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HIDETSUGU IKEGAMI ET AL
MAGNET ASSEMBLY CAPABLE OF CONTROLLING
DISTRIBUTION OF MAGNETIC FIELD

3,296,569

Filed Aug. 27, 1962

2 Sheets-Sheet 1

FIG. 1

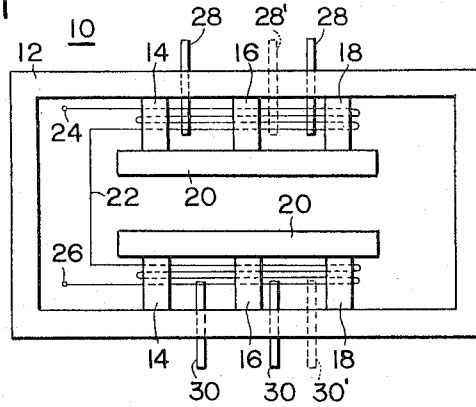


FIG. 2

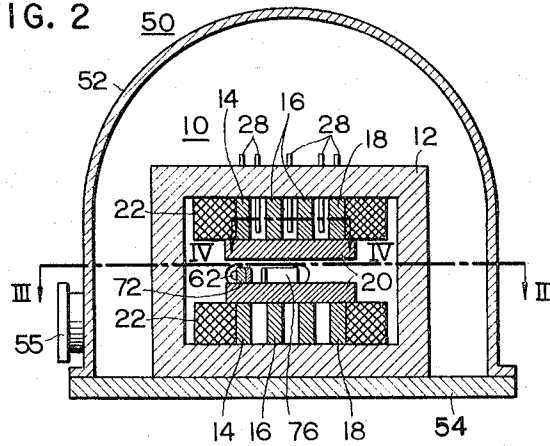


FIG. 3

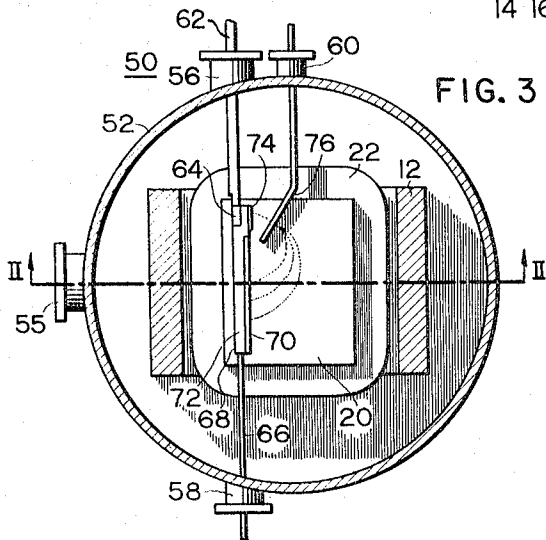
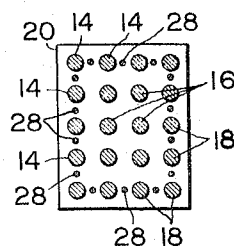


