

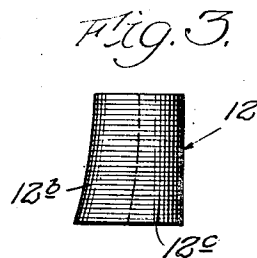
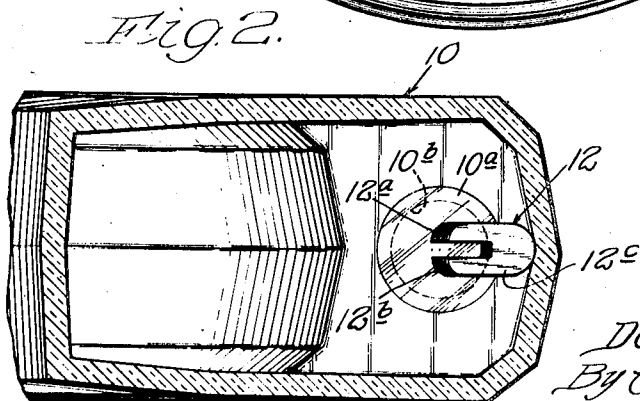
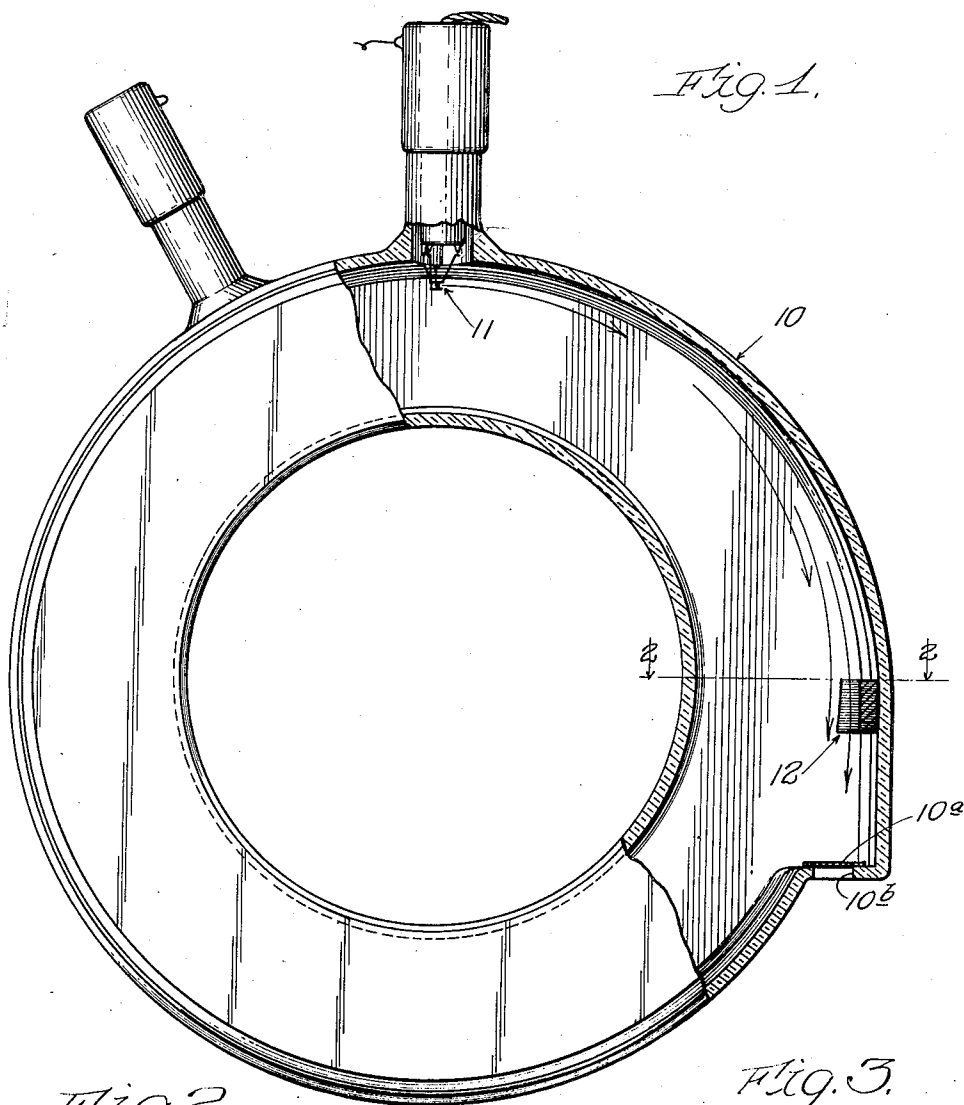
March 20, 1951

D. W. KERST
INDUCTION ACCELERATOR

2,545,958

Filed March 22, 1946

2 Sheets-Sheet 1



Inventor:
Donald W. Kerst,
By Clinton Schroeder,
Merrill K. Jorgensen, Attorneys.

