July 12, 1966 C. M. LUCAS 3,260,877

MULTIPLE-BEAM INJECTOR FOR MAGNETIC INDUCTION ACCELERATORS

Filed April 17, 1963

FIG. 1

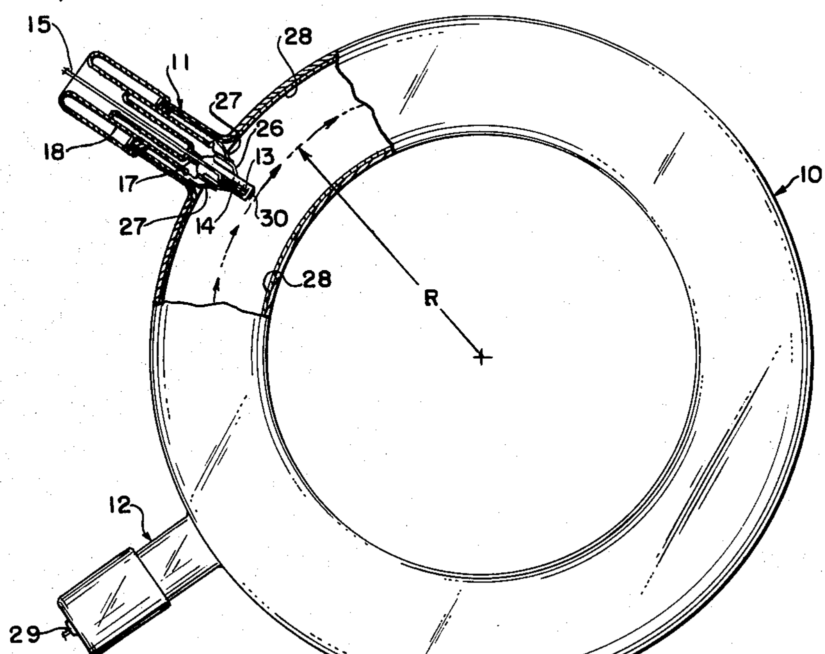
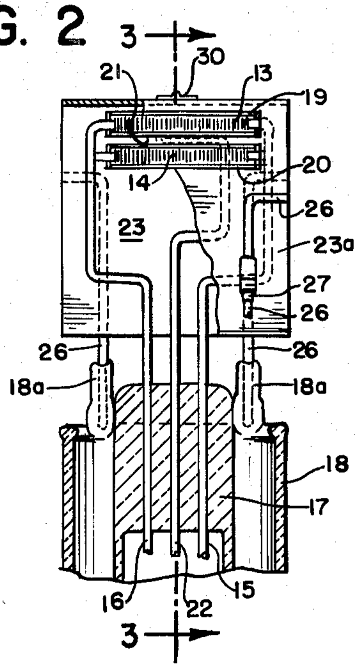


FIG. 2



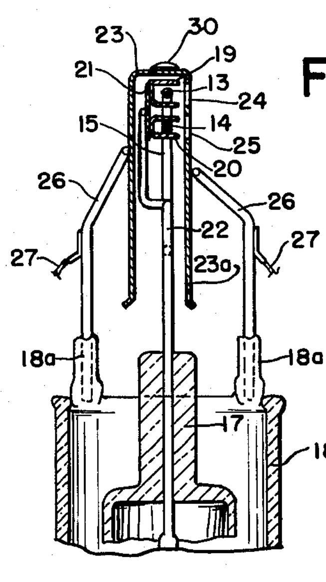


FIG. 3

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MULTIPLE-BEAM INJECTOR FOR MAGNETIC INDUCTION ACCELERATORS

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13 Claims. (Cl. 313—70)

The present invention relates to an electron tube structure for a magnetic induction accelerator, and more particularly to apparatus for injecting electrons into orbit in a betatron accelerator for the production of X-rays. The invention provides an improved betatron tube structure having a longer operating life and a lower rate of power consumption.

In the betatron, electrons are ejected from a heated cathode supported within a hollow toroidal envelope. An alternating, radially symmetrical magnetic field, which is coaxial with the toroid and the outer portion of which passes through the toroid, causes the electrons to follow a substantially fixed circular orbital path. During the increasing portion of the sinusoidally varying field (i.e. the first quarter of the cycle) the electrons are accelerated to energies of, for example, 25 mev. At or near the end of the first quarter of the cycle, an auxiliary magnetic field of low flux density is produced by applying a current to a small auxiliary coil so as to disturb the orbital equilibrium conditions set up by the main field. The orbit electrons spiral out of orbit and impact upon a target, producing X-rays, or emerge from the envelope as a beam of electrons.