FIG. 4



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FIG. 5

DEVIATION

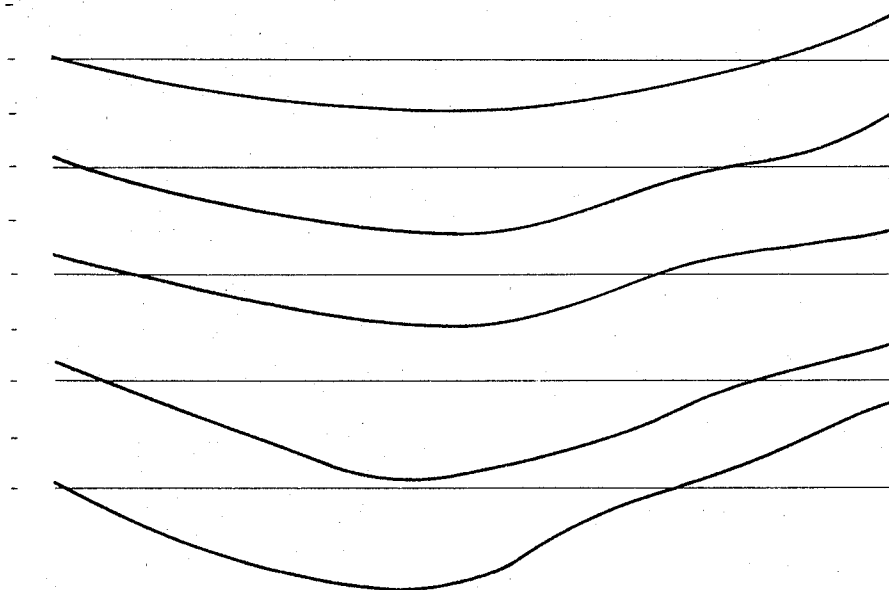
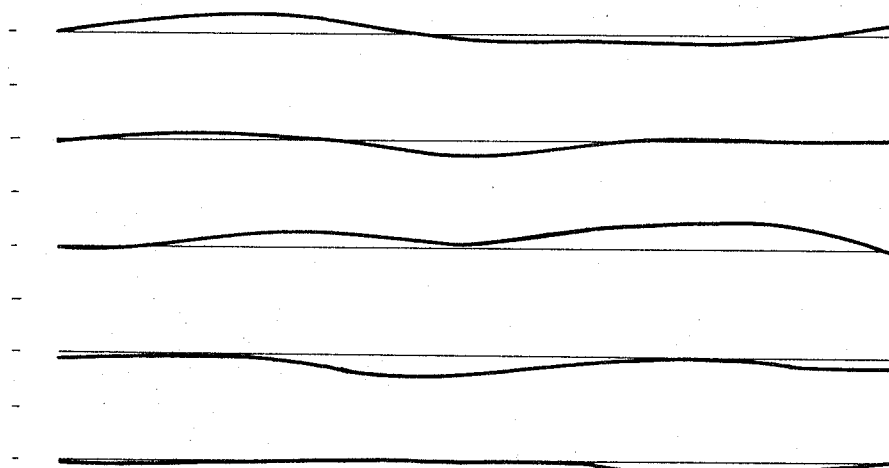


FIG. 6

DEVIATION



1

2

3,296,569

MAGNET ASSEMBLY CAPABLE OF CONTROLLING DISTRIBUTION OF MAGNETIC FIELD

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This invention relates to a magnet device and more particularly to a magnetic device for use in a charged particle energy spectrograph, a nuclear magnetic resonance apparatus and the like.

In general, it is extremely difficult to establish a uniform magnetic field by a relatively large magnet assembly comprising a plurality of permanent magnet members disposed in parallel relationship. This results from the fact that magnetic materials used lack uniformity of magnetic characteristics and that magnetic fluxes established in magnetic cores by an electric current applied to the associated exciting winding or windings are not uniform. It is also known that the penetration effects or the shielding effects of permanent magnet members are not uniform.

The chief object of the invention, therefore, is to provide an improved magnet device for establishing a uniform or desired magnetic field in extremely simple manner.

An additional object of the invention is to provide an improved magnet device especially suitable for use in a charged particle energy spectrograph such as a beta-ray spectrograph or a nuclear magnetic resonance apparatus for establishing a magnetic field having uniformity or any desired distribution in gradient.

With the above objects in view the present invention resides in a magnet device for use in a magnetic apparatus, comprising a pair of magnetic pole pieces between which any desired magnetic field is established, a plurality of magnet steel members operatively connected to each of said magnetic pole pieces and disposed in parallel relationship, a magnet yoke operatively connected to said plurality of magnet steel members, winding means wound on said plurality of magnet steel members to magnetize the same, one or more elongated compensating magnetic elements adjustably disposed in proximity of predetermined one or ones of said plurality of magnet steel members and/or one or more elongated adjusting elements including one end portion made of a permanent magnet and adjustably disposed in proximity of predetermined one or ones of said plurality of magnet steel members, said or each elongated element partially extending in the interior of said magnet device to locally affect a magnetic field portion essentially caused by the associated magnet steel member, and means for controlling said or each elongated element as to a length of that portion thereof extending into the interior of said magnet device.

Preferably, said compensating magnet element or elements may be adjustably disposed in proximity of the magnet steel member or members disposed on the outer periphery, or of the inner magnet steel member or members to locally decrease magnetic field strength.

Similarly, said adjusting element or elements may be adjustably disposed in proximity of the inner magnetic steel member or members or of the outer magnetic steel member or members to locally increase magnetic field strength.

