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ELECTROMAGNETIC DEFLECTION YOKE

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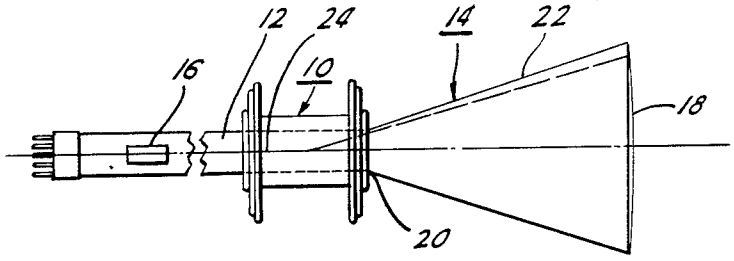
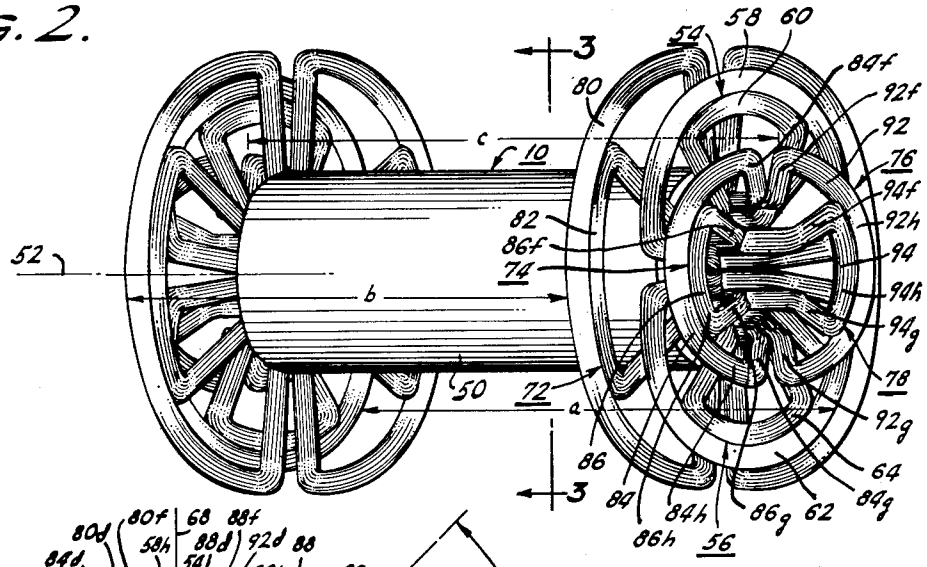


FIG. 1.

FIG. 2.



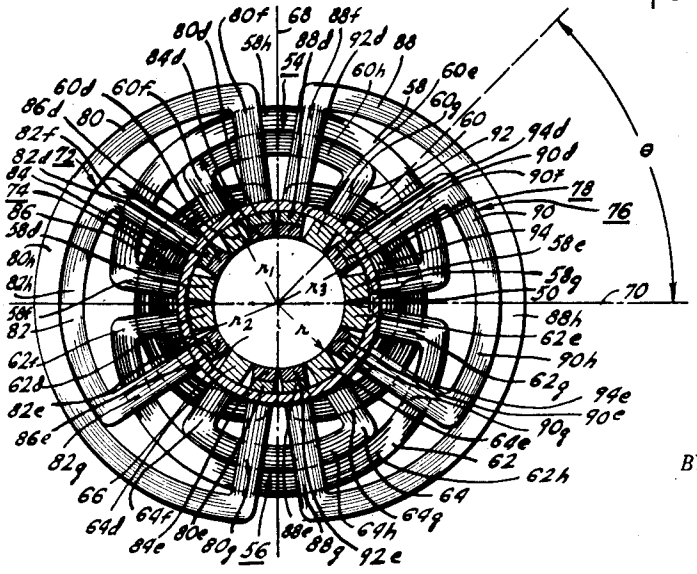


FIG. 3.

