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Hashmi et al.

[11] **3,748,612**

[45] **July 24, 1973**

[54] **CHARGED PARTICLE BEAM DEFLECTION CONTROL YOKE**

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[73] Assignee: **Ford Motor Company**, Dearborn, Mich.

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[52] **U.S. Cl.** **335/210**, 313/74

[51] **Int. Cl.** **H01f 7/00**

[58] **Field of Search** .... 313/74 X; 315/22, 315/25; 335/210, 213

[56] **References Cited**

UNITED STATES PATENTS

2,239,865 4/1941 Urtel 335/213

Primary Examiner—George Harris

Attorney—Keith L. Zerschling et al.

[57] **ABSTRACT**

A control yoke for deflecting a beam of electrically charged particles is described. The yoke includes a pair of parallel and spaced bars on each of which a plurality of electrical coils are positioned. The bars are made from a magnetic material. Current in the coils produces a magnetic field between the bars which varies in flux density, thereby, to vary the amount of deflection of the beam.

5 Claims, 9 Drawing Figures

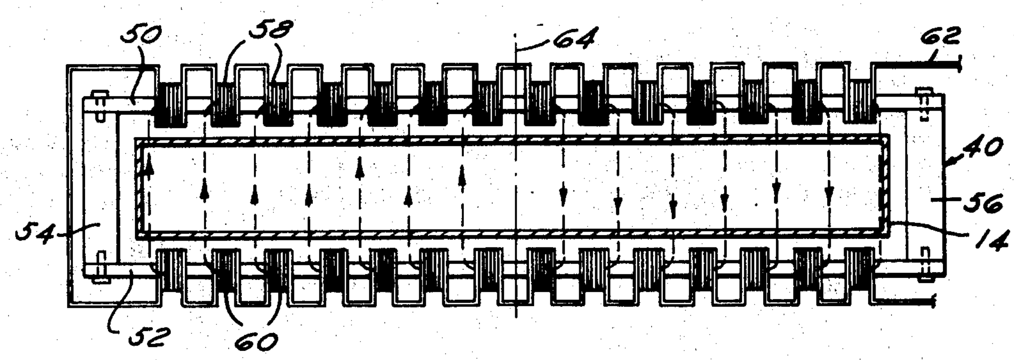


FIG. 1

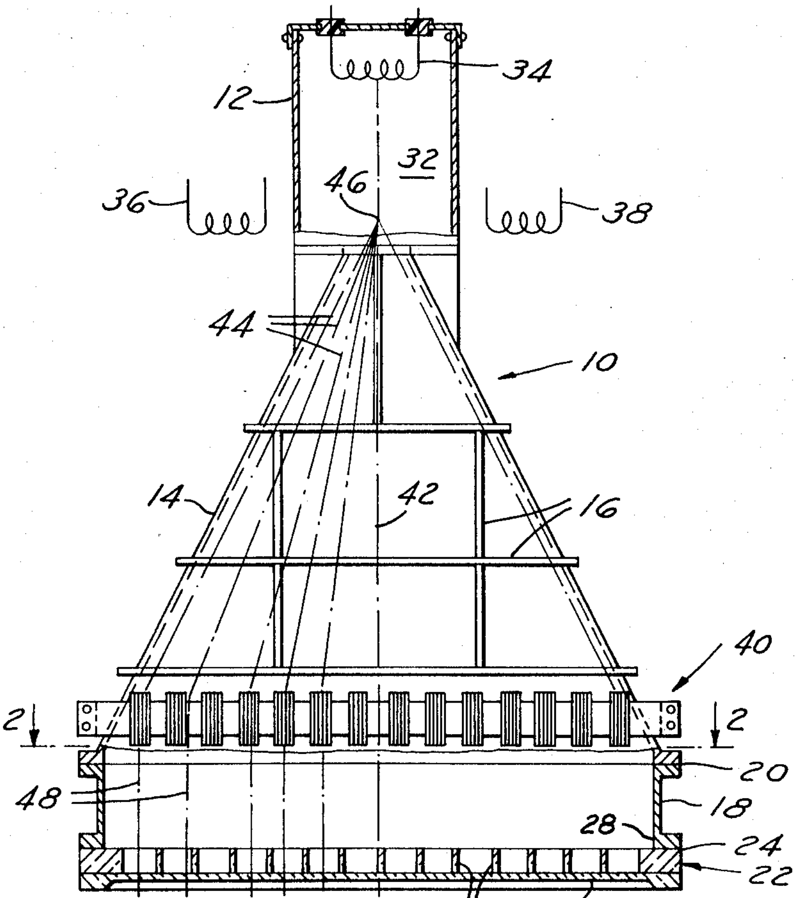


FIG. 2

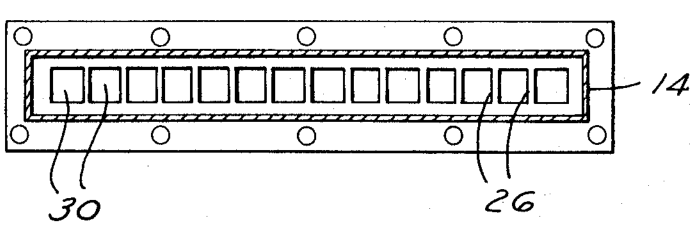


FIG. 3

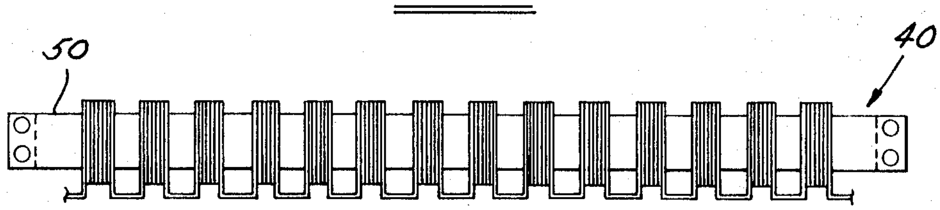


FIG. 4

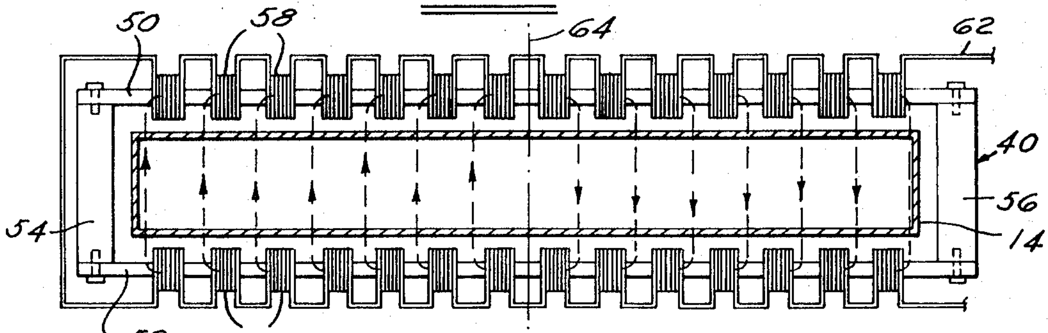


FIG. 5

