United States Patent

Avery et al.

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[54] PRINTED CIRCUIT STEERING COILS

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[73] Assignee: **The United States of America as represented by the United States Atomic Energy Commission**

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[52] **U.S. Cl.** **335/213,** 336/200

[51] **Int. Cl.** **H01f 5/00**

[58] **Field of Search** 335/210, 213; 174/68.5; 336/200

[56] **References Cited**

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[57] **ABSTRACT**

A printed circuit steering coil on a flexible board for producing a charged particle beam deflecting magnetic field wherein rectangular, continuous planar spiral coils are etched on the circuit board opposite sides such that as each of at least two boards are bent into cylindrical shapes and disposed interiorly in a steel tube of high permeability permitting beam passage, the coils provide for individual horizontal and vertical steering of the charged particles.

6 Claims, 5 Drawing Figures

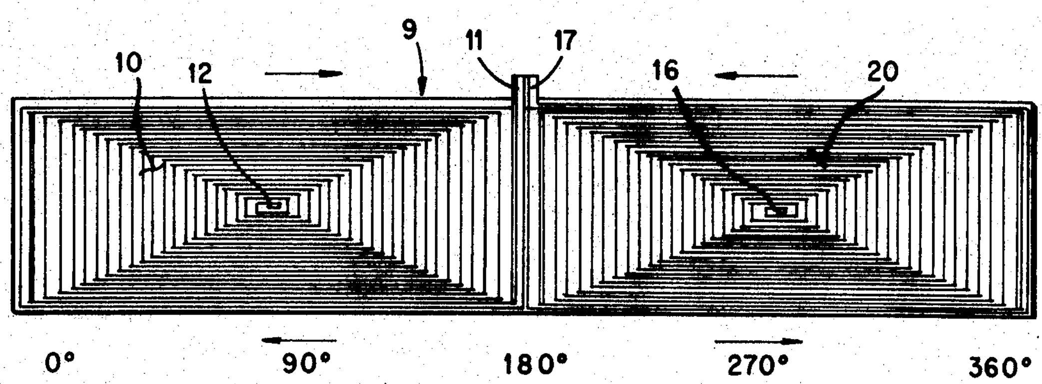

Fig. 1a

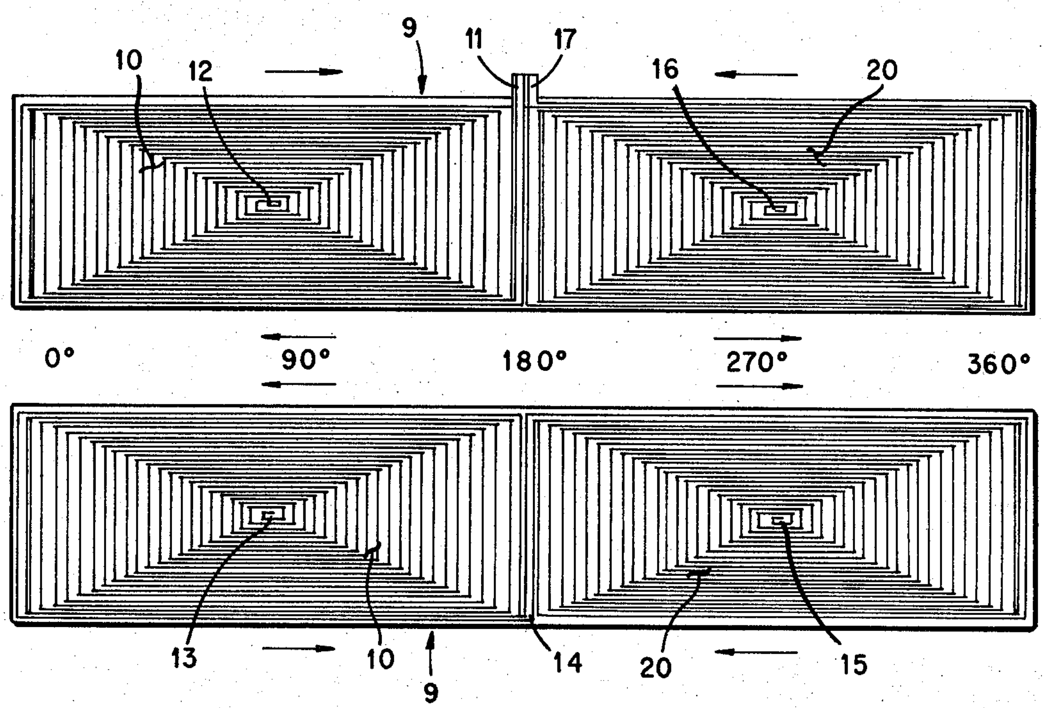

Fig. 1b

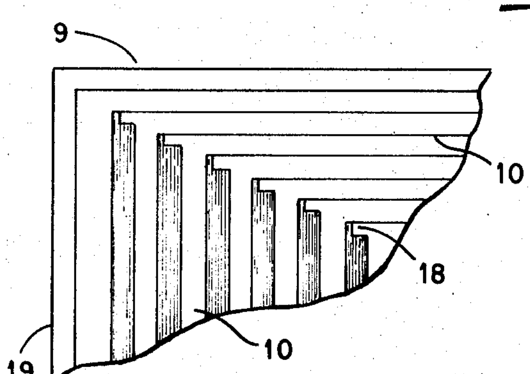

Fig. 1c

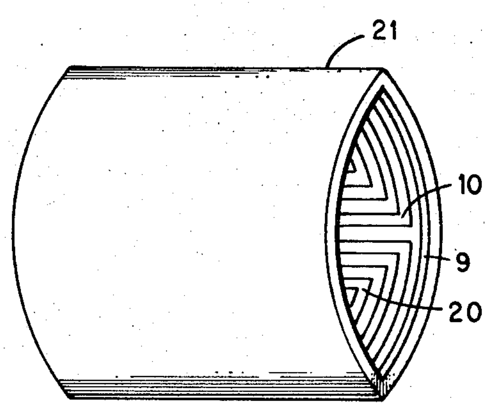

Fig. 2

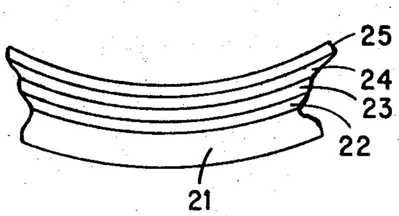

Fig. 3

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PRINTED CIRCUIT STEERING COILS

BACKGROUND OF THE INVENTION

The invention described herein was made in the course of, or under, Contract No. W-7405-ENG-48, with the United States Atomic Energy Commission.

