Dec. 22, 1953 R. WIDERÖE 2,663,813

MAGNETIC INDUCTION ACCELERATOR

Filed Nov. 30, 1950 3 Sheets-Sheet 1

Fig. 1.

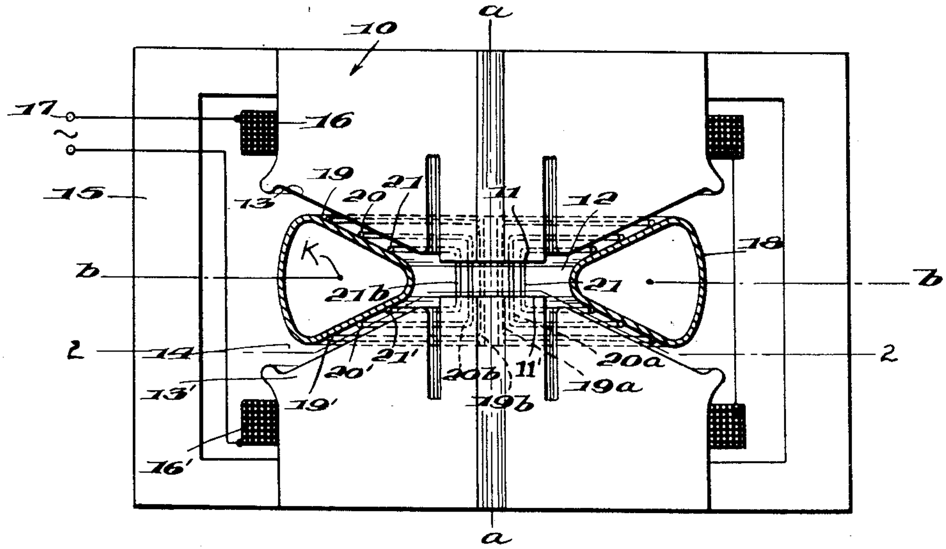
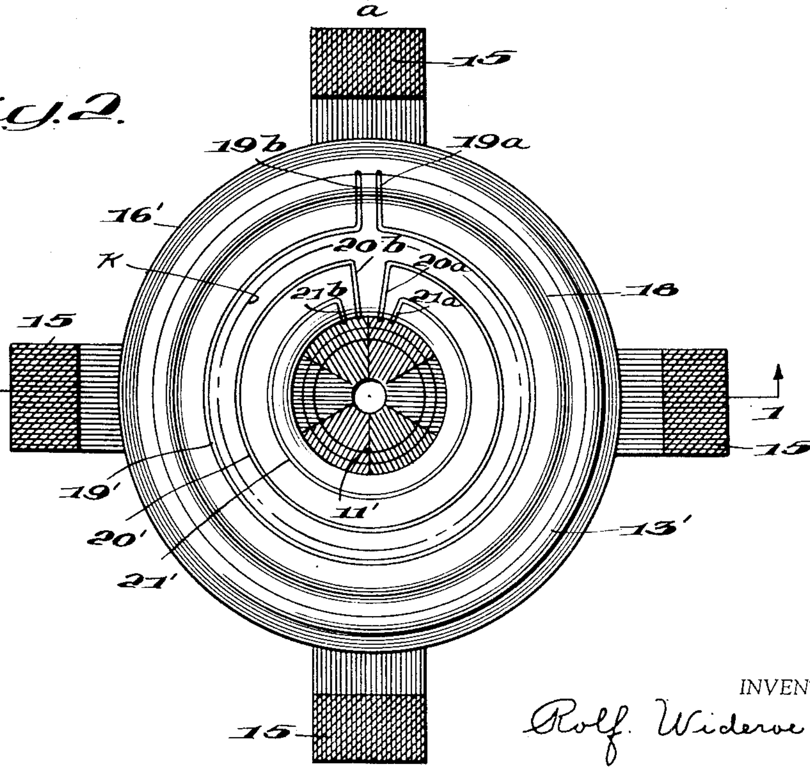


Fig. 2.



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Dec. 22, 1953 R. WIDERÖE 2,663,813

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Filed Nov. 30, 1950 3 Sheets-Sheet 2

Fig. 3.