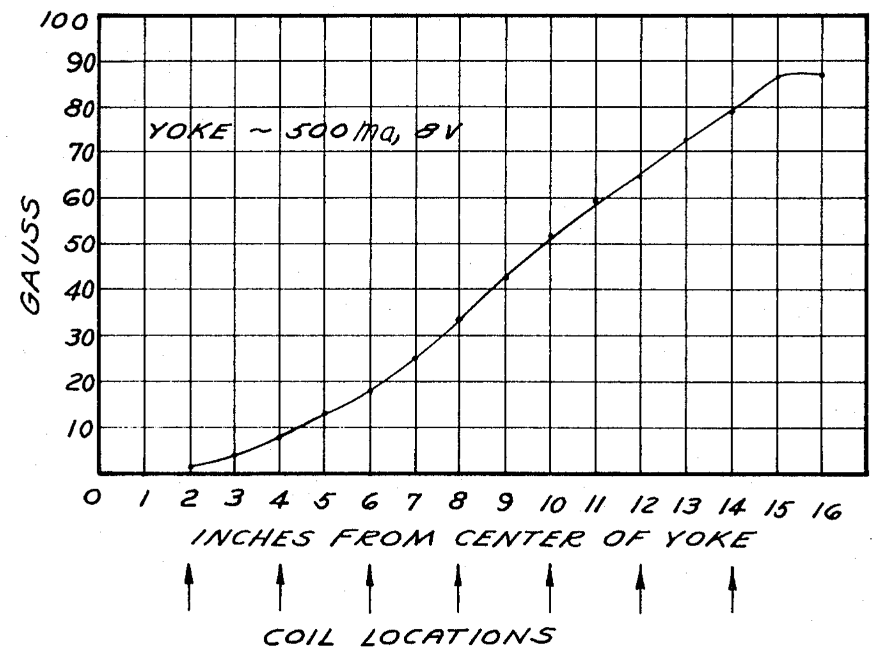


FIG. 6

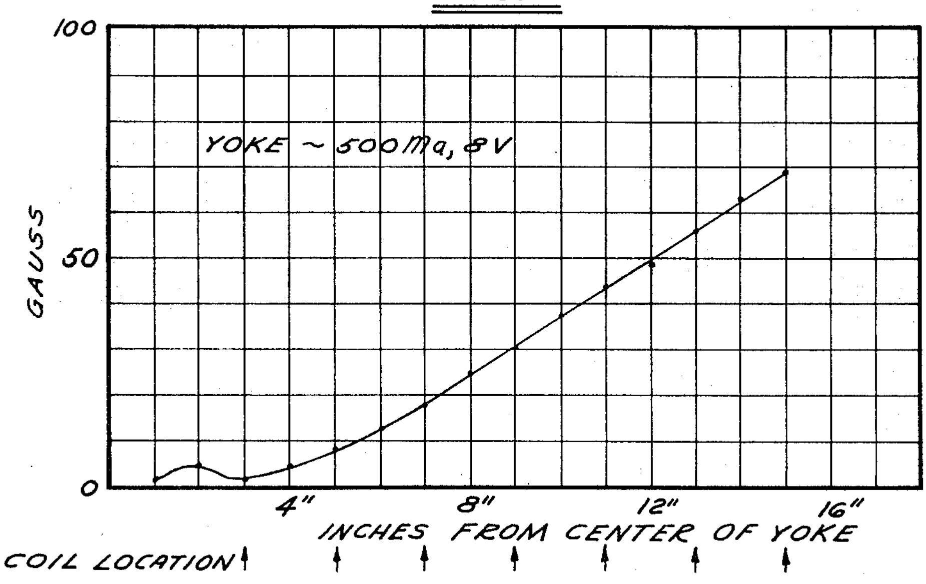


FIG. 7

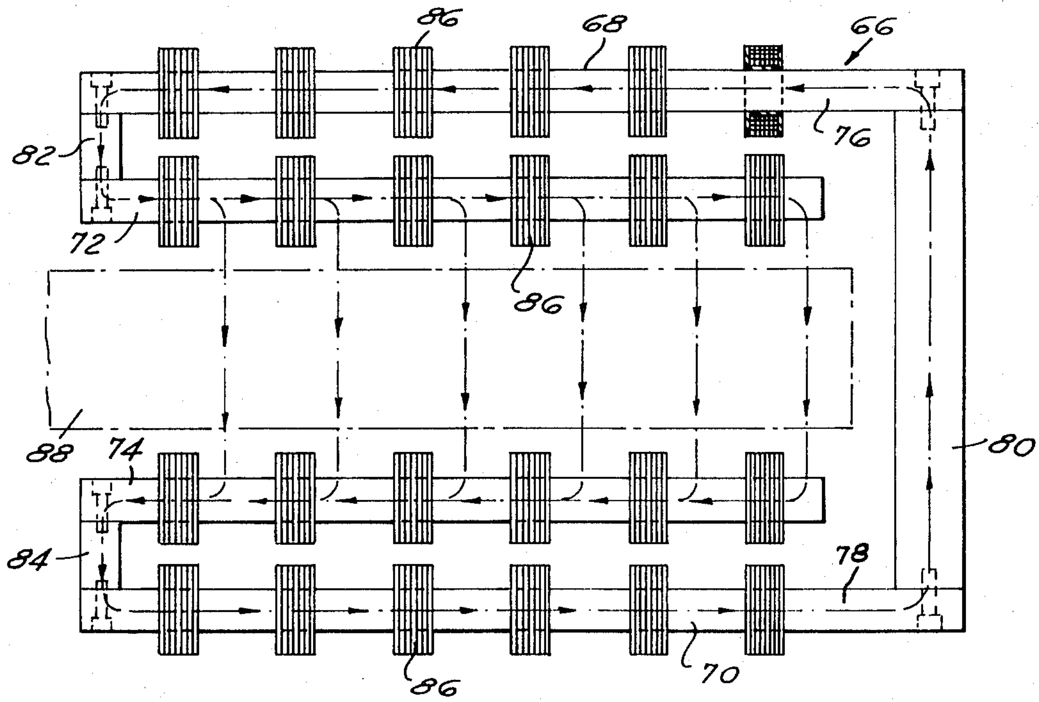


FIG. 9

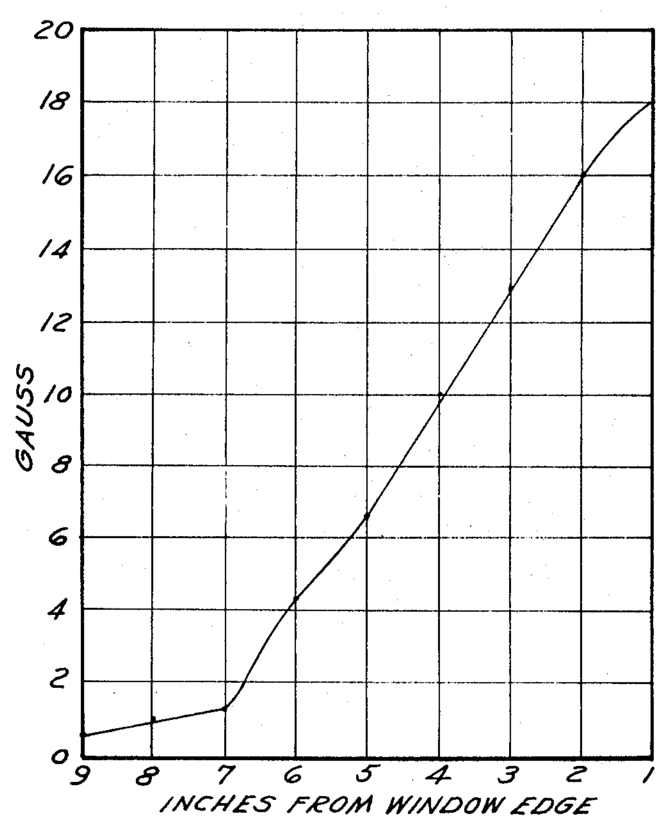
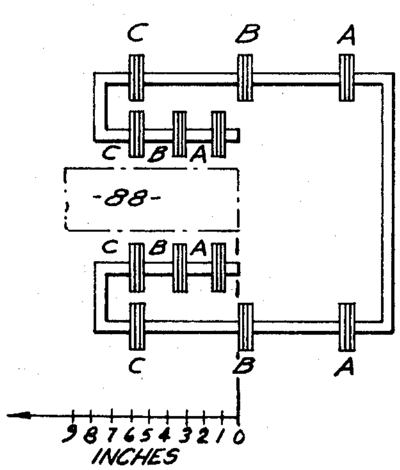


FIG. 8



CHARGED PARTICLE BEAM DEFLECTION CONTROL YOKE

BACKGROUND OF THE INVENTION

This invention related to a control yoke for deflecting a beam of electrically charged particles, such as an electron beam.