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ELECTROMAGNETIC DEFLECTION YOKE

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9 Claims. (Cl. 175—21)

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This invention relates to electrical apparatus, and more particularly, to improved yokes for electromagnetically deflecting a beam of electrically charged particles. Such yokes are particularly adapted for use in television image transducers, in which they serve to deflect the electron beam of the picture tube as determined by applied horizontal and vertical scanning signals, and it is with respect to this use that the invention will be specifically described.

An important objective in the design of television transducers is to produce an electron beam having uniform focus throughout the scanning area of the cathode-ray tube. The need for maintaining a uniformly focussed beam throughout the image area is particularly apparent in the case of picture tubes for producing color television images, since beams exhibiting variations in focus throughout the scanning area produce erroneous changes in the saturation values of the colors reproduced by such tubes. The successful attainment of this objective has, however, become increasingly difficult in recent years because of the trend toward the use of cathode-ray tubes having increasingly large viewing screens which requires that the beam be deflected through correspondingly increased angles in order to scan the entire image area.

In order to produce a beam which is uniformly focussed for all values of the deflection angle, it is necessary that the beam be free from astigmatism at all values of this angle. An astigmatic electron beam may be defined as a beam having an elliptical cross-section and exhibiting first and second lines of focus. These two lines of focus are normal to the axis of the beam, are spaced apart along the said axis and lie in mutually perpendicular planes. As a general rule, at a point between the first and second lines of focus, the cross-section of the beam becomes a circle, known as the circle of least confusion. An astigmatic beam is generally considered to be "focussed" when the circle of least confusion is coincident with the screen surface. It has been found that this circle of least confusion does not remain coincident with the surface of the screen throughout the scanning area, so that the beam spot changes in size as a function of the deflection angle. In the case of tubes having large screens with corrrespondingly large deflection angles, the spot size increases to such an extent that fine image detail cannot be reproduced.

The astigmatism above mentioned is largely due to the electromagnetic systems heretofore used for deflecting the beam. More particularly,

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it has been found that the prior-art deflection yokes produce a magnetic deflection field which changes in configuration along the axis of the yoke as the ratio of the horizontal and vertical scanning signals applied to the yoke is varied. The configuration of a deflecting field may be defined with reference to a plurality of sectioning planes taken normal to the longitudinal axis of the deflection yoke at regular intervals between the ends thereof and defining a plurality of field areas, and a reference plane containing the said longitudinal axis and normal to each of the sectioning planes. It is found, in the case of prior-art yokes, that the magnetic vectors contained in successive field areas exhibit different lengths and directions with respect to each other for different ratios of the vertical and horizontal deflection currents applied to the yoke. More particularly, during the scanning of the screen, at which time the ratio of the horizontal and vertical scanning currents changes, the vectors defining the field produced by prior-art yokes do not maintain the same relative magnitudes throughout the length of the field and do not maintain constant relative values as a function of their radial position from the axis of the yoke. These effects are particularly pronounced at the ends of the yoke where the problem of maintaining uniform direction and magnitude of the field along the axis of the field and along the radius of the field is made more severe because of the fringing magnetic fields existing at these regions. These deviations of the resultant magnetic field from geometric-similitude with rotation and with radial and axial displacement, for changes in the afore-mentioned current ratio, are primary factors imparting an astigmatic character to the beam.

It is accordingly an object of the invention to provide improved means for electromagnetically deflecting a beam of electrically charged particles.

Another object of the invention is to provide improved electromagnetic yokes adapted to deflect an electron beam without imparting astigmatism to the beam.

A further object of the invention is to provide improved anastigmatic electromagnetic deflection yokes which are relatively simple and inexpensive.

Yet another object of the invention is to provide improved deflection yokes adapted to deflect electron beams over wide angles without imparting astigmatism to the beam, and which are particularly adapted for use in color television systems.

A specific object of the invention is to provide improved electromagnetic yokes in which the space-configuration of the magnetic lines of force produced thereby is substantially independent of the ratio of the values of the currents applied to the vertical coil system and the horizontal coil system thereof.