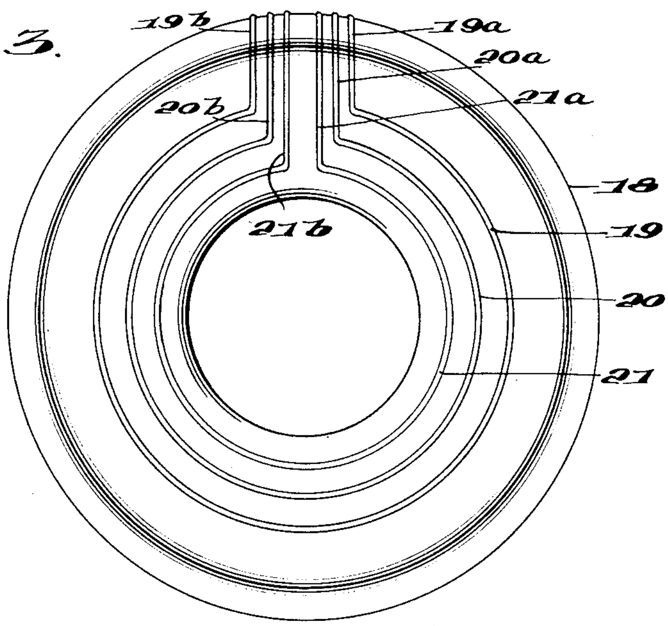

Fig. 4.

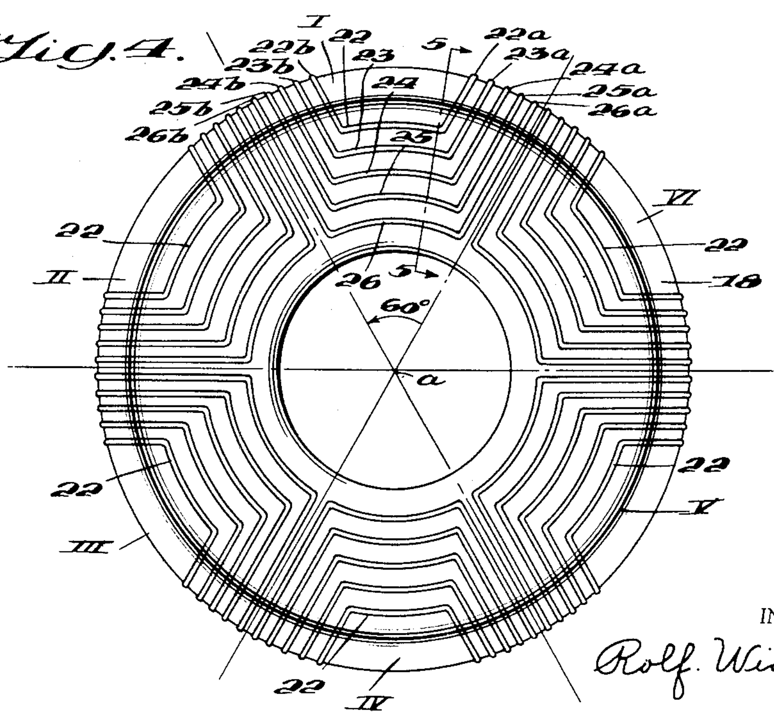

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Fig. 6.