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2 Sheets-Sheet 2

Fig. 4.

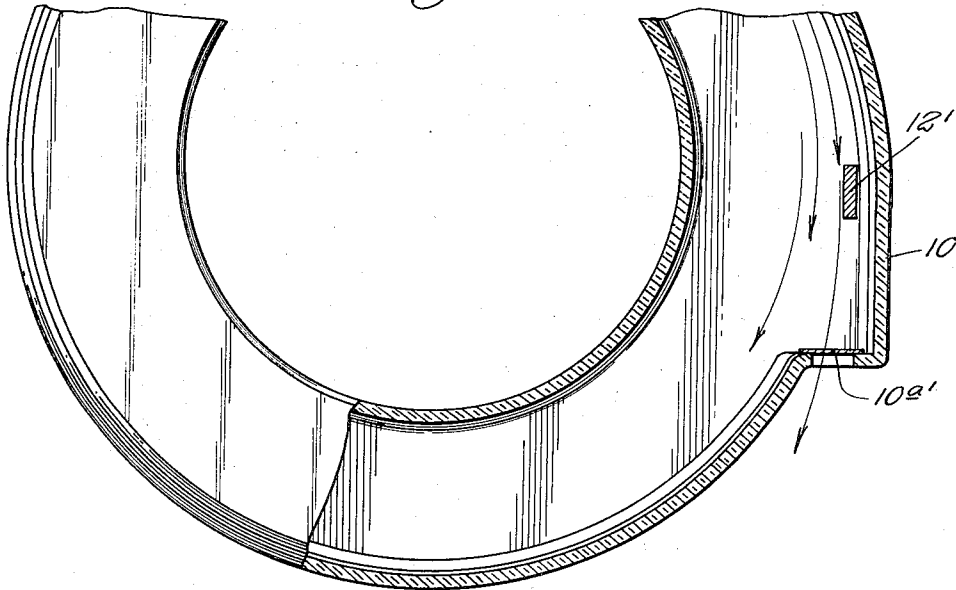


Fig. 5.

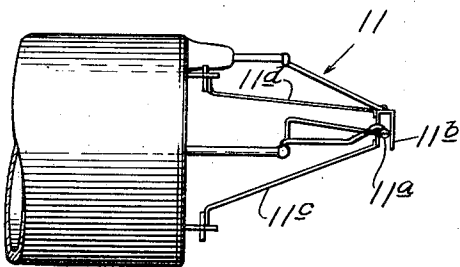


Fig. 6.

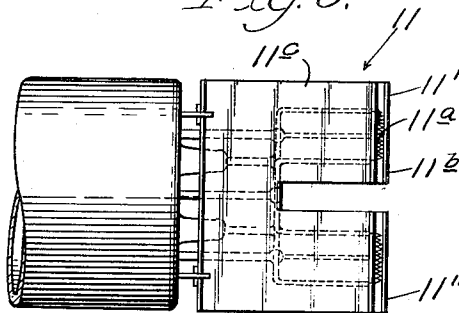


Fig. 7.

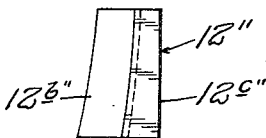
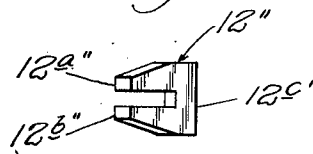


Fig. 8.



Inventor:
Donald W. Kerst,
By Chas. Schroeder,
Merriam, N.Y. atty.

UNITED STATES PATENT OFFICE

2,545,958

INDUCTION ACCELERATOR

Donald W. Kerst, Champaign, Ill., assignor to
The Board of Trustees of the University of
Illinois, Urbana, Ill.

Application March 22, 1946, Serial No. 656,314

4 Claims. (Cl. 250—27.5)

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This invention relates to an induction accelerator, and more particularly to an improved arrangement for causing the accelerated charged particles, as electrons, to be ejected from the induction accelerator in a usable beam.

