Feb. 21, 1950 D. W. KERST 2,497,891

BETATRON INJECTOR STRUCTURE

Filed Sept. 19, 1945

Fig. 1.

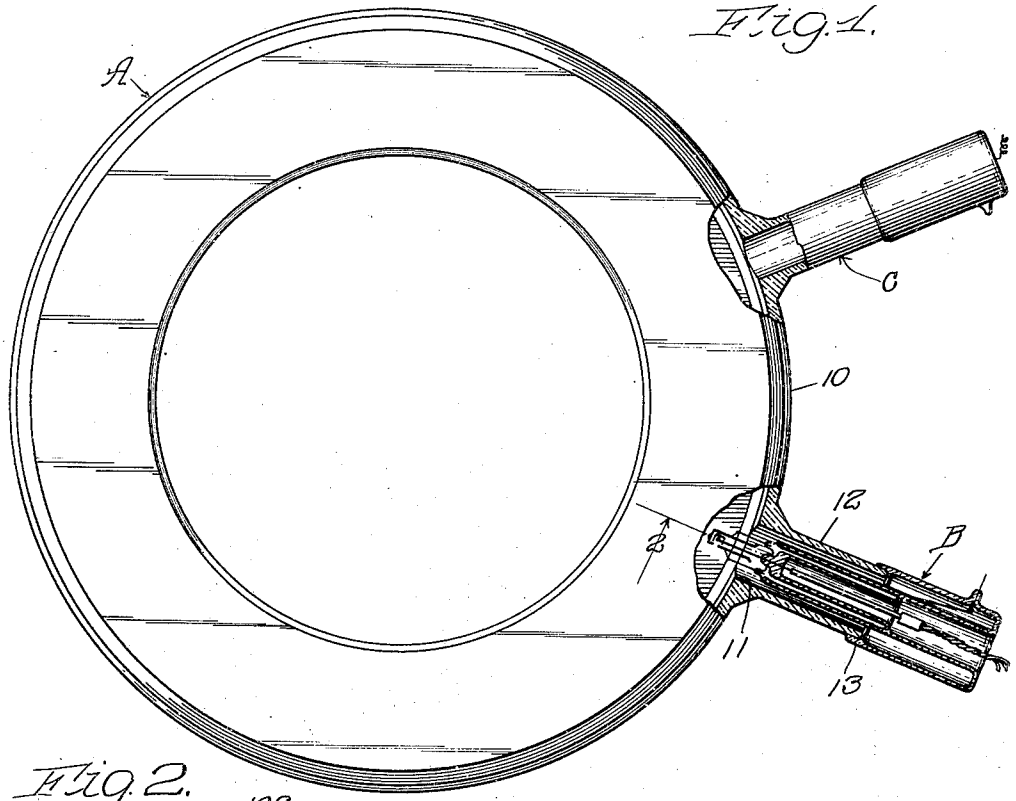



Fig. 2.

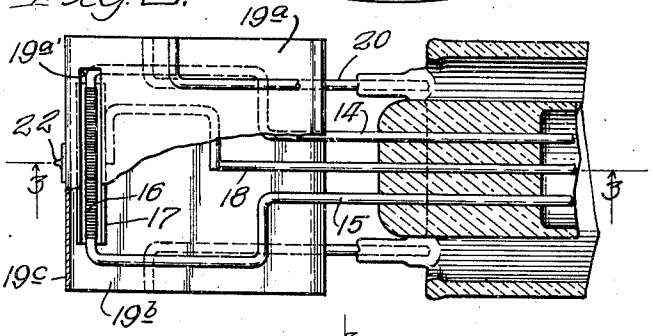



Fig. 4.

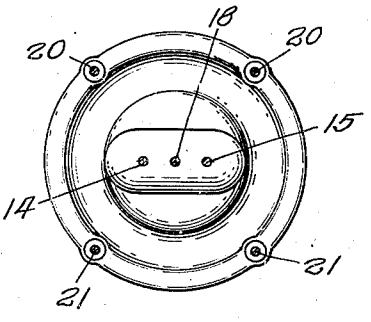
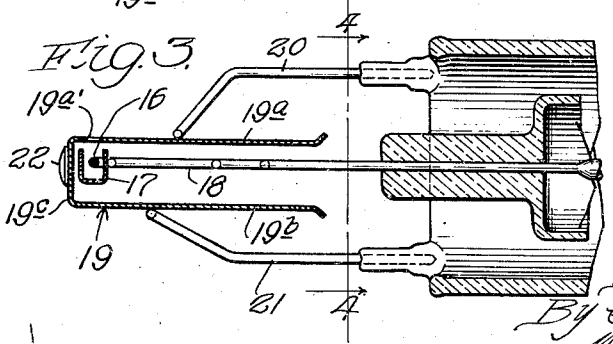



Fig. 3.