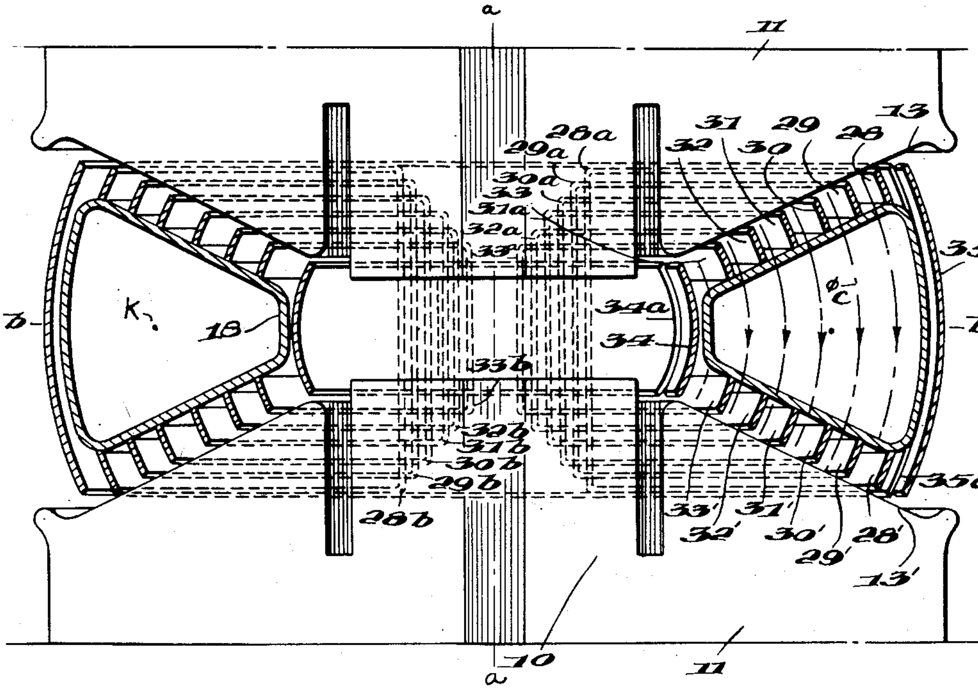


Fig. 5.

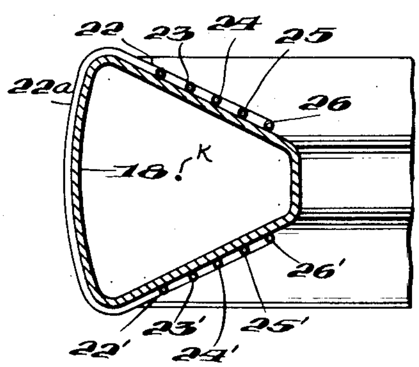
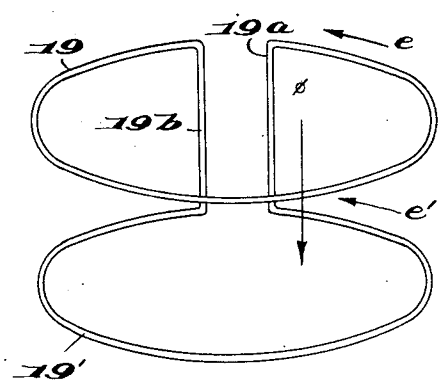


Fig. 7.



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MAGNETIC INDUCTION ACCELERATOR

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Application November 30, 1950, Serial No. 198,325

Claims priority, application Switzerland December 2, 1949

8 Claims. (Cl. 313—62)

1

This invention relates in general to devices for accelerating charged particles such as a stream of electrons to high velocity and hence high potential on an orbital path by the principle of magnetic induction.

Electron accelerators of the magnetic induction type now generally known as a "betatron" or "ray transformer" are comprised of an evacuated toroidal tube into which electrons are introduced from an electron emissive cathode or electron gun, and a magnetic system which produces a magnetic field varying with time having a space distribution such that the injected electrons are accelerated by the field along a circular orbit. The magnetic field divides into components, one component being known as the induction field which produces the electron acceleration and the other as the control or guiding field which produces a centripetal effect upon the electrons to offset the centrifugal forces resulting from the circular motion. The electrons reach an enormously high energy level at which time they can then be diverted from the orbit for producing desired results such as for example to bombard a target and produce X-rays.

In the control field space of the betatron, the radial field components above and below the plane in which it is calculated the orbital path will lie should be of like magnitude and exactly opposite one another. However this ideal relationship is not always possible. For example, if it should happen that a removable part of the magnetic structure above the tube is not aligned exactly with the corresponding structural part below the tube when initially installed or when replaced after having been removed to replace the tube, the mis-alignment between the two parts may cause the orbit to become established in a plane other than the one calculated for it with a possible attendant loss of those electrons in the stream which should happen to impinge against the wall of the tube in the course of their range of normal oscillatory displacement from the orbital path during their acceleration along the path. Other factors may also result in impingement of some electrons in the stream upon the tube wall thus reducing the potential yield of the electron stream.