My invention is based on the discovery that, in order to achieve a yoke having horizontal and vertical deflection coil systems adapted to deflect a beam in two dimensions over a screen surface without imparting astigmatic properties to the beam, it is necessary that the mutually perpendicular coil systems have substantially identical mean dimensions, not only along the axis of the yoke, but also radially from the latter axis. More particularly, I have found that a yoke structure achieving the above-noted objects may be produced by constructing the same so that the windings of the mutually perpendicular coil systems overlay one another in a manner such that the mean length of the axially extending conductor portions of the first coil system is equal to the mean length of the axially extending conductor portions of the second coil system, the bent-up end windings of both coil systems are symmetrically disposed at each end of the yoke, about a given plane normal to a plane containing the longitudinal axis, and the arc described by the end-turns of the mutually perpendicular coil systems conforms to a specified mean dimension. Furthermore, in order to achieve the desired anastigmatic characteristics, the axially extending conductors and the radially extending conductors of each coil system should exhibit a cosinusoidal distribution, and the arcuate conductors of each coil system should exhibit a sinusoidal distribution, of the ampere-turns.

Because of this novel construction, wherein extreme symmetry in the dimensions of the two coil systems is achieved, it has been found that the two magnetic fields produced are mutually perpendicular throughout the whole field volume, and the magnetic field maintains the same space configuration irrespective of the ratio of the exciting currents.

The invention will be described in greater detail with reference to the appended drawings forming part of the specification, and in which:

Figure 1 is a side view of a cathode-ray tube utilizing a yoke in accordance with the invention;

Figure 2 is a perspective view of one form of yoke designed in accordance with the invention; and

Figure 3 is a section along the line 3—3 of Figure 2, taken normal to the longitudinal axis of the yoke.

The assembly shown in Figure 1 comprises a yoke **10** constructed in accordance with the invention and positioned on the neck portion **12** of a cathode-ray tube **14** to produce horizontal and vertical deflection of the electron beam of the tube. The cathode-ray tube **14** itself may conform to well known design and may comprise an electron beam-generating-and-accelerating gun assembly **16** and a viewing screen **18**, the latter element consisting of a layer of a luminescent, tenebrescent or color-producing phosphor material. The yoke **10** fits coaxially about the neck portion **12** of the tube and is preferably positioned so that one end thereof coincides with the plane of the junction **20** of the neck and bulb portions **12** and **22** respectively.

By applying appropriate potentials to the electron gun assembly **16** of the cathode-ray tube and to auxiliary focussing means (not shown), a collimated electron beam **24** is produced having a direction substantially coincident with the longitudinal axis of the tube **14** and the deflection yoke **10**. The electron beam **24**, in passing through the magnetic field established within the yoke and at the entrance and exit portions of the yoke, is subjected to the desired deflection which, in accordance with the invention, takes place without concurrently imparting astigmatism to the beam. That is, in the process of deflection, cross-sections of the beam taken along its length are preserved substantially circular, and no distortion of the beam cross-section into the elliptical areas characteristic of astigmatism occurs. Because of this anastigmatic deflection, the minimum cross-section of the beam is not limited to that of a circle-of-least-confusion of an astigmatic beam, but may be focussed to a very fine spot at all points of the raster, thus producing a uniformly sharp, high definition image on the cathode-ray tube screen.

In accordance with the invention, the deflection of the beam is produced, without imparting an astigmatic character thereto, by means of a yoke assembly **10** which produces a magnetic field exhibiting a fixed configuration during its rotation about the longitudinal axis of the yoke under the influence of the horizontal and vertical scanning currents applied to the yoke. A specific form of the yoke **10**, according to the invention and adapted to produce such a field, is shown in greater detail in Figures 2 and 3. The yoke **10** comprises first and second coil systems arranged in mutually perpendicular planes to produce mutually perpendicular deflection of the electron beam, and may further comprise a low reluctance return path for the magnetic flux, such a path being provided by an enclosing cylinder **50** of ferromagnetic material, e. g. of molded powdered iron.

