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ACCELERATOR TARGET
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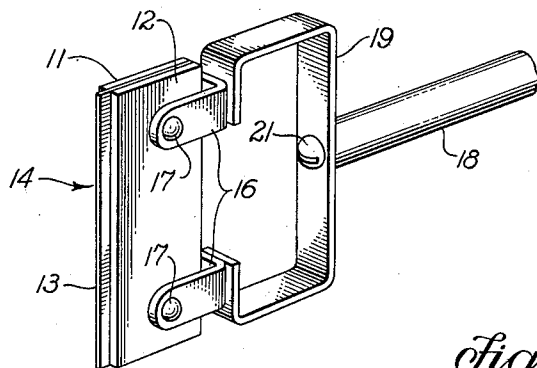


Fig. 1.

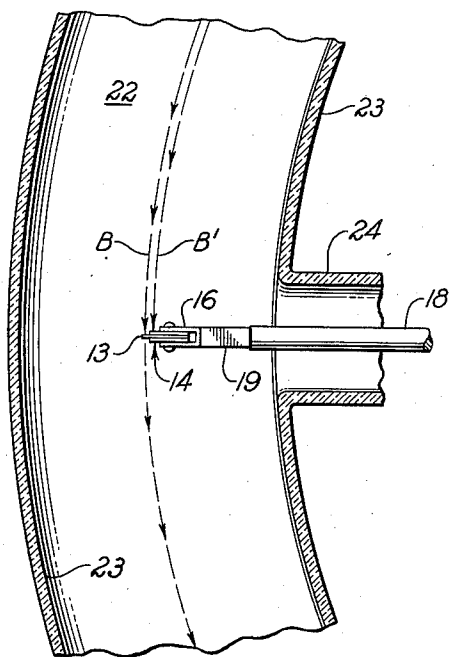


Fig. 2.

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ACCELERATOR TARGET

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7 Claims. (Cl. 250—27)

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The present invention relates to an improvement in targets for particle accelerators and particularly relates to the provision and utilization of a thick target in an orbital particle accelerator.

In the acceleration of subatomic particles, as for example electrons, it has been found advantageous to accelerate the particles about a generally circular orbit with the particle energy being increased incrementally each revolution. Of the apparatus designed for this type of acceleration, synchrotrons and bevatrons have proven eminently successful, and it is with respect to the utilization of high energy electrons accelerated in a synchrotron that the following disclosure of the invention is referenced, although it will be apparent to those skilled in the art that the invention is not so limited.

Commonly the beam of electrons from a synchrotron is directed upon a thin target which thereby produces a narrow beam of X-rays. This X-ray beam is then employed to irradiate selected specimens or materials for the purpose of studying the action of such X-ray beams or of studying and utilizing the specimen or material so radiated. Limitations upon this procedure exist in that only a small portion of the beam energy may be converted into radiation without appreciable distortion of the radiant energy. While high energy electron beams from such as a synchrotron are almost universally employed in the above-noted manner, certain advantages and objects may be realized from a somewhat different utilization, namely production of a wide beam of X-rays by a much greater portion of the electron beam than heretofore employed. Such a result may be realized by the use of a thick target which is struck directly by the electron beam with the resultant production of a large quantity of X-rays in the form of a divergent beam. Difficulty arises, however, in attempts to realize this situation in that the adjacent orbits in a synchrotron are so close together that a thick target cannot be satisfactorily inserted in the beam path without extension into adjacent orbits with a resultant disruption of the electron beam and undesirable target impingement. The present invention is adapted to overcome this difficulty and does so by the accomplishment of the following objects.

It is an object of the present invention to provide an improved method and means of producing high energy X-rays.

It is another object of the present invention to provide an improved method and means for pro-

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ducing very strong X-ray radiation over a large area.

It is another object of the present invention to provide an improved method and means for radically increasing the radius of curvature of an orbit of electrons in a synchrotron.

It is still another object of the present invention to provide an improved target means for a particle accelerator.