The general objective of the present invention is to prevent any reduction in yield of the electron stream, and is attained through the use of like circularly curved conductors disposed respectively above and below the equatorial plane of the tube and which are counter-connected, i. e. short-circuited with each other.

2

Various different arrangements for the conductors are possible within the scope of this invention and a few typical embodiments are shown in the accompanying drawings.

Fig. 1 is a view in vertical diametral section on line 1—1 of Fig. 2 through a magnetic induction accelerator in which the short circuited, arcuate conductors, located respectively above and below the equatorial plane of the annular tube are comprised of a plurality of interconnected sets of substantially single turn coils stepped in diameter and arranged in planes parallel with the equatorial plane.

Fig. 2 is a horizontal sectional view on line 2—2 of Fig. 1;

Fig. 3 is a view in top plan of a tube showing a modified arrangement for the leads interconnecting the corresponding conductor coils above and below the equatorial plane in opposition;

Fig. 4 is a view in top plan of a tube illustrating a somewhat different construction for the arcuate conductors in which the latter extend for only a portion of a complete circle;

Fig. 5 is a view in transverse section on line 5—5 of Fig. 4;

Fig. 6 is a view in vertical section of a further modification of the invention wherein the upper and lower short-circuited arcuate conductor sets are comprised of bands having a curvature corresponding to that of the lines of flux of the magnetic control field; and

Fig. 7 is a diagrammatic view showing the arrangement for one set of the arcuate conductors.

With reference now to the drawings, and Figs. 1, 2 in particular, the magnetic induction accelerator is seen to be comprised of a magnetic structure 10 made up from steel laminations of appropriate contour stacked radially on edge to provide a pair of confronting cylindrical induction poles 11—11' separated by air gap 12 and located concentrically along the central vertical axis *a—a*, and a pair of confronting annular control poles 13—13' also concentric with axis *a—a* with an air gap 14 therebetween. Yoke members 15 complete the magnetic circuit for a cyclic, time varied magnetic flux set up in the annular and cylindrical poles. The magnetic flux in the control poles constitutes the guiding or control field previously mentioned, and the flux in the induction poles constitutes the induction field.

The magnetic flux is produced by a winding split into two coil sections 16—16' connected in series for energization from a source, indicated by terminals 17, of alternating current of suitable frequency as for example 100 cycles/sec.

An annular evacuated glass tube 18 rests in the air gap 14 between control poles 13—13'. Tube 18 is also concentric with axis a—a and the particular one illustrated has a substantially trapezoidal cross-section. By means of an electron emissive cathode not shown and which may be located within the tube 18 or in an arm portion arranged tangentially thereto, streams of electrons are injected in timed relation to the time-varied magnetic field produced in the structure 10 by the time-varied current in the energizing coils 16—16' and are continuously accelerated along an orbital path indicated by the circle k. Upon completion of the acceleration phase, the electron stream is then caused to leave the orbit and impinge upon an anode also not shown to yield X-rays, or the stream may be removed from the tube for other purposes as for use in an ionization chamber.

None of the interrelated controls for injecting the electron streams into the tube and removing the streams from the orbit have been illustrated since many different systems of control are well known and moreover are not essential to an understanding of the present invention.

All the structure so far described is conventional. Coming now to the present invention, it will be seen that on the exterior wall surface of the tube 18 I have located a plurality of circularly curved, electrically conductive wires stepped in diameter and arranged in spaced, parallel relation in planes parallel with the horizontal equatorial plane b—b through the tube, and in which plane the orbit k will also lie under perfect design conditions. All of the conductors are concentric with the vertical axis a—a, i. e. the axis of tube 18. The three conductors 19, 20 and 21 located above the equatorial plane b—b are paired with twin counterparts 19', 20' and 21' located at like spatial positions below plane b—b, and each pair 19—19', 20—20' and 21—21' are interconnected by conductor portions 19a—21a and 19b—21b, respectively.