A substantial problem associated with the design of such betatron devices is that of injecting a sufficient amount of electrons into orbit so as to produce a useful X-ray or electron beam output. The injection of electrons into orbit may be considered as a two-part problem. First, a substantial electron current must be produced and, second, electrons must be captured by the magnetic field for orbital acceleration. Heretofore, the first problem has been attacked by utilizing a high emission, heated helix of either pure tungsten or, more recently, thoriated tungsten. The pure tugnsten filament was operated at high temperatures and wattage (e.g. 36 watts) in order to produce the required current output and, because of such high operating temperatures, was susceptible to early filament burnout or sagging (e.g. after some 200 hours of operation). The thoriated tungsten filament produces the same emission at lower wattage and temperature, thus prolonging filament life. However, thoriated tungsten is susceptible to positive ion poisoning which severely reduces current output.

Considering the second portion of the injection problem, i.e. the capture of electrons by the magnetic field, it has been considered necessary to emit the electrons with high initial energies (50–75 kv.) at a point which is practically on the desired orbital path. The filament and associated structure must not, however, project into the orbital path since electrons would impact thereon after a few orbits, rather than after traversing the several hundred thousand orbits typically required for acceleration to the desired energy. If the electrons are not emitted close to the orbital path, the natural self de-focussing tendency of the beam, caused by the mutual electron repelling forces, scatters the electrons away from the orbital path such that they are not captured by the magnetic field. These scattered electrons drift to the wall of the tube and are collected there. Hitherto therefore, so far as I am aware, the electron capture problem has been approached from the standpoint of placing a single electron-emitting filament as close to the desired orbital path as possible.

In accordance with the present invention, an electron injection structure for a betatron is provided wherein a pair of relatively low temperature, low emission tungsten filaments are arranged geometrically substantially parallel to each other, one being nearer the orbital path than the other. Thus, in the assembled betatron the two filaments are spaced from each other (in practice by a small distance radially of the axis of the toroidal envelope or "betatron tube." A separate focusing electrode and a separate aperture in a common accelerating anode are associated with each of the filaments so that each develops an electron beam, the two beams being radially spaced with respect to the electron orbit and with respect to each other outside the orbit. The two relatively low current electron streams act together to inject sufficient electrons into orbit.

The invention will now be further described with reference to the accompanying drawing in which:

FIGURE 1 is a plan view, partially in section, of a toroidal electron tube structure embodying this invention;

FIGURE 2 is an enlarged view of the electron injector structure of FIGURE 1; and

FIGURE 3 is a sectional view taken along line **3—3** of FIGURE 2.

Referring now to FIGURE 1, an electron tube structure for a magnetic induction accelerator constructed in accordance with the present invention comprises an evacuated, hollow toroidally-shaped envelope **10**. Toroidal envelope **10** may, for example, be made of porcelain or other ceramic material. Two tubular horns **11** and **12** protrude radially from the outside surface of envelope **10**. Horns **11** and **12** are part of the vacuum envelope **10** and provide a means for bringing electrical leads into envelope **10**.

Referring now to FIGURES 2 and 3 in connection with FIGURE 1, the electron injection structure which is supported in horn **11** will be described.

The electron injection structure comprises a pair of helical electron-emissive filaments **13** and **14** which are preferably made of tungsten. Filaments **13** and **14** are supported within envelope **10** by a pair of relatively rigid high voltage leads **15** and **16** which are brought out of envelope **10** through horn **11** by means of stem press **17**. Stem press **17** forms a part of reentrant glass wall member **18** which acts to seal the opening in horn **11**. By means of leads **15** and **16**, filaments **13** and **14** are connected electrically in parallel as shown in FIGURE 2.