It is a further object of the present invention to provide an improved method and means for bombarding a thick target with high energy subatomic particles from an orbital particle accelerator.

Numerous other objects and advantages of the present invention will become apparent to those skilled in the art from the following disclosure taken together with the accompanying drawing in which:

Figure 1 is a mechanical representation of one preferred embodiment of the invention; and

Fig. 2 illustrates the general disposition of the target within a synchrotron chamber.

Before preceeding with a description of the physical characteristics of the invention, it is advantageous to consider the problem and method of solution thereof as contemplated by the present invention.

An electron beam within a synchrotron may be utilized to bombard a target either at the outside or inside of the synchrotron chamber depending upon the mode of synchrotron operation employed. In one type of operation the radio frequency accelerating voltage is removed while the magnetic field is still increasing and this causes the electron beam to spiral inwardly on an orbit of constantly decreasing radius. As a result of the proximity of successive orbital traverses of the electron beam spiralling inwardly under the influence of the increasing magnetic field, it is not feasible to directly interpose a thick target in the path of the beam. Such a target could at best be only bombarded upon one corner with a resultant undesirable X-ray production, and it is thus proposed to materially decrease the energy of the electron beam at a point on its orbit which will therefore decrease the radius of curvature of the electron beam to such an extent that its subsequent separation from its previous orbit will be sufficient for there to be satisfactorily interposed in the beam path a thick target that will be bombarded directly by the beam at a distance from the target edge. This energy loss by the beam may be best accomplished by passing the beam through a ma-

terial within which an appreciable energy loss occurs and which is adaptable to intercept the beam directly. The electron beam is subject to two main effects from such a system, one being electron scattering and the other being energy loss by ionization. Electron scattering is relatively undesirable in that scattered electrons may require more than one revolution to reach the desired position or radius; however, ionization energy loss is substantially constant in magnitude and therefore preferable.

The beam displacement resulting from beam interception by a thin element or fin of a material having a surface density of N mols/cm.² and an atomic number Z may be determined from a consideration of the ionization energy loss ΔW . For electrons having an energy W between one and 300 m. e. v. the ionization energy loss in a solid material is given approximately by the relation:

$$\Delta W = 3.6ZN(\text{m. e. v.})$$

and the R. M. S. scattering angle (a_0) is given by:

$$a_0 = 1.0(Z/W)N^{1/2} \text{ (radians)}$$

As the electron beam travels in a magnetic field H the loss of energy ΔW causes a decrease in the radius r of the instantaneous orbit as determined by the relation:

$$\Delta r = (1-n)^{-1}(r\Delta W/W)$$

wherein n =field index.

The above equations together with the fact that the electron oscillates about the new instantaneous orbit with a frequency $(1-n)^{1/2}$ times the circulation frequency and the assumption that the initial orbit is circular, lead to the following expression for the change in radius Δr at an angle θ following passage through the fin:

$$\Delta r = 3.3(Z/H) \{ 3.6[N/(1-n)] [\cos(1-n)^{1/2}\theta - 1] + [N/(1-n)]^{1/2} \sin(1-n)^{1/2}\theta \} \text{ (cm.)}$$

and a corresponding expression for the axial displacement Δz :

$$\Delta z = \pm 3.3(Z/H) [N/n]^{1/2} \sin^{1/2}\theta \text{ (cm.)}$$

From the expressions for Δr and Δz the fin may be so constructed as to produce the desired electron orbit variation and it will be noted that as the ionization energy loss varies as the atomic number of the fin material and the scattering depends upon the square of the atomic number, a maximum proportion of ionization energy loss is obtained by employing a fin material having a low atomic number.