The first of these coil systems, which may be utilized to deflect the beam in a horizontal direction, comprises first and second coil-pairs **54** and **56**. The coil-pair **54** consists of an outer coil **58** and an inner coil **60**, whereas the second coil-pair **56** similarly consists of an outer coil **62** and an inner coil **64**.

Each of the aforesaid coils consists of a multiplicity of parallel, axially arranged, insulated conductor portions which extend into loop-ends preferably bent at substantially right angles to the axially arranged conductor portions and forming the so-called end-turns of the coils. In the present case, each coil is further shaped so that the axially extending conductor portions conform to a cylindrical surface of radius r, and, because of this configuration, the end-turns comprise first conductor portions in which the conductors extend substantially along a radius of the said cylindrical surface and second conductor portions in which the conductors are more or less arcuate.

Thus, the outer coil **58** of coil-pair **54** comprises parallel, axially extending conductor portions **58***d*, **58***e*, radially extending conductor portions **58***f*, **58***g*, and arcuate conductor portions **58***h*, while the inner coil **60** comprises axially extending conductor portions **60***d*, **60***e*, radially extending conductor portions **60***f*, **60***g*, and arcuate conductor portions **60***h*. Similarly, the outer coil **62** of coil-pair **56** comprises axially extending conductor portions **62***d*, **62***e*, radially extending conductor portions **62***f*, **62***g*, and arcuate conductor portions **62***h*, while the inner coil **64** comprises axially

extending conductor portions 64*d*, 64*e*, radially extending conductor portions 64*f*, 64*g*, and arcuate conductor portions 64*h*.

It is noted that the axially arranged conductor portions are symmetrically oriented with respect to a vertical axis 68 and are arranged about the cylindrical surface of radius *r*. Furthermore, the end-turns of the inner coils, 60 and 64 are so dimensioned that the arcuate conductor portions 60*h* and 64*h* fit within the arcuate conductor portions 58*h* and 62*h* of the outer coils 58 and 62 respectively, and are coplanar therewith.

The ratio of the number of axially extending conductor portions N_1 in the outer coils 58 and 62 to the number of axially extending conductor portions N_2 of the inner coils 60 and 64 of the coil-pairs 54 and 56 is adjusted so as to produce an ampere-turn distribution varying approximately as the cosine of the angle θ, where θ is measured with respect to an axis 70 normal to axis 68. The manner of calculating this ratio of turns to produce the desired ampere-turn distribution is well-known to those skilled in the art and, in a specific case, $N_1:N_2$ may be made substantially equal to 1.18 when the centers of the cross-sections of the axially extending conductor portions 58*e*, 60*e*, 60*d* and 58*d* of coil-pair 54 are located at values of the angle θ of substantially 11.25°, 56.25°, 123.75° and 168.75°, respectively, and the centers of the cross-sections of the axially extending conductor portions 62*d*, 64*d*, 64*e* and 62*e* of coil-pair 56 are located at corresponding diametrically opposite angle values. Because of the manner in which the coils of coil-pairs 54 and 56 are shaped, and because of the space distribution of the axially extending conductor portions, the radially extending conductor portions are also characterized by an approximately cosinusoidal ampere-turn distribution, whereas the distribution of the arcuate conductor portions approximates a sinusoidal ampere-turn distribution.

The second of the coil systems, which in the specific embodiment herein described is utilized to deflect the beam in a vertical direction, comprises two coil assemblies, the first of which is constituted by two coil-pairs 72 and 74, and the second of which is constituted by two coil-pairs 76 and 78.

The coil-pair 72 comprises an outer coil 80 and an inner coil 82. The outer coil 80 comprises axially extending conductor portions 80*d*, 80*e*, radially extending conductor portions 80*f*, 80*g*, and arcuate conductor portions 80*h*, while the inner coil 82 comprises axially extending conductor portions 82*d*, 82*e*, radially extending conductor portions 82*f*, 82*g* and arcuate conductor portions 82*h*. The coil-pair 74 comprises an outer coil 84 and an inner coil 86. The outer coil 84 comprises axially extending conductor portions 84*d*, 84*e*, radially extending conductor portions 84*f*, 84*g*, and arcuate conductor portions 84*h*, while the inner coil 86 comprises axially extending conductor portions 86*d*, 86*e*, radially extending conductor portions 86*f*, 86*g* and arcuate conductor portions 86*h*.