This invention relates to magnetic coils and more particularly to steering coils for deflecting moving charged particle beams. Steering coils consisting of a multiplicity of wire turns forming roll-like structures have particular application to charged particle accelerators as means to magnetically deflect or measurably change the charged particle's path. Another common application of steering coils is as the horizontal and vertical deflection coils on the cathode ray tube of a television set, each coil arcuate in shape and laying circumjacent each of the four quadrants of the tube neck.

There are printed circuit means in the prior art by which plated lines on flexible rolled laminates form a plurality of electrical wire turns such as shown in "Coils Are Wound Topologically From Flexible Laminates," *Product Engineering*, Oct. 12, 1970; however, such constructed coils are not adaptable to steering coil type application for reasons obvious from their construction.

SUMMARY OF THE INVENTION

The present invention comprises economical, compact, high quality steering coils designed to produce uniform angular deflection of moving charged particles which also permit, in their construction, uniformity between coils. Two separate rectangular, inwardly coiled, continuous, planar helical spirals are etched on the front side of a flexible printed circuit board and then continued on the reverse side. The circuit boards are rolled into a cylinder and disposed inside a short steel tube. The coils form a passageway for the charged particle beam. Different boards for vertical and horizontal steering of a charged particle beam are located in separate layers interiorly to the steel tube. The embodiment of the invention produces an integrated deflection field when current excited which obtains high quality uniform angular deflection of all charged particle beams passing therethrough.