The conductor portions 20a, 21a and 20b, 21b interconnecting arcuate conductor sets 20—20' and 21—21' pass through the central opening within tube 18 while the conductor portions 19a, 19b interconnecting arcuate conductor set 19—19' pass over the outer side of the tube. However all the interconnecting conductors could pass through the tube center, or all could be passed over the outer side of the tube as shown in Fig. 3 wherein the various arcuate conductors have been given the same reference numerals for purpose of comparison.

Each of the arcuate conductors 19—21 and 19'—21' extends for substantially 360° and hence the interconnecting conductors 19a—21a and 19b—21b would actually be much closer together than appears in the drawing where a rather wide spacing has been maintained for purposes of clarity. Assuming equal radial flux components above and below the equatorial plane b—b of tube 18, the flux ϕ traversing the conductor turns 19—19' will produce in each identical voltages e, e', respectively, as indicated in Fig. 7, and these voltages nullify one another since the two turns 19—19' are connected in opposition. The same will be true for conductor turns 20—20' and 21—21'. If however, the radial flux components at corresponding spatial positions at opposite sides of the equatorial plane are not alike in all respects, the voltages e—e' will differ thus setting up a compensating short-circuit current in the interconnected turns 19—19'. The same result will obtain for the other conductor pairs 20—20' and 21—21' which likewise function as short-circuit windings.

Experience has shown that with the aid of short-circuit windings of the type illustrated in Figs. 1 and 2, the electron yield of the betatron and hence also the intensity of X-rays produced by impingment of the accelerated electron stream against an anode, or the ionization effected in an ionization chamber by the accelerated electron stream will be increased substantially.

A somewhat different arrangement for the compensating short-circuited conductors is illustrated in Figs. 4 and 5 wherein each of the arcuate conductors concentric with the vertical axis a—a, extends over only a portion of the complete circumference. Each of the six sets I–VI of paired conductors extends over 60° of arc. In set I, conductors 22—26 disposed at the upper side of tube 18 are paired with and counter-connected to conductors 22'—26' disposed at the under side of tube 18 and located at corresponding radial distances from axis a—a. The connections between the conductor pairs are designated 22a—26a and 22b—26b, and it will be observed that all of these connections pass over the outer side of tube 18. The paired conductors in the other five sets II–VI are arranged in identically the same manner as those of set I, and lie at corresponding radial distances from axis a—a. That is, the conductors 22—22' of each set lie on the same radius, and the conductors 23—23' of each set lie on the same but shorter radius, etc.

Another embodiment of the invention is illustrated in Fig. 6 wherein the paired conductors are constituted by bands of electrically conductive, metallic strip material, preferably copper having a thickness of the order of 1 mm. or less and a width of the order of 5 mm. or more. The six radially spaced bands disposed along the upper surface of tube 18 concentric with axis a—a are numbered 28—33, and those disposed at the lower surface of the tube are numbered 28'—33'. As in the Fig. 1 construction, the paired conductive bands extend over an arc of substantially 360° and are interconnected by conductors 28a—33a and 28b—33b. Each band is curved in the direction of its width to conform to the curvature of the path taken by the control field ϕ_c shown in broken lines between the confronting faces of the control poles 13—13'. Basically these counter-connected bands function in the same manner as the conductor wires of the other previously described embodiments. However, in the case of the band which also prevents, through the short-circuit effect, the occurrence of magnetic fluxes extending perpendicularly to it, the magnetic control lines of force between the bands are brought exactly into the desired direction and will therefore take the desired course within the tube 18 with better approximation than can be obtained when band-shaped conductors are not used.

The construction shown in Fig. 6 also includes two more bands 34, 35 disposed respectively at the inner and outer sides of tube 18 and symmetrically with respect to the equatorial plane b—b. The strip material forming these latter bands is likewise given a curvature conforming to the path of the control flux ϕ_c and the bands extend in the direction of this path from the upper edges of the upper set of bands 28—33 to the lower edges of the lower set of bands 28'—33'. Because of the relatively greater widths, the two bands 34, 35 influence the control field ϕ_c especially effectively through the short circuited currents produced in them. The bands **34**, **35** are broken at one point in their circumference such as by narrow slots **34***a* and **35***a*, respectively.