The coil-pair 76 comprises an outer coil 88 and an inner coil 90. The outer coil 88 comprises axially extending conductor portions 88*d*, 88*e*, radially extending conductor portions 88*f*, 88*g*, and arcuate conductor portions 88*h*, while the inner coil 90 comprises axially extending conductor portions 90*d*, 90*e*, radially extending conductor portions 90*f*, 90*g*, and arcuate conductor portions 90*h*. The coil-pair 78 comprises an outer coil 92 and an inner coil 94. The outer coil 92 comprises

axially extending conductor portions 92*d*, 92*e*, radially extending conductor portions 92*f*, 92*g*, and arcuate conductor portions 92*h*, while the inner coil 94 comprises axially extending conductor portions 94*d*, 94*e*, radially extending conductor portions 94*f*, 94*g*, and arcuate conductor portions 94*h*.

It will be noted that the axially extending conductor portions of coils 80 and 82 overlie the corresponding axially extending conductor portions of coils 84 and 86, and that the axially extending conductor portions of coils 88 and 90 overlie the corresponding axially extending conductor portions of coils 92 and 94. As in the case of the horizontal deflection coil system above described, the axially extending conductor portions and the radially extending conductor portions of the vertical deflection coil system are characterized by an approximately cosinusoidal ampere-turn distribution, and similarly the arcuately arranged conductor portions are characterized by an approximately sinusoidal ampere-turn distribution. The ratio of the number of axially extending conductor portions N_1 in the outer coils 80 and 84 of coil-pairs 72 and 74 to the number of axially extending conductor portions N_2 of the inner coils 82 and 86, is adjusted so as to produce the above-noted ampere-turn distributions in the first coil assembly. In the specific case shown, this ratio may be set at 1.18 when the axially extending conductor portions 80*d*, 84*d*; 82*d*, 86*d*; 82*e*, 86*e*, and 80*e*, 84*e* are located at values of the angle θ of substantially 101.25°, 146.25°, 213.75° and 258.75° respectively.

The coil-pairs 76 and 78 of the second coil assembly are mirror images of the coil-pairs 72 and 74 respectively, and these coils accordingly conform to the geometry above described.

In accordance with the invention, all of the mean dimensions of the horizontal deflection coil system are made substantially identical to the mean dimensions of the vertical deflection coil system. More particularly, and as appears in Figure 3, the average distance, from the longitudinal axis 52 of the yoke, of the axially extending conductor portions 58*d*, 58*e*, 60*d*, 60*e*, 62*d*, 62*e*, and 64*d*, 64*e* of the horizontal deflection coil system, is made equal to the average distance from this axis of the axially extending conductor portions 80*d*, 84*d*; 82*d*, 86*d*; 82*e*, 86*e*; 80*e*, 84*e*; 88*e*, 92*e*; 90*e*, 94*e*; 90*d*, 94*d* and 88*d*, 92*d* of the vertical deflection coil system, notwithstanding the fact that the vertical deflection coil system comprises twice as many coil elements as the horizontal deflection coil system. This is achieved by means of the overlaying of the coils as above described. The mean lengths of the axially extending conductor portions of the vertical and horizontal coil deflection systems are also made substantially equal by reason of the novel construction shown in Figure 2 whereby the coil-pairs 72 and 76, and the coil-pairs 74 and 78 are arranged so that a plane preferably normal to the longitudinal axis 52 and containing the end-turns of the coil-pairs 54 and 56, lies equidistant between corresponding planes containing coil-pairs 72 and 76, and coil-pairs 74 and 78. Thus the mean dimension *a*, between the end-turns of the horizontal deflection system, is substantially equal to $(b+c)/2$, where *b* is the mean dimension between the end-turns of the coil-pairs 72, 76, and *c* is the mean dimension between the end-turns of the coil-pairs 74, 78.