Accordingly, it is an object of the present invention to provide a compact, high quality charge particle beam steering coil.

It is also an object of the present invention to provide a charged particle beam steering coil wherein there is uniformity between successive sets of coils.

Other objects of the present invention will become readily apparent from the following description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1*a* and 1*b* are pictorial schematics of the front and reverse sides respectively of the flexible printed circuit board showing the etched turns pattern.

FIG. 1*c* is an enlarged broken-out portion of the front side of the flexible printed circuit board showing the "spikes" in the etched turns.

FIG. 2 is a pictorial view of the printed circuit steering coil disposed inside the steel tube.

FIG. 3 is a broken-out enlarged portion of FIG. 2.

DETAILED DESCRIPTION

For small-angle charged particle steering in the absence of iron, only currents in the charged particle beam direction contribute to the net angular steering. If the current distribution on a cylindrical shell satisfies the equation:

$$\int \frac{\partial i_z}{\partial \theta} dz \propto \cos \theta$$

Then the resultant integrated magnetic steering field is uniform for all charged particle beams at any x and y coordinate where x and y are a coordinate plane perpendicular to the cylinder and charged particle beam axis (z axis), where $(\delta i_z/\delta\theta)$ is the partial derivative of the current component in the direction of the beam travel with respect to angle θ between the x-coordinate and the element of current under consideration, and α means "varies as." If the conductors are placed inside a close-fitting iron shell of high permeability, image currents approximately double the uniform integrated magnetic steering field.

The embodiment of the invention in FIG. 1*a* showing the front side of the flexible printed circuit board **9** comprises the input electrical lead **11** which initiates the first half of the rectangular spiral coil **10** and continues to wind inwardly upon itself to center point **12** at which place the circuit board **9** is drilled to pass an electrical lead (not shown) therethrough which connects point **12** to center point **13** (FIG. 1*b*) of the last half of first coil **10** on the reverse side of the printed circuit board. The last half of the first coil **10** then winds outwardly from the center point **13** with the same winding sense as the first half of the coil (as viewed from a single exterior point) in order that the combined magnetic effect will be additive. The first coil **10** terminates at point **14** on the printed circuit reverse side which also is the second coil **20** starting point. The second coil **20** is wound in the opposite winding sense as first coil **10** and the turns comprise a rectangular inwardly wound continuous spiral to center point **15** at which point the printed circuit board is drilled to pass an electrical connection (not shown) therethrough to connect point **15** to the center point **16** (FIG. 1*a*) of the last half of the second coil **20** on the front side of the printed circuit board. From center point **16**, the last half of the second coil **20** expands rectangularly outwardly in a continuous spiral in the same winding sense as the first half of the second coil **20** but in the opposite direction as coil **10** (as viewed from a single exterior point), also so the combined magnetic effect will be additive. The second coil **20** terminates at the output electrical lead **17**. FIG. 1c is an enlarged section of the corner of printed circuit board **9** showing the "spikes" **18** which were added at the corners of the rectangular turns of coil **10** in order to discourage the electrical current from short-cutting the rectangular path of the coil. Protective border strip **19** is etched around coils **10** and **20**. The indications 0°, 90°, 180°, 270°, and 360° shown in FIGS. 1*a* and 1b indicate the relative positions of the flexible printed circuit board after it has been rolled into a cylinder and as in the preferred embodiment, although not necessary, disposed in the steel tube of high permeability shown in FIG. 2.