A pair of focussing electrodes **19** and **20**, of cup shaped section in planes transverse to the length of filaments **13** and **14**, one associated with each filament, are disposed about three sides of filaments **13** and **14**. A rigid strap **21** of conducting material is coupled to focussing electrodes **19** and **20** and to supporting lead **22** so as to support electrodes **19** and **20** in close proximity to filaments **13** and **14**. Strap **21** also serves electrically to connect electrodes **19** and **20** to each other and to lead **22**. Lead **22**, in turn, is brought out of horn **11** through stem press **17** for connection to a suitable potential source. A generally U-shaped anode structure **23**, including a pair of parallel, rectangular apertures **24** and **25** in the face **23**a thereof, is disposed about the filaments **13** and **14** and focussing electrodes **19** and **20**. Aperture **24** is aligned with filament **13** and focussing electrode **19** while aperture **25** is aligned with filament **14** and focussing electrode **20**. Anode **23** is supported by rods **26** which are mounted in supporting posts **18**a on reentrant glass wall member **18** and which are mechanically connected to the sides (such as **23**a) of anode **23**. Rods **26** also serve to electrically connect anode **23**, via connectors **27** (shown in FIGURE 1), to conductive coating **28** on the inside wall of envelope **10**. Conductive coating **28**, which may for example be made of palladium or platinum, serves to conduct away stray electrons which may come in contact with it. Accordingly, this coating **28** is connected to ground via a lead 29 which is brought out through horn 12. A target 30, which may, for example, be made of platinum, is connected both mechanically and electrically to the top of anode 23. Target 30 serves to produce the X-ray output of the betatron when high energy electrons impact upon it.

This electron tube structure is designed to be located between the pole pieces of an induction accelerator magnetic structure which forms no part of this invention and is therefore not shown. Such a magnetic structure is designed to produce a magnetic field perpendicular to the plane of FIGURE 1 and coaxial with the envelope 10, having a strong central portion radially inside the envelope and a weaker field at the toroid, and alternating with time. The portion of the field passing through the envelope is moreover shaped, with respect to its variation with radial position, so as to effect radial and vertical focusing of the electrons into the desired orbit. Thus, electrons injected into the field with an initial energy at a point close to the orbital path of radius "R" will be captured and accelerated during that portion of the period of the alternating magnetic field during which the field increases.

As shown in FIGURE 1, the electron injection structure constructed in accordance with this invention extends in a generally radial direction into envelope 10 such that the radially innermost point thereof, target 30 lies just outside the orbital path of radius "R" shown by the dashed arrow line. The orbital path is shown as being in the clockwise direction or sense and apertures 24 and 25 in anode structure 23 are accordingly disposed in a clockwise direction from filaments 13 and 14 respectively.

In a typical installation of apparatus of this type designed to produce electron energies of the order of 25 mev., the orbital radius is of the order of 8 inches, the center-to-center spacing between filaments 13 and 14 is of the order of one-eighth inch and the spacing between the inner filament 13 and the orbital path is also of the order of one-eighth inch.

Furthermore, the following electrical connections are made. Focussing electrodes 19 and 20 are externally connected, via lead 22, to filament lead 15. A low voltage alternating current heater supply of, for example, 3.6 volts delivering 4 amperes to each of filaments 13 and 14, is connected in series with a high voltage pulse transformer (not shown) across leads 15 and 16. The total filament power is thus approximately 30 watts. Anode 23 is, as mentioned earlier, connected to ground potential.

In operation, the alternating magnetic field is varied, for example, at a frequency of 180 cycles per second. Near the beginning of each cycle (i.e. just after the flux level passes in an increasing direction through zero), a highly negative voltage pulse (for example, 50 kv., 4 microseconds wide) is applied to filament lead 16. Electrons emitted by virtue of the heater current of 4.1 amperes are "kicked" from filaments 13 and 14 by the highly negative voltage pulse. Focussing electrodes 19 and 20, in conjunction with apertures 24 and 25 in anode 23 serve to focus these high energy electrons into a pair of sheet-like electron beams traveling initially in the clockwise orbital direction. Electrons from both beams are captured by the magnetic field and travel in orbits which initially oscillate about the desired orbit. After several revolutions these oscillations are damped out by the magnetic field. The electrons are accelerated during each revolution until the desired energy level, e.g. 25 mev., is reached. At this time, the electrons are caused to spiral out of orbit by means of an auxiliary coil which produces a small icnrement of flux to disturb the equilibrium conditions of the main field. The electrons impact upon target 30 and produce X-rays in the well-known manner.

Any emitted electrons which did not initially go into orbit drift to the wall of envelope 10 and are removed via conductive coating 28 and lead 29.

The lower operating wattage of the two tungsten filaments as compared with that required where only a single tungsten filament is used serves to increase the life of the filaments.

While the invention has been described herein in terms of a preferred embodiment, it is not restricted either to that embodiment or to the mode of operation set forth. Thus, for example, in the embodiment described, approximate dimensions have been mentioned to provide an indication of the relative orders of magnitude involved. The invention contemplates, however, that these dimensions may be greater or less, depending upon all of the operating parameters and size of the tube. This and other modifications may be made in the particular structure and procedure which has been described herein without departing from the scope of the invention, which is rather set forth in the appended claims.