This invention relates to magnetic induction accelerator devices which generally comprise an evacuated doughnut-shaped tube, as of glass or porcelain, with means for periodically introducing charged particles, as electrons, into the tube, as a heated filament periodically placed at a high voltage differential with respect to an associated electrode; magnetic means for causing the charged particles to circulate in or near a certain orbit in the tube, generally termed the equilibrium orbit, for a very large number of revolutions, accelerating them continuously during this circulation, this means comprising means for setting up magnetic fields across the orbit and the space within the orbit in certain desired relationships, and for varying the strengths of these fields; and means for utilizing the kinetic energy of the charged particles, as by providing a target which the particles may strike to create X-rays, or by causing the charged particles to leave the tube in a beam which may be used for therapeutic or other purposes. The circulating charged particle has a centripetal force requirement varying with the radius of its orbit, and field strength relationships are so provided radially as to provide a magnetic holding force also varying as a function of the radius, the equilibrium orbit on or about which the particle travels having a radius where these forces are equal.

The general principles of operation of a magnetic induction accelerator are known to the art and have heretofore been published in various patents and publications, particular reference in this regard being made to my Patent 2,297,305 of September 29, 1942, and an article by me entitled "The Betatron," which appeared in vol. 10, No. 5, of the American Journal of Physics (October, 1942). Magnetic induction accelerators of this type have also been the subject of a number of other patents and publications including the following: Slepian Patent 1,645,304; Steenbeck Patent 2,103,303; Smith Patents 2,143,459 and 2,289,220; Penney Patent 2,193,602; Baldwin Patent 2,331,788; and my Patent 2,335,014. Other articles by me are: "The Acceleration of Electrons by Magnetic Induction" which appeared in vol. 60, No. 1, of The Physical Review (July 1, 1941) and "A 20-Million Electron-Volt Betatron or Induction Accelerator" which appeared in vol. 13, No. 9, of The Review of Scientific Instruments (September, 1942).

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The principal feature of this invention is that, at an appropriate time, the charged particles, as electrons, circulating in or near the equilibrium orbit are caused to spiral away from this orbit and eventually to reach a space of little or no magnetic field strength, resulting in ejection of the particles from the tube immediately following their passage through this space, the substantial reduction in field strength in this space resulting in sufficient change in direction of the charged particles to prevent their continued circulation within the tube.

Other features and advantages of this invention will be apparent from the following specification and the drawings, in which:

Figure 1 is a top plan view of the tube of an induction accelerator embodying my inventions, partly in horizontal section; Figure 2 is a transverse sectional view along the line 2—2 of Figure 1; Figure 3 is an enlarged plan view of the device for providing a space of reduced magnetic field strength; Figure 4 is a partial view similar to Figure 1 showing another form of device for reducing the magnetic field strength in a certain space within the tube; Figure 5 is an enlarged detail view of the electron injection structure; Figure 6 is a view of the structure shown in Figure 5, looking from the bottom of such figure; Figure 7 is a plan view of another form of device for producing a space with reduced magnetic field strength; and Figure 8 is an end elevational view of the device shown in Figure 7.

Inasmuch as the general principles of operation of a magnetic induction accelerator have been fully described in the patents and publications listed above, the description of the general construction and operation of the betatron will be kept brief, and reference may be made to such other publications to supplement this general description if desired.

In the particular embodiment illustrated herewith the tube providing the annular chamber in which the charged particles circulate is here identified as 10, and it is provided at one point in its periphery with injector means here identified as 11. The tube is preferably made of porcelain for ease in formation, as is more fully described and claimed in the copending application of Almy and Hursh, Serial No. 596,460, filed May 29, 1945 (now abandoned), although it may be made of glass or any other suitable material; and it is preferably coated on the inside with a high resistance conductive coating, as with a very thin film of palladium. In a complete magnetic induction accelerator, as shown in the above-mentioned patents and publications, the tube 10

is disposed between two generally circular pole pieces having main field producing coils associated therewith. The field strength relationships, to provide an equilibrium orbit within the tube, must be such that the rate of change of average field strength within the orbit is double that at the orbit. This may be accomplished by using pole pieces with outwardly tapered or diverging configurations as shown and fully described in my above-mentioned Patent 2,297,305, with nothing more than the main energizing coils associated with the pole pieces; or it may be accomplished by use of main and auxiliary (or flux forcing) coils to provide the desired relationships, as is fully disclosed in my copending application Serial No. 627,481, filed November 8, 1945.