Electron accelerators conventionally are used to irradiate a target by means of an electron beam that is developed within an evacuated housing chamber and that exits the housing chamber through an opening in a wall thereof. Chamber vacuum is maintained by a seal, usually in the form of an electron permeable window formed from a thin sheet of metal, such as aluminum, positioned in this opening. The electron beam is emitted by a cathode positioned at one end of the chamber and is accelerated by and directed to an anode by a large potential difference existing between the cathode and anode. The electron permeable window may comprise a part or all of the anode structure.

In order to protect the integrity of the window from electron beam energy, the beam usually is scanned along the window so that it impinges along the window in an infinite number of angularly diverging paths. Also, it is advantageous to prevent displacement of the window by forces caused by atmospheric pressure by providing the window with a grid structure for its support.

Individual elements of the grid must be oriented at angles to one another corresponding to the angular relationship between the electron beam paths in order to allow the beam to pass through the grid and minimize the dissipation of energy caused by the beam impinging on grid elements. Such grids inherently are costly and difficult to manufacture because of the precise angular dispositions required of the grid elements.

Although the control yoke of the invention is generally useful for deflecting a beam of electrically charged particles, it is particularly useful when employed with an electron accelerator of the kind described above. In this connection, the control yoke is used to control the paths of a scanned accelerator electron beam such that the beam passes through the grid and window in parallel paths as it is scanned. Such electron beam control allows use of a grid having relatively easily formed, parallel grid elements, and it prevents excessive and objectionable energy dissipation due to beam impingement on the grid structure. Beam control yokes intended for a somewhat similar purpose and having a somewhat similar construction may be seen in U.S. Pat. Nos. 3,299,314, issued Jan. 17, 1967, to Tatsuya Yamada, et al., and 3,469,139, issued Sept. 23, 1969, to A. D. Colvin.

SUMMARY OF THE INVENTION

In accordance with the invention, a control yoke for deflecting a beam of electrically charged particles comprises a pair of spaced and parallel bars. The bars are made from a magnetic material. Each of the bars has a plurality of helically wound coils positioned on them which are spaced from one another along the length of the bars. Preferably, the coils are electrically connected in series with one another. When a current is present in the coils, a magnetic field is produced between the bars which varies in flux density from one end of the bars to the other end of the bars. In the region between one end of the bars and approximately the midpoint thereof, the magnetic field has a first direction and a magnitude which gradually diminishes. At or about the center of the bars, the magnetic field becomes zero and then gradually increases in magnitude, but with a direction opposite to that on the other side of the center of the bars.

In an alternative embodiment, which is particularly useful when it is desired to deflect a scanned beam in only a portion of its over-all scan range, four bars made from magnetic material, each of the bars having a plurality of helically wound coils thereon, are employed. The four bars are parallel to and spaced from one another. Low reluctance paths are provided between the various bars in a manner and for a purpose described hereinafter.

The invention will be better understood by reference to the detailed description which follows and to the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of an electron accelerator that includes a control yoke constructed in accordance with the invention;

FIG. 2 is a sectional view taken along the line 2—2 in FIG. 1 and illustrates the construction of the grid and window of the electron accelerator;

FIG. 3 is a plan view of a control yoke for deflecting a beam of electrically charged particles, and is similar to the control yoke shown in FIG. 1;

FIG. 4 is an elevational view of the control yoke of FIG. 3;

FIG. 5 is a graph of the magnetic flux density produced by a control yoke of the design illustrated in FIGS. 3 and 4 for a particular positioning of the coils in the yoke;

FIG. 6 is a graph similar to that of FIG. 5, but differing therefrom in the positioning of the coils;

FIG. 7 is an elevational view of another embodiment for a control yoke constructed in accordance with the invention;

FIG. 8 is a sketch of an experimental control yoke similar to that of FIG. 7; and

FIG. 9 is a graph of the magnetic flux density produced by the experimental control yoke of FIG. 8.