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# UNITED STATES PATENT OFFICE

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## BETATRON INJECTOR STRUCTURE

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Application September 19, 1945, Serial No. 617,255

8 Claims. (Cl. 250—27.5)

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This invention relates to a betatron injector structure, and more particularly to improved shielding means for an injector structure for initially accelerating charged particles in an induction accelerator apparatus.

This invention relates in general to magnetic induction accelerator devices which comprise an evacuated doughnut-shaped tube, as of glass or porcelain, with means (as a heated filament) for periodically introducing electrons or other charged particles into the tube; magnetic means for causing the charged particles to circulate in an orbit in the tube for a very large number of turns, accelerating them continuously during this circulation, this means comprising magnets above and below the tube with pole faces of outwardly tapered or divergent configuration, with means for increasing the magnetic field continuously during the circulation of the charged particles; and means for utilizing the kinetic energy of the charged particles, as a target which they may strike to create X rays. The circulating charged particle has a centripetal force requirement varying with the radius of its orbit, and the pole face tapered configuration or divergence is such as to provide a magnetic holding force also varying as a function of the radius, the equilibrium orbit of the charged particle 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 Kerst Patent 2,297,305 of September 29, 1942 and an article entitled "The Betatron," by D. W. Kerst, 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; Kerst Patent 2,335,014. Other articles by D. W. Kerst 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).

One feature of this invention is that it provides an improved injector structure, and more particularly an injector shielding arrangement which substantially increases the yield (as for example where the betatron is being used for generation of X rays) by preventing undesirable electrostatic effects upon the circulating charged particles.

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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 torus or tube of a betatron, partly broken away better to show the injector structure and the evacuating connection; Figure 2 is an enlarged fragmentary elevational view of the active end of the injector structure; Figure 3 is a sectional view of the injector structure parts shown in Figure 2, along the line 3—3 thereof; and Figure 4 is a transverse sectional view along the line 4—4 of Figure 3.

Inasmuch as the general principles of operation of a magnetic induction accelerator have been fully described in the patents and publications listed above, and the present invention is concerned only with improvement of the injector structure of such an accelerator, the description of the general construction and operation of the betatron will be kept brief, and reference may be made to such patents and 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, as electrons, circulate, is here identified as A, and is provided at one point in its periphery with an injector arrangement here identified in general as B, to be more fully described hereinafter. It is provided at another point in its periphery with a connector arrangement here identified as C, this latter arrangement serving to evacuate the tube and to provide a ground connection for the conductive inner surface thereof. 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 but conductive coating, as a very thin film of palladium, this inner conductive coating serving as a shield to prevent stray electrostatic impulses from having any effect on the electrons circulating in the tube or torus. Acceleration of the charged particles in the tube is effected by mounting the tube between two generally circular pole pieces of outwardly tapered or diverging configuration to provide lines of magnetic force crossing the tube vertically (when the tube has its axis vertical, as is

generally the case in practice), this magnet structure not being shown here as reference may be had to Kerst Patent 2,297,305 for a showing and description of a representative field creating arrangement. The pole pieces have magnet coils associated with them and these magnet coils are energized by an alternating current of considerable amplitude, the coils preferably being connected in parallel with condensers and energized from an alternating current generator at the resonant frequency of the tuned circuit thus provided (as at a frequency of 180 cycles per second), very large circulating currents thus flowing in the magnet coils with the generator merely providing an actuating current replacing losses in the system.