The pole pieces are preferably part of a magnetic structure including a rectangular frame, and the magnetic or main energizing coils are preferably energized by an alternating current of considerable amplitude. These coils may be connected in parallel with condensers, for example, in an arrangement resonant at or about 180 cycles per second, and energized from an alternating current generator of the same frequency, the resonating circuit providing for high circulating currents. The electron injecting mechanism is operated, as by excitation of a thyatron grid by voltage from a pick-up or peaking strip in the field of the main magnet coils to inject the electrons into the tube at the beginning of the rising quarter cycle of current on the positive side. The injector structure is arranged to inject the electrons into the tube in a direction substantially tangent to the circular path, and with substantial initial energy of at least several electron volts and preferably of the order of 1,000 electron volts or more. The general principles of structure and design of injectors are shown in the abovementioned issued patents and publications, and in my copending application Serial No. 617,255, which issued February 21, 1950 as Patent No. 2,497,891, so that the injector will be passed for the time being and returned to later in connection with details of particular relation to this invention.

Interaction between the electrons, moving with their initial energy, and the vertical lines of force of the varying field set up through the tube cause them to be accelerated both radially and circumferentially. Where the injector is outside of the equilibrium orbit, as here, the field strength relationships are arranged such that the electrons are given an inward radial acceleration and spiral in toward the equilibrium orbit as the increasing magnetic field accelerates them circumferentially. This initial radial acceleration may be increased, if desired, by use of an arrangement of the kind shown in the co-pending Adams application Serial No. 607,416, which issued June 14, 1949 as Patent No. 2,473,123.

When the electrons reach the equilibrium orbit they continue to circulate at or near this orbit with an acceleration which continues during the entire rising portion of the positive quarter cycle of energizing current, as the magnetic field is increasing during this time; and since the electrons may have described several thousand revolutions in the time during which they are thus subjected to a continually increasing magnetic field strength, their energy may be worked up to millions of electron volts. During the time the electrons are describing revolutions in and about the equilibrium orbit, maintenance of the electrons at or near such orbit is effected, in the case

of radial stability, by proportioning of the field relationships such that the average change of field strength throughout the area within the orbit is double the change of field strength at the orbit itself; and vertical (or axial) stability results from the curvature of the lines of force in a vertical plane passing through the orbit.

After the electrons have traveled around in or near the equilibrium orbit for as many revolutions as may be necessary to give them the desired high kinetic energy, they may then be caused to follow a generally spiraling instantaneous path, as for example an outwardly spiraling path, to some point or space where there is an action effecting the desired ultimate use of the electron energy. Most betatron installations heretofore made have provided a target of suitable material mounted at an appropriate point in the tube (on the injector structure 11, for example) and caused the accelerated electrons to impinge against this target to effect generation of X-rays, as is more fully described in some of the abovementioned patents and publications, or in the co-pending application Serial No. 534,060, which issued August 17, 1948 as Patent No. 2,447,255, of myself and Serber. The present invention, however, is concerned with means spiraling the accelerated electrons to a space in the tube where the field strength is very low relative to other areas in the tube, to cause a relatively sudden change in direction of electron movement enabling the electrons to be proected from the tube in an electron beam.

I secure a space of very low relative field strength by placing in the tube at one point a field diminishing element or member 12, referring to the embodiment of my invention illustrated in Figures 1-3. This member must be of high magnetic permeability, as ferrous material, the preferable embodiment illustrated in Figures 1-3 being made of laminations of transformer core iron with the laminations vertical (speaking with respect to an induction accelerator arranged with the axis of rotation vertical, as is common). The member 12 is generally U-shaped or horse-shoe shaped in cross section, with inwardly extending arm portions 12a and 12b providing a slot therebetween in the plane of the equilibrium orbit, this member having a connecting or back portion 12c having a thickness (in the plane of the equilibrium orbit) of the same order as the depth of the slot, preferably being at least equal to such depth. This portion 12c must also be of substantial dimensions in a direction transverse to the plane of the slot, since its purpose is to carry, without exceeding saturation and preferably at levels below saturation, all of the lines of force which would normally exist in the entire area comprising a projection of this member 12 in the plane of the equilibrium orbit. That is, lines of magnetic force entering the top of the deflecting member 12 should substantially entirely take a path through the back or solid portion of this member rather than across the gap provided by the slot; and the lines of force will take such path if it is made of sufficiently low reluctance by the provision of sufficient iron in the unslotted portion of the member. The result is that the space in the slot between the portions 12a and 12b, and even slightly outside of this slot as a result of the attraction to such portions of lines of magnetic force, comprises a space of very greatly reduced field strength at any time relative to the field strength existing in adjacent areas in the tube. In order to secure satisfactory results,

the field strength in the slot should not exceed half of the field strength in adjacent areas, and preferably should be of the order of only 5% or 10%, so that for all practical purposes it is a space of substantially no magnetic field strength. The walls of the slot are substantially straight, by which is meant said walls are without sharp deviations, although the walls need not necessarily be perfectly straight as they are illustrated in Fig. 2.