The invention will become more readily apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 shows diagrammatically a view of a magnet device constructed in accordance with the teachings of the invention;

FIG. 2 shows schematically a sectional front view of a beta-ray spectrograph embodying the teachings of the invention, the section being taken along the line II—II of FIG. 3 and viewed in the direction of arrows illustrated in FIG. 3;

FIG. 3 shows schematically a sectional plan view of the spectrograph of FIG. 2 taken along the line III—III of FIG. 2 and viewed in the direction of arrows illustrated in FIG. 2; and

FIG. 4 shows schematically a fragmental sectional plan view taken along the line IV—IV of FIG. 2 and viewed in the direction of arrows illustrated in FIG. 2.

FIGS. 5 and 6 show graphs useful in explaining the results of the invention.

Referring now to FIG. 1 of the drawings, there is illustrated a magnet device constructed in accordance with the teachings of the invention. A magnet device generally designated by the reference numeral 10 comprises a magnet yoke 12 having a pair of parallel opposed portions which each is provided on the inside with a plurality of spaced members of magnet steel 14, 16 and 18 disposed in parallel relationship and including a common magnetic pole piece 20 attached thereto at their free ends. MK steels, KS steels and Alnicos can be satisfactorily used as the magnet steel members. It is, however, understood that other magnet steels may be used. As shown in FIG. 1, an exciting or magnetizing winding 22 is wound on both sets of magnet steel members 14, 16 and 18 in series circuit relationship and is connected to a suitable source of direct current illustrated as terminals 24 and 26. With the arrangement above described it will be seen that the energization of the magnetizing coil 22 from the source 24, 26 magnetizes the members of magnet steel 14, 16 and 18 to thereby establish a magnetic field between the pair of opposed magnetic pole pieces 20 and 20 with the polarity and strength determined by the direction of magnetizing current flowing through the coil and the ampere turns of the same respectively.

However, the arrangement previously described cannot generally establish a uniform magnetic field between the magnetic pole pieces 20 and 20 even in the case they would be disposed in exactly parallel relationship. The reason for this is that a magnet steel member is magnetized by a magnetizing current applied to the associated exciting winding to an extent dependent upon its position relative to the winding. More specifically, the application of a direct current to the magnetizing winding 22 will magnetize the outer members 14 and 18 stronger than the intermediate member 16 disposed near the center of the winding even though all the magnet members would be made of the same magnet steel, owing to the penetration effect or shielding effect of the magnetized members. Thus a magnetic field established by the magnetized members 14, 16 and 18 has its strength higher on its marginal portion than on the central portion. On the other hand, the magnet steel members thus magnetized will be partially demagnetized by a flow of direct current through the winding in the opposite direction to that used in magnetizing the same.

According to the invention, this disadvantage is avoided by disposing one or more compensating rods of a magnetic material in proximity of a predetermined magnetized member or members to locally decrease the strength of magnetic field portion essentially caused by the predetermined magnetized member or members.

As shown in FIG. 1, a pair of compensating rods 28 which may be made of any suitable magnetic material such as electrolytic iron are adjustably disposed substantially parallel to and adjacent the outer magnetized

members 14 and 18 respectively. The rod 28 extends partially in the interior of the magnet device 10 through a suitable hole formed on the portion of the yoke 12 adjacent the outer member 14 or 18 and can be controlled as to a length of that portion of the same extending inside the device 10 by any suitable control means (not shown). This control may be effected automatically or manually. While a pair of compensating rods has been illustrated in FIG. 1 any desired number of the compensating rods may be used if desired.

As previously pointed out, the magnetic field established by the conventional type of permanent magnetic device including no compensating rod 28 has its strength higher on the marginal portion or in the vicinity of the outer magnetized members 14 and 16 than on the central portion when the device is magnetized toward its saturation. It will be readily apparent that the compensating magnetic rod 28 disposed adjacent the outer magnetized member 14 or 18 decreases the relative strength of magnetic field portion in the vicinity of the associated magnet member with respect to that of the central portion and in accordance with a length of that portion of the rod extending inside the device 10.

Also, the partial demagnetization of the magnetized members 14, 16 and 18 results in a magnetic field whose strength is higher on the central portion than on the marginal portion. In such a case, the compensating magnetic rod can be similarly disposed in proximity of the intermediate magnetized member 16 or in a position illustrated by dotted line 28' in FIG. 1 to locally decrease the strength of the central portion of the field. It is to be understood that more than one of the compensating rods may be used in similar manner.

