate, a pair of spaced non-magnetic support bars extending between said side plates and supporting said permanent magnet means, magnetic adjusting plates pivotally secured to said end plates and having other securing means to vary the spacing thereof from said side plates, thereby creating a variable air gap, a pair of pole pieces, means securing said pole pieces together in spaced parallelism, and means removably mounting said pole pieces on said support bars between said permanent magnet means in aligned spaced relation thereto.

9. Magnet apparatus for producing a highly homogeneous magnetic field which comprises, in combination, rectangular magnetic yoke means having opposing end plates and side plates, a pair of opposing permanent magnet core assemblies each secured to an end plate, a magnetic triangular flux adjusting plate pivotally secured to each of the lower corners of said end plates, fastening means between each said adjusting plate and its adjacent side plate which permits adjustment of the spacing thereof so as to create a variable air gap, a pair of pole pieces having optically finished pole face surfaces, non-magnetic spacer means between said pole pieces having optically finished end surfaces in contact with said pole face surfaces, bolt means extending through said pole pieces and spacer means, and non-magnetic mounting means securing said pole pieces and said spacer means to said yoke means between said permanent magnet core assemblies in aligned spaced relation thereto.

10. A pole piece cartridge comprising, in combination, a non-magnetic base member, a plurality of upstanding non-magnetic posts secured at spaced points to said base member, non-magnetic spacer means having parallel end surfaces supported by said posts, a pair of pole pieces having opposing optically finished pole face surfaces arranged one on either side of said spacer means in contact with the end surfaces thereof, and means securing said pole pieces to said spacer means.

11. A pole piece cartridge comprising, in combination, an elongated base member of non-magnetic material, a pair of upstanding non-magnetic posts secured to said base member at opposite ends thereof, each said post having a plurality of apertures therethrough, non-magnetic spacer members received in said apertures, a pair of bevelled pole pieces having opposing optically finished pole face surfaces arranged one on either side of said spacer members in contact therewith, magnetic equalizer plates spaced from said pole pieces on either side thereof and having inwardly directed rims, and means for securing said equalizer plates and said pole pieces to said spacer members.

12. A magnet for producing a highly homogeneous field comprising, in combination, magnetic yoke means, opposing magnet core assemblies mounted on said yoke means, a pair of pole pieces, and non-magnetic means for mounting said pole pieces on said yoke means in spaced apart alignment between said core assemblies independently of said core assemblies to provide a stable main flux gap between said pole pieces.

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