A preferred embodiment of the invention constructed in accordance with the above principles is shown in Fig. 1 wherein there is illustrated a pair of plates 11 and 12 of relatively large thickness. Interposed between plates 11 and 12 is a very thin plate or fin 13 which extends beyond plates 11 and 12 a distance uniform throughout its length. Plates 11 and 12 and fin 13 intermediate thereto are maintained in intimate relation to form in combination an improved accelerator target 14. Clamping means such as shown at 16 in Fig. 1 may be employed to hold plates 11 and 12 and fin 13 together and such means may consist of a pair of U-shaped members engaging the exterior surfaces of plates 11 and 12 and extending from the opposite edge of the target from the extension of fin 13 and may hold plates 11 and 12 and fin 13 together either by the spring action of the arms of clamps 16 or by bolts or rivets 17 passing through plates 11 and 12, fin 13, and the arms of clamp 16 and

compressing the target assembly 14. Accelerator target 14 and associated clamping means 16 may be mounted upon a stem 18 through the medium of a C-shaped element 19 which is secured to clamps 16 and stem 18. Preferably a rotatable mounting is employed to facilitate alignment of target 14 and this mounting may comprise a bolt 21 threaded into the end of stem 18 and passing through element 19 whereby element 19 and connected clamps 16 and target 14 may be rotated upon bolt 21 to a desired position prior to the tightening of bolt 21 which secures element 19 in fixed relation to stem 18.

The accelerator target assembly is mounted within the accelerating chamber of a particle accelerator as shown in Fig. 2. In the illustrated embodiment, target 14 is shown mounted within a vacuum chamber 22 formed by the walls 23 of a synchrotron, shown only in part in the interest of clarity. Stem 18 extends into chamber 22 from the direction of the center of radius of the synchrotron and may enter chamber 22 via a tube 24 extending therefrom. Target 14 is oriented within chamber 22 with the surface of plates 11 and 12 and fin 13 normal to the direction of travel of the synchrotron electron beam indicated at B, Fig. 2. Also target 14 is aligned parallel to the magnetic field existing within synchrotron chamber 22 and normal to the plane of Fig. 2. Preferably target 14 is adapted for radial motion in order that projecting fin 13 may be positioned to intercept the synchrotron beam at a desired radius. Radial adjustment may be provided in various ways known to those skilled in the art and thus none is illustrated.

In operation, target 14 is inserted in synchrotron chamber 22 and oriented parallel to the magnetic field therethrough by rotating element 19 and then tightening bolt 21 to secure the target in this position. Stem 18 is disposed along a radius of the electron beam orbit and thus target 14 is normal to the beam B. Target 14 is then adjusted radially until fin 13 is disposed at the desired radius. During a cycle of synchrotron operation the radiofrequency accelerating voltage is turned off near the peak magnet field strength when the magnet field is increasing. The electron beam is thus constrained by the increasing magnetic field to spiral inwardly until it strikes fin 13 projecting from target 14. The electron beam loses energy in passing through fin 13; however, the majority of this energy loss results from ionization and thus the emergent beam remains relatively focused. The energy loss by the electron beam causes the beam to be additionally deflected toward the center of its orbit, an amount given by the above expression for Δr and the displaced beam B' impinges directly upon the thick portion of target 14, 360° along the electron orbit from the point of energy loss. The amount that the beam moves radially in one traverse of the chamber 22 is materially increased by the energy loss in fin 13 and thus it is possible to strike a thick target with the beam at a distance from the edge of the beam.

An example of a suitable fin constructed in accordance with this invention and employed in a bevatron with $H=3$ kilogauss and $n=.8$ is a beryllium fin, having an atomic number of 4, and a thickness of 0.002 inch ($N=0.00104$ mol/cm.²). This fin produces a circular beam cross section at the thick target with radial and axial standard deviations of 1.0 mm. and the radial displacement of the center of the beam being 1.5 mm.

While the present invention has been disclosed

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with reference to but a single preferred embodiment it will be apparent to those skilled in the art that numerous modifications and variations are possible within the spirit and scope of the invention and thus the invention is not to be limited except by the terms of the following claims.