Therefore, the magnetic field between the pair of opposed magnetic pole pieces 20 and 20 has its strength capable of being controlled by adjusting the length of that portion of the compensating rods 28 extending inside the device 10 whereby the magnetic field can become uniform.

It will be also appreciated that the magnetic field between the magnetic pole pieces 20 and 20 can possess any desired distribution in gradient by properly controlling lengths of those portions of plural compensating rods extending inside the device 10 respectively and by suitably selecting the number of and/or spacings between the magnet steel members with the pair of magnetic pole pieces parallel or tilted to each other.

While the invention has been described in terms of local decrease in magnetic field strength it is to be understood that the invention is applicable to local increase in magnetic field strength in order to obtain a magnetic field having uniformity or any desired distribution in gradient.

In order to locally increase the strength of magnetic field portion resulting from a predetermined magnetized member or members, for example, from the intermediate magnetized member 16 alone, one or more permanent magnets can be disposed in proximity of the member 16. To this end, adjusting rods 30 which each includes one end portion formed of any suitable permanent magnet and the remaining portion preferably made of any suitable non-magnetic material such as aluminum can be adjustably positioned in the same manner as that previously described in conjunction with the compensating rods 28. The adjusting rods 30 serve to locally increase the strength of magnetic field portions in proximity of the intermediate magnet 16. Thus by properly selecting the physical size and magnetic characteristics of the adjusting rods as well as their positions relative to the associated magnetized members the magnet device can provide a magnetic field having uniformity or any desired distribution in gradient. It is understood that, instead of two adjusting rods any desired number of such rods may be used.

It will be readily appreciated that the adjusting rod or rods may be similarly disposed in proximity of outer mag-

netized member or members, for example, in a position illustrated by the dotted line 30' in FIG. 1 to locally increase the magnetic field strength.

While the magnet device according to the invention has been illustrated as including both the compensating rods and the adjusting rods it is to be noted that only either the compensating rods or the adjusting rods may be employed to accomplish the desired purpose.

The compensating and/or adjusting rods are individually controlled in operative length on the basis of results of field mapping measurement. Once these rods have been properly set in the magnetized magnet device, re-magnetization of the device which has been demagnetized provides the same magnetic field as initially established.

The magnet device thus far described could be advantageously used as a nuclear magnetic resonance device without the necessity of employing certain auxiliary equipments such as a power supply extremely stabilized.

Referring now to FIGS. 2 through 4 wherein like reference numerals have been employed to identify the components corresponding to those shown in FIG. 1, there is illustrated a beta-ray spectrograph embodying the teachings of the invention. A beta-ray spectrograph generally designated by the reference numeral 50 comprises a vacuum-tight enclosure 52 within which a magnet device 10 according to the invention is mounted on a base 54. The enclosure 52 is provided with an exhaust opening 55 through which the vessel is exhausted by any suitable vacuum pump (not shown), a pair of opposed insertion openings 56 and 58 and an operating opening 60 disposed adjacent the insertion opening 56.

The magnet device 10 in this example is similar to the magnet device previously described in conjunction with FIG. 1 and need not be described. However, it will be noted that a plurality of spaced members made of any suitable magnet steel are arranged in columns and rows with compensating rods 28 alternating the outer magnet members 14 and 18 (see FIG. 4). That portion of each compensating rod 28 extending inside a magnet device 10 is controlled in length by any suitable control means (not shown) to provide a uniform magnetic field between a pair of opposed magnetic pole pieces 20 and 20.

As shown in FIG. 3, a supporting rod 62 extends through the insertion opening 56 into the evacuated enclosure 52 without breaking vacuum seal and serves to guide and place a radioactive source 64 to be measured on one of the magnetic pole pieces 20 near its one corner. Another supporting rod 66 extends vacuum-tightly through the insertion opening 58 into the evacuated enclosure 52 without breaking vacuum seal and serves to guide and place a beta-ray detector 68 on the one magnetic pole piece 20 and in a position illustrated in FIG. 3. The beta-ray detector 68 may include a beta-ray sensitive plate 70, a supporting plate 72 for supporting the sensitive plate 70 and an exit slit 74. From FIGS. 2 and 3, it will be seen that, with the beta-ray detector disposed in its operative position the beta-ray sensitive plate 70 has its sensitive surface substantially perpendicular to the magnetic pole piece 20 and the slit 74 is positioned in front of the radioactive source 64. A movable shutter 76 is disposed in front of the radioactive source 64.