Furthermore, the average length of the radially

extending conductor portions **58***f*, **58***g*, **60***f*, **60***g*, **62***f*, **62***g*, and **64***f*, **64***g* of the horizontal deflection coil system is equal to the average length of the radially extending conductor portions **80***f*, **80***g*, **82***f*, **82***g*, **84***f*, **84***g*, **86***f*, **86***g*, **88***f*, **88***g*, **90***f*, **90***g*, **92***f*, **92***g*, and **94***f*, **94***g*, of the vertical deflection coil system, so that the mean radius r_1 of the end-turns of the horizontal deflection coil system is equal to the average of the mean radii r_2 and r_3 of the end-turns of the vertical deflection coil system, i. e., $r_1=(r_2+r_3)/2$.

Because of the substantially complete identity of the corresponding mean dimensions of the windings of the horizontal and vertical coil systems, not only as to the axial length of the respective coils but also as to the radial dimensions of the end-turns thereof, a uniform magnetic field is produced by the windings which exhibits a substantially fixed configuration irrespective of the rotational position of the deflection field determined by the relative magnitudes of the currents supplied to the space-quadratured windings. Consequently, since there is no change in the configuration of the uniform magnetic field with rotation thereof, the initially anastigmatic beam entering the deflection field remains anastigmatic throughout all of the deflection angles of the beam.

While the invention has been described in connection with the specific form of the deflection yoke shown in Figures 2 and 3, it is apparent that alternative constructions may be used. More particularly, while the mean radius r_3 of the arcuate conductor portions of coil-pair **76** is shown in Figure 3 to be greater than r_1, which in turn is greater than r_2, it is well understood that all of these mean radii may be made equal, or of increasing value in the opposite sense, as long as the condition $r_1=(r_2+r_3)/2$ is fulfilled.

In addition, while the end-turns have been shown in the preferred embodiment of the invention to be positioned in planes perpendicular to the longitudinal axis **52** of the yoke, these end-turns may be positioned in planes forming an acute angle with the longitudinal axis.

Furthermore, while the assembly of coil-pairs **54** and **56** has been shown as constituting the horizontal deflection coil system of the yoke, and the assembly of coil-pairs **72**, **74**, **76** and **78** has been shown as constituting the vertical deflection coil system of the yoke, the respective assemblies may be interchanged in their functions.

Moreover, while each of the coil-pairs of the deflection yoke of the invention is set out above as a lumped-coil approximation for producing a cosinusoidal distribution of ampere-turns of the axially extending conductor portions and corresponding ampere-turns distributions of the radially extending and arcuate conductor portions, a distributed winding having a cosinusoidal distribution of ampere-turns and having the end-turns of one of the coil systems divided as above-described, is equally feasible.

Additionally, while, in the specific arrangement shown, one of the coil systems is divided into two sections in order to obtain the desired interleaving of the end-turns of the two coil systems, it is evident that this coil system may be divided into $(n+1)$ sections in order to achieve interleaving with a coil system divided into n sections.

Also, while the axially extending conductor portions of the respective coil systems have been shown as defining a right circular cylinder, it is apparent that this construction may be modified so that these conductor portions define a flared yoke of the sort disclosed in U. S. Patent 2,570,425 of Carlo V. Bocciarelli, granted October 9, 1951, to the assignee of the present invention, when such a geometry is desirable.

While I have described my invention by means of specific examples and in a specific embodiment, I do not wish to be limited thereto, for obvious modifications will occur to those skilled in the art without departing from the spirit and scope of the invention.