DETAILED DESCRIPTION OF THE INVENTION

With reference now to the drawings, in which like numerals refer to like parts, and in particular to FIGS. 1 and 2, the numeral **10** denotes generally an evacuated chamber electron accelerator. The electron accelerator includes a tubular member **12** and a bucket **14**. The bucket **14** has generally diverging sides and has a rectangular cross-section. The bucket **14** is provided with reinforcing ribs **16**. A bucket extension **18** is connected at **20** to the bucket **14**, and a grid structure and electron permeable window, generally designated **22**, is connected at **24** to the bucket extension **18**.

The grid structure is formed by parallel ribs **26** which extend across the opening **28** in the bucket extension **18**. The parallel ribs **26** of the grid structure support an electron permeable window **30**, which typically is made from a thin sheet of metallic foil, for example, aluminum foil. The tubular member **12**, the bucket **14**, the bucket extension **18**, and the grid and window structure **22** together cooperate to form an evacuated chamber **32**. Preferably, the parts which comprise the chamber

32 are made from a non-magnetic material, such as non-magnetic stainless steel.

A cathode 34, shown greatly enlarged, is positioned at one end of the chamber 32 and is capable of emitting a beam of electrons. A pair of electromagnetic scanning coils 36 and 38 are positioned on opposite sides of the tubular member 12 along the length thereof. As is well known in the accelerator art, scanning of the electron beam emitted from the cathode 34 can be effected by varying the proportion of current passing through the coils 36 and 38. For a full discussion of the use of coils similar to coils 36 and 38 for the scanning of electron beams, attention is directed to U.S. Pat. No. 3,066,238, issued Nov. 27, 1962.

An electron beam control yoke, generally designated by the numeral 40, is positioned near the end of the bucket 14.

During operation of the accelerator 10, the chamber 32 is evacuated and a small diameter beam of electrons is emitted from the cathode 34. This beam is directed along the central axis 42 of the chamber 32 and is greatly accelerated within the chamber 32 due to a large potential difference between the cathode 34 and the structure at the opposite end of the chamber 32 including the grid and window structure 22. As the electron beam enters the magnetic field between and created by the scanning coils 36 and 38, it is scanned through an infinite number of angularly diverging paths represented in part by the lines 44. This angular divergence is represented as occurring at the point 46. As the electron beam is directed along one of the diverging paths 44, it enters the magnetic field produced by the control yoke 40. When the electron beam passes through the control yoke 40, the beam is bent once again so that it takes parallel paths 48 as it is scanned from one side of the accelerator to the other. It should be noted that the amount of bending required decreases as the beam traverses from one side of the accelerator to the central axis 42 thereof and then the angle once again increases, but is in the opposite direction. Thus, the control yoke 40 must produce a mangetic field which varies both in flux density and in direction from one side thereof to the other.

Reference is now made to the plan view of FIG. 3 and to the elevational view of FIG. 4, which shows the position of the opening of the bucket 14 relative to the control yoke 40. The control yoke 40 comprises a first bar 50 and a second bar 52. The bars 50 and 52 are spaced from and parallel to one another, are made from a magnetic material, and preferably have a rectangular cross-section for the purpose of increasing the length of the magnetic field through which the electron beam must pass. Spacers 54 and 56, made from a non-magnetic material, are provided to maintain the separation between the bars 50 and 52.