In all of the embodiments of the invention which have been illustrated, the compensating conductors preferably are disposed on the exterior surface of the wall of tube **18** and may be attached to the same by any suitable adhesive such as glue or cement.

It is to be understood that the various embodiments of this invention which have been described and illustrated are but typical of the many practical structural arrangements possible within the scope of the basic inventive concept disclosed and as hereinafter defined in the appended claims.

I claim:

1. A magnetic induction accelerator for charged particles comprising a toroidal evacuated tube, means including a magnetic structure adjacent said tube and winding means thereon for producing a time-varying magnetic field having induction and control components of such spatial distribution relative to said tube as to normally confine electrons within the tube to a substantially circular orbit around the tube while accelerating them along said orbit, a pair of curved conductors having a like radius of curvature mounted concentric with the axis of said tube and disposed at corresponding positions above and below the equatorial plane of said tube in planes parallel with said equatorial plane, and means interconnecting said conductors in short-circuit relation with each other whereby the voltages induced respectively therein by said magnetic field are opposing.

2. A magnetic induction accelerator as defined in claim 1 wherein said conductors are secured directly upon the exterior surface of said tube.

3. A magnetic induction accelerator as defined in claim 1 and which further includes a curved band of electrically conductive metallic strip material mounted concentric with the axis of said tube and disposed symmetrically with respect to the equatorial plane of said tube, said band being also curved in the direction of its width to coincide with the curvature of the path taken by the control component of said magnetic field.

4. A magnetic induction accelerator as defined in claim 3 wherein said band is located within the central opening of the said toroidal tube.

5. A magnetic induction accelerator as defined in claim 3 wherein said band surrounds the said toroidal tube.

6. A magnetic induction accelerator for charged particles comprising a toroidal evacuated tube, means including a magnetic structure adjacent said tube and winding means thereon for producing a time-varying magnetic field having induction and control components of such spatial distribution relative to said tube as to normally confine electrons within the tube to a substantially circular orbit around the tube while accelerating them along said orbit, a plurality of pairs of curved conductors mounted concentric with the axis of said tube, each pair of conductors having a different radius of curvature and the conductors of each pair being disposed at corresponding positions above and below the equatorial plane of said tube in planes parallel with said equatorial plane, and means interconnecting the conductors of each pair in short-circuit relation with each other whereby the voltages induced respectively therein by said magnetic field are opposing.

7. A magnetic induction accelerator for charged particles comprising a toroidal evacuated tube, means including a magnetic structure adjacent said tube and winding means thereon for producing a time-varying magnetic field having induction and control components of such spatial distribution relative to said tube as to normally confine electrons within the tube to a substantially circular orbit around the tube while accelerating them along said orbit, a pair of curved bands of electrically conductive metallic strip material having a like radius of curvature mounted concentric with the axis of said tube and disposed at corresponding positions above and below the equatorial plane of said tube parallel with said equatorial plane, said bands being also curved in the direction of their width to coincide with the curvature of the path taken by the control component of said magnetic field; and means interconnecting said bands in short-circuit relation with each other whereby the voltages induced respectively therein by said magnetic field are opposing.

8. A magnetic induction accelerator for charged particles comprising a toroidal evacuated tube, means including a magnetic structure adjacent said tube and winding means thereon for producing a time-varying magnetic field having induction and control components of such spatial distribution relative to said tube as to normally confine electrons within the tube to a substantially circular orbit around the tube while accelerating them along said orbit, a plurality of pairs of curved bands of electrically conductive metallic strip material mounted concentric with the axis of said tube, each pair of bands having a different radius of curvature and the conductors of each pair being disposed at corresponding positions above and below the equatorial plane of said tube parallel with said equatorial plane, said bands being also curved in the direction of their width to coincide with the curvature of the path taken by the control component of said magnetic field, and means interconnecting the bands of each pair in short-circuit relation with each other whereby the voltages induced respectively therein by said magnetic field are opposing.

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