What I claim is:

1. An electron beam-deflecting yoke assembly comprising first and second coil systems for producing magnetic lines of force respectively in first and second mutually perpendicular directions, said lines of force defining a magnetic field extending along the longitudinal axis of the said yoke assembly, said axis being substantially perpendicular to the said first and second directions, the said coil systems defining a surface of revolution about the said longitudinal axis, said first coil system comprising first and second coil assemblies of similar geometry, each of the said coil assemblies comprising a first coil having a multiplicity of axially arranged conductor portions conforming to the said surface of revolution, said conductor portions extending into opposing loop-ends each bent away from the said longitudinal axis and arranged respectively in first and second planes perpendicular to a third plane containing the said longitudinal axis and a line parallel to the said first direction, each of the said loop-ends having two groups of radially extending conductor portions, and arcuate conductor portions interconnecting the said radially extending conductor portions, the said second coil system comprising third and fourth coil assemblies of similar geometry arranged in space-quadrature with respect to the said first and second coil assemblies, each of the said third and fourth coil assemblies comprising second and third coils, each having a multiplicity of axially arranged conductor portions conforming to the said surface of revolution, said axially arranged conductor portions extending into opposing loop-ends each bent away from the said longitudinal axis, the loop-ends of the said second coil extending beyond the loop-ends of the said first coil and being arranged respectively in fourth and fifth planes perpendicular to a sixth plane containing the said longitudinal axis and a line parallel to the said second direction, and the loop-ends of the said third coil extending within the loop-ends of the said first coil and being arranged respectively in seventh and eighth planes perpendicular to the said sixth plane, each of said loop-ends of each of the said coils having two groups of radially extending conductor portions, and arcuate conductor portions interconnecting the said radially extending conductor portions, the axially arranged conductor portions of the said second and third coils occupying radially aligned circumferentially spaced positions about the periphery of the said surface of revolution, the mean lengths of the said axially arranged and radially extending conductor portions and the mean radius of the said arcuate conductor portions of the said first coil assembly being substantially equal respectively to the mean lengths of the said axially arranged and radially extending conductor portions and the mean radius of the said arcuate conductor portions of the said second coil assembly.

2. An electron beam-deflecting yoke assembly

according to claim 1 in which the said axially arranged and radially extending conductor portions of the said first coil of the said first and second coil assemblies have ampere-turns distributions approximately proportional to the cosine of an angle measured with respect to the said second direction and the said arcuate conductor portions of the said first coil have an ampere-turns distribution approximately proportional to the sine of the said angle, and in which the said axially arranged and radially extending conductor portions of the said second and third coils of the said third and fourth coil assemblies have ampere-turns distributions approximately proportional to the sine of the said angle, and the said arcuate conductor portions of the said second and third coils have an ampere-turns distribution approximately proportional to the cosine of the said angle.

3. An electron beam-deflecting yoke assembly according to claim 1 in which the said surface of revolution about the said longitudinal axis is a circular cylinder.

4. An electron beam-deflecting yoke assembly according to claim 1 in which the said loop-ends of the said coils of the said first coil assembly are arranged in a first given number of planes and the said loop-ends of the said coils of the said third coil assembly are arranged in a second given number of planes interleaved with the said planes of the said loop-ends of the said first coil assembly, the said second given number being two greater than the said first given number.

5. An electron beam-deflecting yoke assembly according to claim 4 in which the said first and second coil assemblies each comprise one coil-pair and in which the said third and fourth coil assemblies each comprise two coil-pairs.

6. An electron beam-deflecting yoke asembly according to claim 1 in which the said first, second, fourth, fifth, seventh and eighth planes are each perpendicular to the said longitudinal axis.

7. An electron beam-deflecting yoke assembly according to claim 1 in which the mean radius of the said arcuate conductor portions of the said third coil is greater than the mean radius of the said arcuate conductor portions of the said first coil, and the latter said mean radius is greater than the mean radius of the said arcuate conductor portions of the said second coil.