What is claimed is:

1. A method of producing an intense divergent X-ray beam comprising electrostatically accelerating an electron beam, constraining said electron beam to traverse an orbital path of substantially constant radius during acceleration thereof by the application to said beam of an increasing magnetic field at right angles to the direction of travel thereof, removing the electrostatic accelerating influence from said beam when said beam has more than a desired energy and continuing the application of said increasing magnetic field to said beam whereby the radius of the orbital traverse of said beam decreases, substantially reducing the energy of said beam by ionization loss at a point in its traverse whereby the focus of said beam is relatively undisturbed and said beam is deflected thereby, and striking a thick target with said focused and deflected beam at a substantially decreased ion beam orbit radius from the electron beam orbit radius directly prior to the electron beam energy loss whereby an intense divergent X-ray beam is produced without interference from previous orbital electron beam traverses.

2. A method of producing an intense divergent X-ray beam from a high energy electron beam traversing orbital paths of constantly decreasing radius in an electron accelerator comprising the steps of intercepting the electron beam with a thin plate of material having a low atomic number whereby said beam experiences an energy loss from ionization in said plate and the beam focus is substantially unimpaired, and bombarding a thick plate with said electron beam of reduced energy at the same angular point on said beam orbit as said beam interception and at a substantially decreased orbital radius therefrom.

3. An orbital electron accelerator target comprising a thick plate and a thin plate, said thin plate extending slightly from said thick plate, and said target being disposed with the extension of said thin plate from said thick plate at a greater orbital radius than said thick plate and in the path of an electron beam spiralling inwardly in said particle accelerator whereby the electron beam first passes through said thin plate with a consequent loss of energy and subsequently impinges upon said thick plate after one complete revolution in said electron accelerator with the production of an intense X-ray beam.

4. An improved target for an orbital particle accelerator having an electron beam traversing orbits of constantly decreasing radii during the latter portion of each cycle of operation and comprising a thick bombardment plate, a thin interceptor plate disposed adjacent said bombardment plate, and means maintaining said bombardment

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and interceptor plates within said electron accelerator with said interceptor plate at a greater electron orbit radius than said bombardment plate whereby said electron beam first passes through said interceptor plate with a loss of energy that decreases the electron orbit radius so that the electron beam bombards the bombardment plate after traversing 360° of orbit from said interceptor plate.

5. An improved target for an orbital particle accelerator having an accelerated beam of particles traversing in a magnetic field an orbit of constantly decreasing radius during each cycle of operation and comprising a thin interceptor plate disposed in the path of said spiralling electron beam whereby said beam passes through said interceptor plate with a loss of energy, and a thick bombardment plate disposed adjacent said interceptor plate at a substantially smaller electron beam orbital radius than said interceptor plate wherein the radial displacement Δr of the electron beam between interception and bombardment is equal to

$$3.3(Z/H) \{ 3.6[N/(1-n)] [\cos(1-n)^{1/2}\theta - 1] \\ \pm [N/(1-n)]^{1/2} \sin(1-n)^{1/2}\theta \}$$

wherein Z is the atomic number and N the surface density of the interceptor plate, H the magnetic field strength, n the field index, and θ the angular beam traverse between the interceptor plate and the bombardment plate.

6. An improved target for an orbital electron accelerator comprising a pair of thick rectangular plates, a thin plate interposed between said thick plates and secured thereto, said thin plate extending slightly beyond said thick plates along one edge thereof, and a stem secured to said plates and adapted to extend within the chamber of an electron accelerator whereby said thin plate is interposed in the path of an electron beam in the accelerator.

7. An improved electron beam control device comprising in combination with a particle accelerator a thin plate of material having a low atomic number disposed adjacent an electron beam to be controlled and having a thickness of the order of one thousandth of an inch, said plate being adapted for interception of a beam of electrons to reduce the energy thereof by ionization whereby the focus of the beam is substantially unimpaired.

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References Cited in the file of this patent UNITED STATES PATENTS

Number	Name	Date
2,545,958	Kerst	Mar. 20, 1951
2,562,637	Park et al.	July 31, 1951
2,599,188	Livingston	June 3, 1952

FOREIGN PATENTS

Number	Country	Date
561,816	Great Britain	June 6, 1944