I claim:

1. An electron tube structure for a magnetic induction accelerator comprising a plurality of electron-emissive elements for injecting electrons into a circular orbit of a given radius and a given direction, said elements being radially spaced apart outside of said orbit, focussing means disposed about each electron-emissive element for directing emitted electrons in said given orbital direction, and an anode structure disposed about said electron-emissive elements and said focussing means, said anode structure including a surface having a plurality of apertures therein, each aperture being aligned with and disposed in said given orbital direction from one of said electron-emissive elements whereby a plurality of streams of electrons are emitted in the given orbital direction.

2. An electron tube structure for a magnetic induction accelerator comprising a plurality of electron-emissive filaments for injecting electrons into a circular orbit of a given radius and a given direction, said filaments having parallel axes extending in a direction perpendicular to the plane of said orbit and being radially spaced apart outside of said orbit, focussing means disposed about each of said filaments for forming a sheet-like beam of electrons from each filament directed towards said given orbital direction, and an anode structure disposed about said filaments and said focussing means, said anode structure including a surface disposed in the given orbital direction from said filaments having a plurality of apertures therein, each aperture being aligned with one of said electron-emissive filaments whereby a plurality of sheet-like, radially spaced beams of electrons are emitted in the given orbital direction.

3. An electron tube structure for a magnetic induction accelerator comprising a pair of helical electron-emissive filaments for injecting electrons into a circular orbit of a given radius and a given direction, said filaments having parallel axes extending in a direction perpendicular to the plane of said orbit, being radially spaced apart and radially spaced outside of said orbit by distances small in comparison with the radius of said orbit, a pair of focussing electrodes, each of said focussing electrodes being generally cup-shaped in section in planes transverse to the axes of said filaments and each of said focussing electrodes being spaced from one of said filaments in the direction opposite to the direction of said circular orbit so as to focus electrons emitted by each filament into a sheet-like beam traveling in said given orbital direction, and an anode structure disposed about said filaments and said focussing electrodes, said anode structure including a surface disposed on the side of said filaments opposite to said focussing electrodes, said surface having a plurality of apertures therein with each aperture aligned with one of said electron-emissive filaments whereby a plurality of sheet-like, radially spaced beams of electrons are emitted in the given orbital direction.

4. An electron tube structure for a magnetic induction accelerator according to claim 3 wherein said anode structure is generally U-shaped in cross-section in the plane of said circular orbit with the long sides of said U-shape extending in a generally radial direction, and said pair of apertures are disposed in the one of said long sides which is displaced in the orbital direction from said filaments, said apertures being rectangular in shape and radially spaced from each other and from said circular orbit by a distance which is small compared with the radius of said orbit, whereby two sheet-like, radially separated beams are omitted in the direction of said circular orbit at radii close to the given orbital radius.

5. An electron tube structure for a magnetic induction accelerator comprising an evacuable, hollow toroidal envelope, an anode structure projecting radially within said envelope, said anode structure including one side having a pair of parallel apertures therein, the centers of said apertures being located at unlike distances from the center of said toroidal envelope, a pair of electron-emissive filaments supported within said anode, each of said filaments being aligned with one of said apertures, and focussing electrodes associated wtih each of said filaments for directing electrons emitted from said filaments through said apertures, whereby a pair of spaced, sheet-like beams of electrons are injected into said hollow toroidal envelope.

6. An electron tube structure for a magnetic induction accelerator comprising a hollow toroidal envelope, a plurality of electron-emissive elements supported within said envelope and spaced radially from each other and from said toroidal envelope, focussing means disposed about each electron-emissive element for directing emitted electrons toward a desired orbital path within said envelcpe, and an anode structure having a plurality of spaced apertures through one face thereof, said anode structure being disposed about said electron-emissive elements and said focussing means with each of said spaced apertures being aligned with one of said electron-emissive elements whereby a plurality of streams of electrons traveling towards said desired orbital path are produced.

7. An electron tube structure for a magnetic induction accelerator comprising an evacuable, hollow toroidal envelope, a pair of helical electron-emissive filaments projecting within said envelope for injecting electrons in a given sense into a circular orbit of given radius, said pair of filaments being spaced from each other and from said orbit in a radial direction with respect to the axis of revolution of said toroidal envelope, a pair of focussing electrodes cup-shaped in section in planes transverse to the length of said filaments, each of said focussing electrodes being spaced from one of said filaments in the sense opposite to the said sense along said circular orbit so as to focus electrons emitted by each filament into a sheet-like beam traveling in said given orbital sense, and an anode structure disposed about said filaments and said focussing electrodes, said anode structure including a surface disposed on the side of said filaments opposite to said focussing electrodes, said surface having a pair of apertures therein with each aperture aligned with one of said electron-emissive filaments, whereby a plurality of sheet-like, radially spaced beams of electrons are emitted in the orbital sense within said envelope.