The injector structure with which this application is particularly concerned comprises in general a filament within the tube and spaced from the inner surface of a circular wall thereof, electron focusing and initial accelerating means in the form of a cup which may be given a brief high negative excitation with respect to the filament, and shielding means to prevent the voltages and currents being supplied to the filament and tube from undesirably affecting the path of the circulating electrons. The pulse of negative voltage supplied to the cup must be correlated with the frequency of the current flowing in the magnet coils, as by completing this circuit by excitation of a thyratron grid by voltage from a pick-up or peaking strip in the field of the main magnet coils, so as to inject the electrons into the tube at the beginning of the rising quarter cycle of current on the positive side of the cycle. By the injector structure shown in detail in Figures 2, 3 and 4, and more fully described hereafter, the electrons are injected into the tube substantially tangent to the circular path provided, with substantial initial energy of more than several electron volts. Coaction between the moving electrons and the vertical lines of force of the magnetic field cause them to be accelerated radially by the magnetic force, this acceleration being so proportioned as to cause the particles to move toward the equilibrium orbit, inwardly if the injector means is outside of the equilibrium orbit, and then to be so accelerated radially as to maintain them in that orbit. At the same time, the increasing magnetic field accelerates the electrons in that orbital path. The period of acceleration of speed of electrons continues during the entire rising portion of the positive cycle of the current, as the magnetic field is increasing during this time; and since the electrons may have described several thousand revolutions in this time, strong magnetic fields will have worked their energy up to millions of electron volts. At the end of this time means is used to swing the electrons out of their equilibrium orbit, as by a change in the distribution of magnetic field, into collision with a target, for example. During the time the electrons are describing revolutions in and about the equilibrium orbit, maintenance of the electrons at and near the equilibrium orbit is effected, in the case of radial stability, by proportioning of the field relationships such that the average flux density throughout the area within the orbit is double the flux density at the orbit; and vertical or axial stability is secured by the curvature of the lines of force in a vertical plane.

Referring now more particularly to the injector structure, the tube A will be seen to have an outer circular wall **10** with an opening **11** therethrough, the inner surface of this circular wall being



otherwise coated with a conductive material, as has heretofore been mentioned, this material being normally grounded in use through a connection taken off through the arm C. Around the opening **11** is a neck portion **12** of the material of which the tube is made, as porcelain, to which is sealed the body **13** of the injector structure tube, which may be of glass. Extending up inside the neck **12** of the porcelain tube are concentric generally cylindrical glass members of the injector structure tube, the ends of these carrying supporting and connecting means for the filament, cup and shield which at least partly project through the opening **11** into the interior of the main tube.

Referring now more particularly to Figures 2, 3 and 4, connecting and supporting members **14** and **15** carry at their outer ends the filament **16**, which may be of helical form and which, when heated to incandescence, provides the electron emitting means. Surrounding the filament **16** on three sides is a cup or electrode member **17** adapted to be rendered considerably negative with respect to the filament to give electrons a desired initial direction and acceleration in excess of at least several electron volts, the electrons being started off generally tangent to the circle formed by the main tube and thereafter accelerated and controlled by the effect thereon of the magnet lines of force. The negative pulse applied to the cup is normally of only very brief duration, as for example a few microseconds, but of relatively high potential difference with respect to the filament, which might be at ground potential, sometimes as high as 50,000 or 60,000 volts. This voltage is applied to the cup through a connecting and supporting member here identified as **18**, and the voltages in the connecting members **14**, **15** and **18**, and particularly the latter, have heretofore created a loss of electrons by electrostatic deflection of some of the electrons from the desired orbit.

While shielding means for the filament and cup have heretofore been used, I have discovered that this was not sufficient, but that shielding means must be employed in such manner as to prevent electrostatic fields from the voltages and currents in the connecting members from undesirably influencing the electrons in their circulating path. Moreover, the shield arrangement previously used had a cross piece on the same side of the filament as the connecting members, with frequent arcing over between the connecting members and the grounded shield when an attempt was made to use high voltages on the cup, limiting the cup voltages to much lower figures than those now deemed desirable.

I have overcome these and other difficulties by providing a shield member of sheet metal formed in a U-shape with the plane of the sheet metal parallel to the lines of force and the leg portions extending generally radially of the circular path of the electrons, with the filament cup and connecting members lying within the shield. Moreover, I have found it undesirable to have any shield cross piece on the side of the filament and cup from which the connecting members extend; and have found that the leg portions of the shield must extend at least half way from the filament to the arc of the inner surface of the adjacent generally circular wall, and preferably past this arc and into the injector opening in the wall.