When the shutter 76 is open, beta rays emitted by the radioactive source 64 are passed through the slit 74 and along curved paths as illustrated by dotted line in FIG. 2 under the influence of the perpendicular magnetic field established between the pair of magnetic pole pieces 20 and 20 to the beta-ray sensitive plate 70 to affect the same. As well known, a beta-ray bombards a beta-ray sensitive plate at its position determined by its momentums and a magnitude of a magnetic field across which the beta ray passes. Therefore, a material of radioactive source can readily be determined by both that position of a beta ray on a sensitive plate where the beta ray from the source impinges and a magnitude of a magnetic field affecting the beta ray. However, if the magnetic

field will not be of uniformity then this determination may be indefinite and difficult to be made because of the indefinite correspondence between the type of source material and that position of a beta ray on a sensitive plate where the beta ray from the source material impinges.

Any conventional beta-ray spectrograph has the aforesaid disadvantage because of lack in uniformity of the magnetic field established therein. On the contrary, the beta-ray spectrograph embodying the teachings of the invention includes always a uniform magnetic field established therein resulting in elimination of the disadvantage as above described.

As an example, 70 magnet members of MK type 5A steel were disposed on a magnetic pole piece of soft iron 104 cm. long and 67 cm. wide in such a manner that 10 magnet members were aligned on each column and 7 magnet members aligned on each row. A spacing between a pair of the magnetic pole pieces was 6 cm. The magnet members were magnetized to provide between the magnetic pole pieces a magnetic field whose strength was approximately 300 oersteds. When no compensating rod was used a field distribution was obtained substantially as illustrated in FIG. 5 wherein a block represents the face of the magnetic pole piece and various curves show different field distributions along the longitudinal lines on the face. As shown in FIG. 5 the distribution had a deviation of about 3×10^{-3} and is similar to that provided by the conventional type of permanent magnet device.

When 30 compensating magnetic rods 1 cm. in diameter and 18 cm. long alternating the peripheral magnet members were properly set in the arrangement just described a field distribution was obtained substantially as illustrated in FIG. 6 with a deviation being only 6×10^{-4} .

The invention has been described in terms of a beta-ray spectrograph. However, it is to be understood that the invention is equally applicable to momentum analyzers for various kinds of charged particles.

While the invention has been described in conjunction with certain preferred embodiments thereof it is to be understood that various changes in detail of the construction and the arrangement and combination of parts may be made without departing from the spirit and scope of the invention.

What we claim is:

1. A magnet assembly for controlling a distribution of magnetic field, including a pair of spaced pole pieces for producing a desired distribution of magnetic field therebetween, a plurality of magnet steel members coupled in magnetically parallel relationship to each of said

pole pieces, a magnetic yoke member magnetically coupled to said plurality of magnet steel members, and a plurality of elongated magnet elements introducible axially into desired regions between said magnetic yoke member and said pole pieces and each controllable as to the extent of axial introduction into said regions, the magnet elements being arranged such that by position and extent of introduction of each magnet element into a respective region the desired distribution of magnetic field between said pair of magnetic pole pieces is locally controlled to provide the desired distribution of magnetic field between said magnetic pole pieces.

2. A magnet assembly for controlling a distribution of magnetic field, including a pair of spaced pole pieces for producing a desired distribution of magnetic field therebetween, a plurality of elongated magnet steel members coupled in magnetically parallel relationship to each of said pole pieces, a magnetic yoke member magnetically coupled to said plurality of magnet steel members, a plurality of magnet elements introducible axially into desired regions between said magnetic yoke member and said pole pieces and controllable as to the extent of introduction into said regions, winding means wound on said plurality of magnet steel members to magnetize said members, said magnet steel members being arranged such that by selecting the axial position and extent of axial introduction of each magnet element into a respective region, the desired distribution of magnetic field between said pair of magnetic pole pieces is locally controlled to provide the desired distribution of magnetic field between said magnetic pole pieces.

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