FIG. 2 illustrates the flexible printed circuit board 9 with coils 10 and 20 etched thereon rolled cylindrically and disposed interiorly to the steel tube 21. The center point 13 (not shown) of coil 10 is diametrically opposite center point 15 (not shown) of coil 20. As previously stated, coil 10 is wound with the first and second halves magnetically reinforcing each other, similarly with the first and second halves of coil 20, and with coils 10 and 20 wound oppositely and placed opposite each other, the overall effect is that the two coils produce a uniform integrated magnetic deflection field over the whole width of the coils when excited by a current. Magnetic measurements made within the cylinder formed from the printed circuit board at points 0.4 and 0.8 of the bore radius were within 0.5 and 1.5 percent of the value which existed at the center of the bore. One circuit board with the two separate coils thereon serves as steering coils in the vertical or horizontal direction depending on placement relative to the charged particle beam. It therefore is necessary that there be at least two separate printed circuit boards to steer the charged particles in both possible directions, one for the vertical direction and one for the horizontal direction. Boards for the vertical and horizontal steering are located in separate layers separated by insulation sheets. The board which is to serve as the inner of the two layers must be made proportionally smaller in the rolled direction to prevent the board from overlapping at the joining ends, however there is little, if any, change in magnetic field results.

FIG. 3 shows a broken-out, enlarged portion of FIG. 2 illustrating the steel tube 21, insulating material 22, printed circuit board 23 with steering coils for one of the charged particle deflection directions, insulating material 24, and printed circuit board 25 with steering coils for the other of the charged particle deflection directions.

Printed circuit steering coils which have been constructed have 0.004 inch copper turns on both sides of 0.008 inch laminated boards with 0.016 inch insulation sheet between boards.

Although the foregoing embodiment has been described in detail, there are obviously many other embodiments and variation in configurations which can be made by a person skilled in the art without departing from the spirit, scope, or principle of the invention, for example, the printed circuit deflection coils herein described are not to be limited to rectangular spiral coils but may be circular, oval, or any inwardly or outwardly coiled spiral. Therefore, this invention is not to be limited except in accordance with the scope of the appended claims.

We claim:

1. A printed circuit coil unit for steering charged particle beams comprising:

an elongated generally rectangular flexible printed circuit board;

a first rectangular spiral coil portion disposed on a front side of a first half of said circuit board and terminating at a first midpoint thereon, said coil portion having a first turn beginning at a terminal at a first side and continuing near the midplane across said board;

a second rectangular spiral coil portion disposed on the reverse side of the first half of said circuit board, being wound outwardly in the same sense as the first coil portion from a second midpoint thereon and having a last turn extending in proximity to the second side of said circuit board to terminate at the midplane, said first and second midpoints being interconnected;

a third rectangular spiral coil portion disposed on the reverse side of the second half of said circuit board terminating at a third midpoint thereon and beginning with a turn connected to the terminus of the second coil portion at the midplane and extending in proximity to the second side of said circuit board; and

a fourth rectangular spiral coil portion disposed on the front side of the second half of said circuit board being wound outwardly from a fourth midpoint thereon and having a last turn extending in proximity to the midplane across said circuit board to terminate in a second terminal thereon, said third and fourth midpoints being interconnected, wherefor the circuit board.

2. The printed circuit coil for steering charged particle beams as defined in claim 1 wherein said flexible printed circuit board is rolled into a cylinder with the second and third center points diametrically opposed to define a passageway for passage of said charged particle beam therethrough.

3. The printed circuit coil for steering charged particle beam defined in claim 1 further defined in that said first and second center points, and said third and fourth center points are spatially opposite each other on said printed circuit board in order that said electrical interconnection are made by inserting an electrical connector through a hole drilled through said center points location on said printed circuit board.

4. The printed circuit coil for steering charged particle beam defined in claim 3 further defined in that said flexible printed circuit board rolled into a cylinder is further surrounded by a steel pipe of high permeability to further enhance said charged particle steering, said circuit board and steel pipe separated by insulation.

5. The printed circuit coil for steering charged particle beam defined in claim 4 further defined in that at least one printed circuit board is placed within said steel pipe for horizontal charged particle steering and at least one printed circuit board is place within said steel pipe for vertical charged particle steering, said horizontal steering printed circuit board rotated 90° from said vertical steering printed circuit board in spatial arrangement, and separated by electrical insulation.

6. The printed circuit coil for steering charged particle beam defined in claim 5 further defined in that a multiplicity of printed circuit boards are placed within said steel pipe for horizontal charged particle steering and a multiplicity of printed circuit boards are placed within said steel pipe for vertical charged particle steering.

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