As will be readily apparent from a consideration of Figure 1, the equilibrium orbit lies well to the inside (radially speaking) of the position of the deflecting element 12, which is placed in the tube just ahead (speaking with respect to the direction of travel of the electrons) of a shouldered portion provided with a window 10a facilitating exit of the electrons from the tube. This window may consist, for example, of a piece of thin aluminum or other metal foil 10a over a suitable opening 10b in the glass or porcelain wall of the tube. In operation of this device the electrons are injected at a suitable time by the structure 11, spiraled inward to the equilibrium orbit, and accelerated in a large number of turns, as has been heretofore described. They are then caused to spiral away from the equilibrium orbit, outwardly in this case, by any suitable arrangement for changing the field strength relationships, as is more fully described in my article in the Review of Scientific Instruments, vol. 13, pages 387-394 (September, 1942) or in my Patent No. 2,394,070, which issued February 5, 1946. The outward path of electrons is in a spiral with continually diverging turns, with at least several millimeters, and sometimes as much as eight or ten millimeter difference, between the radii of the last two turns in the plane of the deflecting member 12. Accordingly, even though the deflecting member tends to collect lines of force from several times its own area, the electrons are substantially unaffected in their path if they are at least several millimeters from the open end of the slot in the deflector member on the turn immediately preceding that in which they pass into the space provided by the slot. In this last turn the electrons suddenly find themselves in an area of what is substantially zero field strength, so that there is little or no inward radial force to counteract centrifugal force, and the electrons straighten out their path and move toward and through the foil window 10a to provide a well collected beam of electrons which may be used for therapeutic, irradiating, or other purposes.

While a deflecting means can be made of any suitable construction effecting the desired very great reduction in field strength in a certain space, I prefer the particular construction illustrated in Figures 1-3. Since the back or unslotted end is normally in a region of a magnetic field strength of at least 2,000 to 3,000 gauss and since it will carry field strength from at least double or several times its own cross section, it must be thick and of material of high magnetic permeability. The particular deflector means illustrated has a total radial thickness of two centimeters, with a slot one centimeter deep and two millimeters wide (transverse to the plane of the equilibrium orbit), the over-all dimensions transverse to the slot being one centimeter and the length of the deflector member (along the line of movement of the electrons) being about 10 to 15 centimeters.

In order to use a beam extracting arrangement

of the kind just described it is necessary that the electrons be initially injected from an injector structure which will not interfere with the ultimate spiraling path of the electrons at the end of their acceleration period; i. e., either inside the equilibrium orbit or above or below the plane of the orbit, or both, if outside the equilibrium orbit, where the ultimate spiraling is to be outwardly. While the space of reduced magnetic field strength could be provided to the inside of the equilibrium orbit and the electrons spiraled in at the end of their acceleration, I have shown an arrangement where this space is outside of the orbit and the electrons are spiraled outwardly, as this results in larger pitch changes between turns of the instantaneous electron path during spiraling, and in easier handling of the beam on the way out of the tube. Where the electrons are spiraled outwardly it may be preferable to use an injector structure accomplishing injection to the inside of the equilibrium orbit in place of the injector structure shown. In order to inject the electrons nearer the equilibrium orbit from an injector structure outside of such orbit without at the same time interfering with the outward spiraling at the end of the acceleration period, I have provided what is in effect a double injector structure, as may be best seen in Figures 5 and 6. This structure comprises upper and lower double portions or sections here identified in general as 11' and 11''. Each section comprises a filament, as the filament 11a; a cup member 11b; shielding plates 11c and 11d; and appropriate mounting and connecting means. As may be best seen in Figure 6, the shielding means cups and filaments are spaced apart so as to provide a central slot at half its center coinciding with the plane of the equilibrium orbit. The filaments are constantly heated, and at the appropriate time for injection, a high negative potential, as several thousand volts negative with respect to the filament, is applied to the cups, resulting in electrons streaming out from the filaments with substantial initial energy and generally tangent to the ultimate equilibrium orbit although slightly above and below this orbit in their initial injection. The inward accelerating force is such that the electrons clear the injector structure as they come around in the first turn, and they then spiral inwardly to the equilibrium orbit where their vertical and radial oscillations are gradually dampened until they are revolving fairly stable in the equilibrium orbit during the major portion of their acceleration. When sufficient acceleration has been effected and they are started in their instantaneous outward spiraling path, they remain in or so close to the plane of the equilibrium orbit that their path for the last couple of turns or so passes through the slot in the injector structure 11, so that this structure, although to the outside of the equilibrium orbit, provides no impediment to the ultimate path desired.