8. An electron tube structure for a magnetic induction accelerator comprising a hollow, evacuable toroidal envelope, a pair of helical electron emissive filaments supported within said toroidal envelope, the longitudinal axes of said filaments being parallel to each other, parallel to the axis of revolution of said toroidal envelope and radially spaced apart from each other, a pair of focussing electrodes cup-shaped in section in planes transverse to said axes of said filaments, each of said focussing electrodes being disposed about one of said filaments so as to focus electrons emitted by each filament into a sheet-like beam, and an anode structure disposed about said filaments and said focussing electrodes, said anode structure including a surface disposed in the path of said sheet-like beam of electrons, said surface having a pair of substantially parallel, rectangular apertures therein, each aperture being aligned with one of said electron-emissive filaments whereby a pair of radially-spaced, sheet-like beams of electrons are emitted in said hollow, toroidal envelope.

9. Electron injection apparatus for a magnetic induction accelerator comprising a pair of elongated electron-emissive elements, said elements being parallel to each other and spaced from each other in a direction perpendicular to their lengths, a pair of focussing electrodes, each electrode being disposed about a substantial portion of the periphery of one of said elements so as to focus emitted electrons into a pair of spaced sheet-like beams, and an anode structure disposed about said electron-emissive elements and said focussing electrodes, said anode structure including a surface having a pair of apertures therein, each of said apertures being aligned with one of said electron-emissive elements in the path of said sheet-like beam whereby a pair of spaced, sheet-like beams of electrons are emitted in substantially one direction.

10. Electron injection apparatus for a magnetic induction accelerator comprising a pair of helical, electron-emissive filaments, said helical filaments being spaced from each other in a direction perpendicular to their longitudinal axes, said longitudinal axes being substantially parallel, a pair of focussing electrodes cup-shaped in section in planes transverse to said longitudinal axes of said filaments, each of said focussing electrodes being disposed about a substantial portion of the periphery of one of said filaments so as to focus emitted electrons into a pair of spaced, sheet-like beams, and an anode structure disposed about said filaments and said focussing electrodes, said anode structure including a surface having a pair of rectangular apertures therein, each of said apertures being aligned with one of said electron-emissive elements in the path of said sheet-like beam whereby a pair of spaced, sheet-like beams of electrons are emitted from said apertures in said anode in substantially one direction.

11. Electron injection apparatus for a magnetic induction accelerator comprising a pair of elongated thermionically-emissive cathodes, said cathodes being substantially parallel to each other and spaced from each other in a direction transverse to their lengths, a pair of focusing electrodes, each of said electrodes being disposed about the periphery of one of said cathodes so as to enclose a portion of the periphery thereof while leaving a portion of said periphery unenclosed, and an anode structure including a plate having a pair of apertures therein, said plate being disposed adjacent the unenclosed portions of the peripheries of said cathodes with each of said apertures aligned with one of said cathodes.

12. Electron injection apparatus for a magnetic induction accelerator comprising a pair of helical, electron thermionically-emissive filaments, said filaments being spaced from each other in a direction transverse to their longitudinal axes, said longitudinal axes being substantially parallel, a pair of focusing electrodes cup-shaped in section in planes transverse to said longitudinal axes of said filaments, each of said focusing electrodes being disposed adjacent a separate one of said filaments so as to enclose a major portion of the periphery of such filament while leaving a minor portion of said periphery unenclosed, and an anode structure disposed about said filaments and said focusing electrodes, said anode structure including a plate having a pair of substantially rectangular apertures therein, said plate being disposed adjacent the unenclosed portions of the peripheries of said filaments with each of said apertures being aligned with one of said filaments.

13. Electron injection apparatus for a magnetic induction accelerator comprising two elongated cathodes, means supporting said cathodes in aligned spaced relation with

their long dimensions substantially parallel, two focusing electrodes, each of said focusing electrodes having a U-shaped cross-section, means supporting said electrodes in fixed position with respect to each other and with respect to said cathodes with each of said cathodes lying substantially within the cross-section of a separate one of said electrodes and with the open sides of said cross-sections in aligned parallel relation parallel to the plane defined by the long dimensions of said cathodes, an anode having a U-shaped cross-section, and means to support said anode with said cathodes and focusing electrodes within the cross-section of said anode, said anode having

two elongated apertures aligned with said cathodes respectively.

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