Referring now more particularly to the specific structure shown in the accompanying

drawings, the shield is identified in general as 19 and is shown as comprising a generally U-shaped piece of sheet metal with the plane of the sheet metal parallel to the lines of force passing through the tube, the U-shaped form comprising radially extending leg portions 19*a* and 19*b* (although it will be understood that these could diverge or converge somewhat, if desired, or both be parallel but not exactly radial, all these situations being contemplated in the term "generally radial") and a cross piece 19*c*. This latter cross piece 19*c* is the only shield portion extending between the leg portions and lies on the other side of the filament and cup members 16 and 17 from the connecting and supporting members. The shield is in turn supported by grounded connecting and supporting members here identified as 20 and 21. The cross piece is here shown as carrying on one surface thereof the target piece 22 on which the electrons are adapted to impinge to create X-rays. The ends of the leg portions 19*a* and 19*b* of the U-shaped shield member are preferably flanged out slightly for rigidity; and these ends extend into the injector opening 11 well beyond the arc of the inner surface of the circular wall 10, as may be best seen in Figure 1, so that the shielding provided by this means extends down past the line of effectiveness of the shielding provided by the conductive coating on the inner surface of this circular wall 10, these two shielding means preferably being at the same potention, as ground potential. One leg portion of the shield, as the one here identified as 19*a*, includes a slot here identified as 19*a'*, this slot registering with the filament 16 and providing an exit opening for the electrons.

In operation of the injector structure, the filament 16 is continuously heated to incandescence by relatively low voltage high current power delivered through the connecting members 14 and 15. When the injection operation is brought into action by triggering of a thyratron tube by means in the main magnet field, as a peaking strip, the cup 17 is made highly negative with respect to the filament, as for example as much as 60,000 volts negative, for a brief period of a few microseconds. This voltage differential causes electrons to stream out of the opening or slit 19*a'* in the shield, causing them to stream clockwise in the tube as shown in Figure 1, preferably with an initial velocity of the order of several thousand electron volts. These electrons are then acted upon by the magnetic field in such manner as not only to accelerate their velocity but also to tend to accelerate them inwardly toward the center of the tube, toward an equilibrium orbit which is preferably just to the inside of the electron gun or injector structure here shown as passing through the outer wall of the tube. The electrons are then caused to travel around in or near the equilibrium orbit for as many revolutions as may be desired, and for as long as the magnetic field of force is rising in strength, and are finally caused to follow an instantaneous orbit of slightly greater radius than the equilibrium orbit (as by changes in the magnetic field distribution) and to impinge on the target 22, this impingement effecting the desired generation of X-rays, as is more fully described and claimed in the copending Kerst and Serber application Serial No. 534,060, filed May 4, 1944, now U. S. Patent No. 2,447,255 issued Aug. 17, 1948.



By omitting any cross piece in the shield structure on the same side of the filament and cup as the connecting members, it is possible to use very much higher initial accelerating voltages on the cup, and thus to start the electrons off with an initial electron voltage hundreds of times that heretofore possible, with a resultant higher eventual electron energy in the same period of magnetic acceleration. Moreover, by having a shield arrangement of the kind shown where the leg portions of the U-shaped shield extend at least half way to the arc of the circular wall in which the injector structure is mounted, and preferably past that arc, it is possible to insert the filament further into the tube, particularly desirable in a porcelain tube, and yet completely to avoid any undesirable electrostatic effects from the connecting members for the filament and cup, and particularly the latter. The particular injector structure here shown and described has provided increased X-ray yields amounting to as much as 300% in some tubes, with other conditions being unchanged.

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 disclosed in the appended claims.

I claim:

1. In an accelerator for charged particles having a closed vessel with at least one generally circular wall defining a chamber within which such particles may move in a generally circular path and said accelerator having means providing magnetic lines of force across said path for accelerating the particles, the inner surface of said wall comprising conductive material, an injector structure including: means for emitting charged particles, this emitting means being within the vessel and spaced from said wall; an electrode member for effecting acceleration of said particles away from said emitting means; connecting members extending from said emitting means and electrode member generally radially of said circular path; and a shield member of sheet metal former in a U-shape with the plane of the sheet metal parallel to the lines of force and the leg portions extending generally radially of said circular path, said emitting means and connecting members lying within said shield member, one leg portion having an opening therethrough adjacent the emitting means, the crosspiece of the U-shape comprising the only transversely extending part of the shield member and lying on the other side of the emitting means from the connecting members, the leg portions of the shield member extending at least half way from the emitting means to the arc of the inner surface of said generally circular wall.