Another embodiment of my deflecting arrangement is illustrated in Figure 4, comprising a substantially rectilinear block 12' of high magnetic permeability. This block may, for example, be about one centimeter high, one-half centimeter thick (radially of the device) and several centimeters, as three to fifteen centimeters, long. This attracts to itself sufficient lines of force to provide a space, within a couple of millimeters or so of its inner surface, wherein the field strength is less than half that of adjacent open areas, sufficient to straighten out the spiral path of the

electrons and cause them to pass out of the window 10a' in the tube 10'.

Still another deflecting member embodying my invention is illustrated in Figures 7 and 8, this embodiment of my inventions being more analogous to the member illustrated in Figures 1-3 and described in connection therewith. While the embodiment of Figures 7 and 8 is illustrated as a single piece of material 12'', again generally U-shaped, it will be understood that it may be of laminations arranged parallel to the axis of circulation of the electrons in a plane passing through such axis. This form of deflecting arrangement differs from that of Figures 1-3 primarily in that the back or base portion 12c'' is considerably wider (in a direction parallel to the axis of the induction accelerator) than the outer dimensions across the leg portions 12a'' and 12b'', providing suitable iron for the lines of force and their changes of direction without reaching or substantially exceeding saturation. Any exceeding of saturation in the iron of the deflecting member, or any portion thereof, tends to result in lines of magnetic force passing across the slot therein, so that this must be minimized in so far as is possible.

The deflecting arrangement or means for extracting electron beams which I have shown and described here operates on a principle different from that shown in my above-mentioned Patent 2,394,070. In the structure shown in that patent it was necessary to time and relate a magnetizing current on the electromagnetic deflecting arrangement in a properly coordinated time and amplitude relationship to the rapidly changing main field through the tube, and this presents many difficulties in practice. By the arrangement shown here I provide an arrangement which does not require any special energization, timing or otherwise, and which operates by getting rid of the magnetic field which would otherwise be present in a certain space in the tube, rather than by trying to create a different magnetic field, the present arrangement being very simple and effective in operation.

While I have shown and described certain embodiments of my invention, it is to be understood that it is capable of many modifications. Changes, therefore, in the construction and arrangement may be made without departing from the spirit and scope of the invention as found in the appended claims.

I claim:

1. A magnetic induction accelerator comprising a closed vessel having therein a deflecting member of material of high magnetic permeability, said member having a portion with a slot in the plane of the electron orbit and a portion in the same plane with a thickness of the same order as the depth of said slot, the slot in said member providing a space of greatly reduced field strength relative to adjacent areas.

2. Apparatus of the character claimed in claim 1, wherein said member is formed of laminations lying in planes perpendicular to that of said orbit and generally radial thereof.

3. A magnetic induction accelerator comprising a closed vessel having therein a deflecting member of material of high magnetic permeability having at least a portion in the plane of the electron orbit, said member being formed of laminations lying in planes perpendicular to that of said orbit and generally radial thereof, said portion being thick enough and having other portions extending at least sufficiently far therefrom to always disturb the symmetry of the accelerating field and to provide a space in the plane of the orbit immediately adjacent said first mentioned deflecting portion wherein the accelerating field has a strength less than half that in other adjacent areas in said plane.

4. A magnetic induction accelerator comprising a closed vessel having therein a deflecting member of material of high magnetic permeability, said member having a portion with a slot in the plane of the electron orbit and an immediately adjacent portion of substantial thickness, the walls of said slot being substantially straight to provide a space of greatly reduced field strength relative to adjacent areas.

DONALD W. KERST.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,103,303	Steenbeck	Dec. 28, 1937
2,394,070	Kerst	Feb. 5, 1946