A plurality of helically-wound coils 58 are positioned in spaced locations on and along the length of the bar 50. Similarly, a plurality of helically-wound coils 60 are positioned on and along the length of the bar 52. Preferably, the coils 58 and 60 are rectangular in shape. In FIG. 4, the coils 58 and 60 are illustrated as being formed from a single strand of conductive wire 62. This is done to illustrate that the coils may be connected in series with one another. The number of turns in the coils and the number of coils may be varied to satisfy design requirements. Also, it is possible to connect the coils on the bar 50 in series with one another, to connect those on bar 52 in series with one another, and then to connect these series combinations in parallel with a source of electrical energy. Of course, the coils could be grouped or separately excited by the source of electrical energy. Moreover, the coils may be uniformly spaced from one another along the respective bars, or, the spacing may be varied as required to produce a desired flux pattern.

In FIG. 4, the magnetic flux produced by the coils 58 and 60 is indicated by broken lines having arrows thereon to indicate magnetic field direction. To the left of the central axis 64, the flux lines are in one direction and to the right thereof the flux lines are in the opposite direction across the bucket 14. The flux density increases in either direction from the central axis 64. The object of the control yoke 40, when used in connection with the electron accelerator illustrated in FIG. 1, is to provide a field which varies linearly from a maximum in one direction to zero along the central axis 64 and then linearly to an oppositely directed maximum at the other end of the control yoke.

With reference now to FIG. 5, there is shown a graph of the flux density of a control yoke such as that shown in FIG. 4, the flux density being plotted against the number of inches from the central axis 64 of the yoke 40. The graph is limited to a plot of one-half of the total field distribution, and the locations of the seven coils on each of the bars 50 and 52 are indicated by the arrows at the lower portion of FIG. 5. The control yoke used to obtain the data plotted in FIG. 5 included a total of 28 identical helically wound coils connected in series with one another. 14 of the coils were positioned on the bar 50, and the other 14 were positioned on the bar 52 in line with those on the bar 50. The bars 50 and 52 were made from iron and the coils carried a current of 500 milliamperes and were operated at 8 volts. From FIG. 5, it may be seen that the field distribution measured in terms of flux density was quite linear and increases from zero at the central axis 64 to a maximum located 16 in. from the central axis 64.

With reference now to FIG. 6, there is shown a graph of the magnetic flux density versus inches from the central axis 64 of the above-described control yoke. The coil locations used to obtain the data plotted in FIG. 6 were different than those used in obtaining the data plotted in FIG. 5. Specifically, the coil locations in FIG. 6 are indicated at the bottom thereof and it may be seen that the first coil was located 3 inches from the central axis 64 of the control yoke 40. This was found to produce a slight non-linearity at the central region of the control yoke, as is indicated by the graph of FIG. 6.

The graphs of FIGS. 5 and 6 illustrate the fact that changes in position for the plurality of coils on the bars 50 and 52 of the control yoke 40 produce changes in the magnetic field distribution between the bars 50 and 52.

With particular reference now to FIG. 7, there is shown a control yoke, generally designated by the numeral 66, which may be used to bend a scanned beam of electrons in only one angular direction. The field produced by the control yoke 66 may be varied in flux density, but it may also be maintained unidirectional in the region of the scanned electron beam. A control yoke of this type is desirable in applications wherein the scanned electron beams must be bent in one direction for a part of its scanned traverse and thereafter be left unaffected by the magnetic field or otherwise deflected. A control yoke of this type may, for example, be used where it is desired to irradiate a target having a curved or otherwise complex configuration.

In FIG. 7, the control yoke **66** comprises a first bar **68** and a second bar **70** spaced from and parallel to the first bar **68.** A third bar **72** is positioned between the first and second bars and is parallel to and spaced from these bars. A fourth bar **74** is positioned between the third bar **72** and the second bar **70.** The fourth bar **74** is also parallel to and spaced from the other bars.

The end portions **76** and **78,** respectively, of the first and second bars are provided with a low reluctance path therebetween by means of a connecting member **80** made from a magnetic material. The other end portion of the first bar **66** is provided with a low reluctance path to the third bar **72** by means of a conncting member **82** made from a magnetic material. Similarly, the other end portion of the second bar **70** is provided with a low reluctance path to the fourth bar **74** by means of a connecting member **84** also made from a mangetic material.