2. In an accelerator for charged particles having a closed vessel with at least one generally circular wall defining a chamber within which such particles may move in a generally circular path and said accelerator having means providing magnetic lines of force across said path for accelerating the particles, said wall having an opening therethrough and the inner surface of the wall comprising conductive material, an injector structure including: means for emitting charged particles, this emitting means being within the vessel and spaced from said wall; an electrode member for effecting acceleration of

said particles away from said emitting means; connecting members extending from said emitting means and electrode member generally radially of said circular path; and a shield member of sheet metal formed in a U-shape with the plane of the sheet metal parallel to the lines of force and the leg portions extending generally radially of said circular path, said emitting means and connecting members lying within said shield member, one leg portion having an opening therethrough adjacent the emitting means, the crosspiece of the U-shape comprising the only transversely extending part of the shield member and lying on the other side of the emitting means from the connecting members, the leg portions of the shield member extending into said opening in said wall past the arc of the inner surface thereof and the shield member and the conductive material being maintained at the same electrical potential.

3. In an accelerator for charged particles having a closed vessel with at least one generally circular wall defining a chamber within which such particles may move in a generally circular path and said accelerator having means providing magnetic lines of force across said path for accelerating the particles, the inner surface of said wall comprising conductive material, an injector structure including: means for emitting charged particles, this means being within the vessel and spaced from said wall; and a shield member of sheet metal formed in a U-shape with the plane of the sheet metal parallel to said lines of force and the leg portions extending generally radially of said circular path at least half way from the emitting means to the arc of the inner surface of the said generally circular wall.

4. In an accelerator for charged particles having a closed vessel with at least one generally circular wall defining a chamber within which such particles may move in a generally circular path and said accelerator having means providing magnetic lines of force across said path for accelerating the particles, said wall having an opening therethrough and the inner surface of the wall comprising conductive material, an injector structure including: means for emitting charged particles, this means being within the vessel and spaced from said wall; and a shield member of sheet metal formed in a U-shape with the plane of the sheet metal parallel to said lines of force and the leg portions extending generally radially of said circular path and into said opening in said wall past the arc of the inner surface thereof and the shield member and the conductive material being maintained at approximately the same electrical potential.

5. In an accelerator for charged particles having a closed vessel defining a chamber within which such particles may move in a closed path and said accelerator having means providing magnetic lines of force across said path for accelerating the particles, an injector structure including: apparatus within said vessel for emitting charged particles; and a shield member



formed in a U-shape with its leg portions extending beyond said emitting means and extending generally radially of said closed path.

6. In an accelerator for charged particles having a closed vessel defining a chamber within which such particles may move in a generally circular path and said accelerator having means providing magnetic lines of force across said path for accelerating the particles, an injector structure including: apparatus within said vessel for emitting charged particles; and a grounded shield member of sheet metal formed in a U-shape with the plane of the sheet metal parallel to said lines of force and the leg portions extending generally radially of said circular path, the interior of said U-shaped shield member being entirely open.

7. In an accelerator for charged particles having a closed vessel defining a chamber within which such particles may move in a closed path and said accelerator having means providing magnetic lines of force across said path for accelerating the particles, an injector structure including: apparatus within said vessel for emitting charged particles; connecting members extending from said means; and a shield member of sheet metal formed in a U-shape with the plane of the sheet metal parallel to the lines of force, and the leg portions extending generally parallel to the connecting members, said emitting means and connecting members lying within said shield member.

8. In an accelerator for charged particles having a closed vessel defining a chamber within which such particles may move in a generally circular path and said accelerator having means providing magnetic lines of force across said path for accelerating the particles, an injector structure including: apparatus within said vessel for emitting charged particles; an electrode member for effecting acceleration of said particles away from said emitting means; connecting members extending from said emitting means and electrode member generally radially of said circular path; and a shield member of sheet metal formed in a U-shape comprising leg portions and a cross-piece, with the plane of the sheet metal parallel to the lines of force and the leg portions extending generally radially of said circular path, said emitting means and connecting members lying within said shield member, one leg portion having an opening therethrough adjacent the emitting means, the crosspiece of the U-shape comprising the only transversely extending part of the shield member and lying on the other side of the emitting means from the connecting members.

DONALD W. KERST.

## REFERENCES CITED

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

UNITED STATES PATENTS

| Number | Name | Date |
|---|---|---|
| 2,297,305 | Kerst | Sept. 29, 1942 |

## Certificate of Correction

Patent No. 2,497,891 February 21, 1950

DONALD W. KERST

It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows:

Column 5, lines 32 and 33, for "potention" read *potential*; column 6, line 48, for "former" read *formed*;

and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 4th day of July, A. D. 1950.

[SEAL]

THOMAS F. MURPHY,
*Assistant Commissioner of Patents.*