8. An electron beam-deflecting yoke assembly comprising first and second coil systems for producing magnetic lines of force respectively in first and second mutually perpendicular directions, said lines of force defining a magnetic field extending along the longitudinal axis of the said yoke assembly, said axis being substantially perpendicular to the said first and second directions, the said coil systems defining a circular cylinder about the said longitudinal axis, said first coil system comprising first and second coil assemblies of similar geometry, each of the said coil assemblies comprising a first coil-pair having an outer coil and an inner coil, each of the said coils comprising a multiplicity of axially arranged conductor portions conforming to the surface of the said circular cylinder, said conductor portions extending into opposing loop-ends each bent away from the said longitudinal axis and arranged respectively in first and second planes substantially perpendicular to the said longitudinal axis, each of the said loop-ends of each of the said coils having two groups of radially extending conductor portions, and arcuate conductor portions interconnecting the radially extending conductor portions, the loop-ends of the said inner coil fitting within and being coplanar with the corresponding loop-ends of the said outer coil, said axially arranged and radially extending conductor portions of each of the said first coil-pairs having ampere-turns distributions approximately proportional to the cosine of an angle measured with respect to the said second direction and the said arcuate conductor portions having an ampere-turns distribution approximately proportional to the sine of the said angle, the said second coil system comprising third and fourth coil assemblies of similar geometry arranged in spaced-quadrature with respect to the said first and second coil assemblies, each of the said third and fourth coil assemblies comprising second and third coil-pairs, each comprising an outer coil and an inner coil, each of said coils having a multiplicity of axially arranged conductor portions conforming to the surface of the said circular cylinder, said axially arranged conductor portions extending into opposing loop-ends each bent away from the said longitudinal axis, the loop-ends of the said outer and inner coils of the said second coil-pair being arranged in third and fourth planes perpendicular to the said longitudinal axis and extending beyond the said loop-ends of the said first coil-pair, and the loop-ends of the said outer and inner coils of the said third coil-pair being arranged in fifth and sixth planes perpendicular to the said longitudinal axis and extending within the said loop-ends of the said first coil-pair, the said first plane lying equidistant between the said third and fifth planes, and the said second plane lying equidistant between the said fourth and sixth planes, each of the said loop-ends of each of the said coils of the said second and third coil-pairs having two groups of radially extending conductor portions, and arcuate conductor portions interconnecting the said radially extending conductor portions, the said axially arranged and radially extending conductor portions of the said second and third coil-pairs having ampere-turns distributions approximately proportional to the sine of the said angle and the said arcuate conductor portions having an ampere-turns distribution approximately proportional to the cosine of the said angle, the said axially arranged conductor portions of the said first coil-pair occupying circumferentially spaced positions about the said surface of the said circular cylinder, being symmetrically disposed with respect to a seventh plane defined by the said longitudinal axis and line parallel to the said first direction, the corresponding axially arranged conductor portions of the said second and third coil-pairs occupying radially aligned circumferentially spaced positions about the said circular cylinder, said latter positions being interspersed between the said circumferentially spaced positions occupied by the said axially arranged conductor portions of the said first coil-pair and being symmetrically disposed with respect to an eighth plane defined by the said longitudinal axis and a line parallel to the said second direction, the mean radius of the said arcuate conductor portions of the said first coil-pair being substantially equal to the average of the mean radii of the arcuate conductor portions of the said second and third coil-pairs respectively, the last-named mean radius being greater than the first-named mean radius, said latter mean radius being greater than the said second-named mean radius, and a circular cylindrical band of ferromagnetic material enclosing the said axially ar-

ranged conductors of the said first and second coil systems.

9. An electron beam-deflecting yoke assembly according to claim 8 in which the said axially arranged conductor portions of the two coil systems form sixteen groups spaced upon the said surface of the said circular cylinder at equal values of the said angle, and in which the ratio of the number of axially arranged conductor portions of the said outer coils of the said first coil-pair to the number of axially arranged conductor portions of the said inner coils of the said first coil-pair is substantially 1.18, and the ratio of the number of axially arranged conductor portions of the said outer coils of the said second

and third coil-pairs to the number of axially arranged conductor portions of the said inner coils of the last-named coil-pairs is substantially 1.18.

JAMES S. BRYAN.

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