Each of the bars **68, 70, 72,** and **74** is made from a magnetic material, preferably has a rectangular cross-section, and has a plurality of helically wound coils **86** positioned in spaced locations along the length thereof. The primary magnetic field paths are indicated by the broken lines containing arrows to indicate direction. The location of an electron permeable window is indicated by the broken lines **88.** The coils **86** of FIG. 7 may be electrically connected in series or otherwise excited by a source of electrical energy.

In FIG. **8,** there is shown a schematic illustration of an experimental control yoke similar to the yoke **66** of FIG. 7. The FIG. **8** control yoke identified A, B, and C, are positioned on each of the arms of the yoke. The A coils had more turns of wire than the B coils, and the B coils had more turns of wire then the C coils. Thus, the number of turns in the coils progressively decreased along the length of the bars.

FIG. **9** is a graph of the field distribution obtained with an experimental control yoke of the type and design illustrated in FIG. **8.** It may be seen from FIG. **9** that the field distribution is quite linear in the region of the window **88** in which the control yoke is located.

It will be evident to one skilled in the art that various modifications may be made in the control yokes described above, such as changes in the number of coils, the positioning thereof, the number of turns therein, and the size and spacing of the bars, without departing from the spirit and scope of the invention.

Based upon the foregoing description of the invention, what is claimed and desired to be protected by Letters Patent is:

1. A control yoke for deflecting a beam of electrically charged particles, said control yoke comprising: first and second bars, said bars being made from magnetic material and being spaced from and parallel to one another; means for providing a low reluctance path between one of the end portions of said second bar; a third bar positioned between said first and second bars, said third bar being made from magnetic material and being spaced from and parallel to said first and second bars; means for providing a low reluctance path between the other end portion of said first bar and one of the end portions of said third bar; a fourth bar positioned between said second bar and said third bar, said fourth bar being made from a magnetic material and being spaced from and parallel to said first, second, and third bars; means for providing a low reluctance path between the other end portion of said second bar and one of the end portions of said fourth bar; a plurality of coils positioned adjacent one another along the length of said first bar; a plurality of coils positioned adjacent to one another along the length of said second bar; a plurality of coils positioned adjacent to one another along the length of said third bar; and a plurality of coils positioned adjacent to one another along the length of said fourth bar.

2. A control yoke in accordance with claim **1,** wherein said first, second, third, and fourth bars are of rectangular cross-section.

3. A control yoke in accordance with claim **1,** wherein all of said coils are connected in series with one another.

4. A control yoke in accordance with claim **1,** wherein the numbers of turns of wire in said coils on each of said bars progressively decrease along the lengths of said bars.

5. In an electron accelerator having means for producing a beam of electrons, means for accelerating said electron beam toward an anode, and scanning coil means for deflecting said electron beam through an infinite number of angularly diverging paths, a beam deflection control yoke positioned along the paths of said angularly diverging beam of electrons for causing said beam paths to be parallel to one another beyond said beam control yoke, said beam control yoke comprising: a first bar made from a magnetic material and having a rectangular cross-section; a second bar made from a magnetic material and having a rectangular cross-section, said second bar being spaced from and parallel to said first bar; a first plurality of helically-wound coils positioned on said first bar, each of said first plurality of coils being rectangular in shape; a second plurality of helically-wound coils positioned on said second bar, each of said second plurality of coils being rectangular in shape, the number of said second plurality of coils being equal to the number of said first plurality of coils, said coils on said first and second bars being spaced from one another along the lengths of said bars, said bars being positioned such that said angularly diverging beam of electrons passes between them; whereby, currents in said coils produce a magnetic field between said bars, said magnetic field having a maximum magnitude and a first direction at one end of said first and second bars, an oppositely directed maximum field at the other end of said bars and a zero field point intermediate the ends of said first and second bars.

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