ELECTRON ACCELERATOR MEANS WITH MEANS FOR REPEATEDLY PASSING THE INITIAL ELECTRONS THROUGH THE ACCELERATOR

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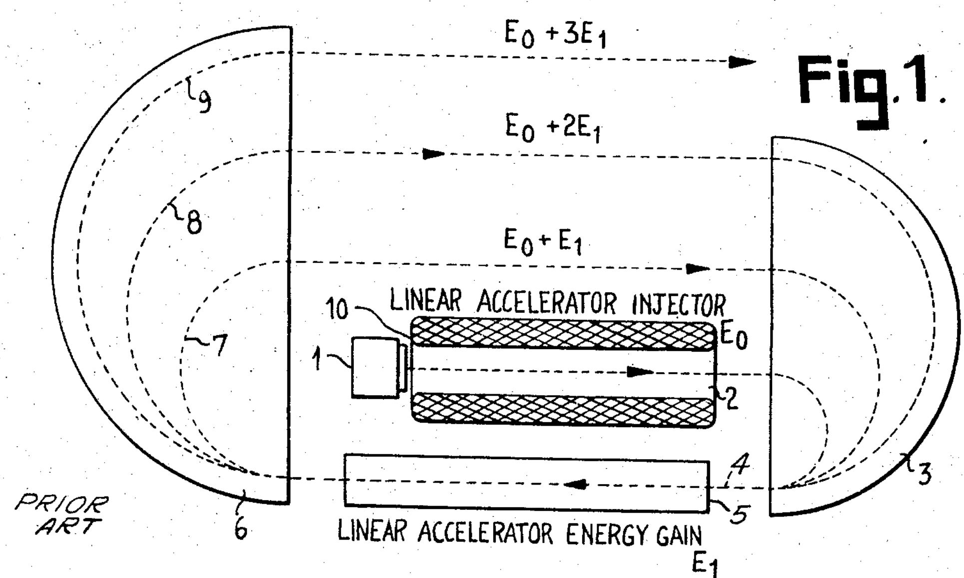

Fig.1.

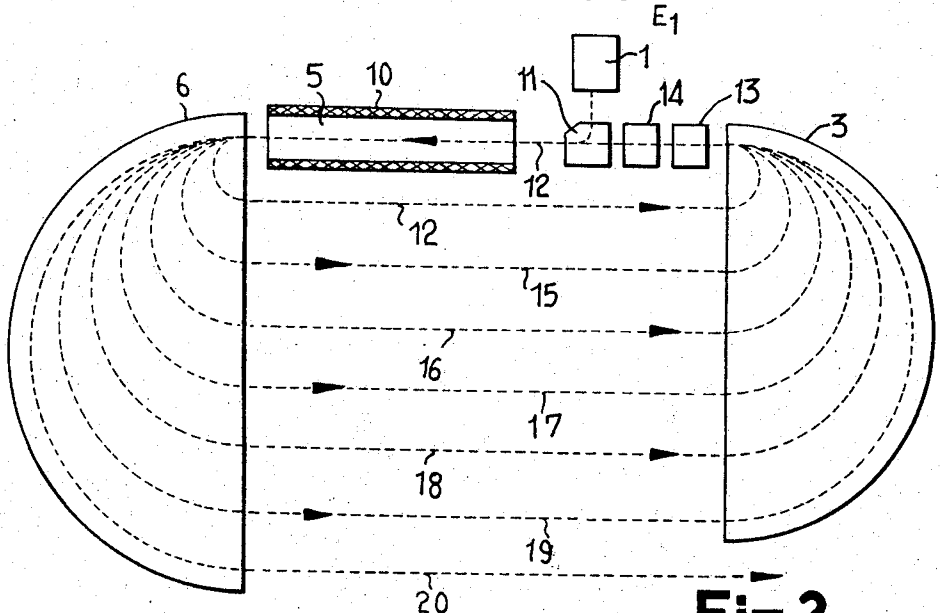

Fig.2.

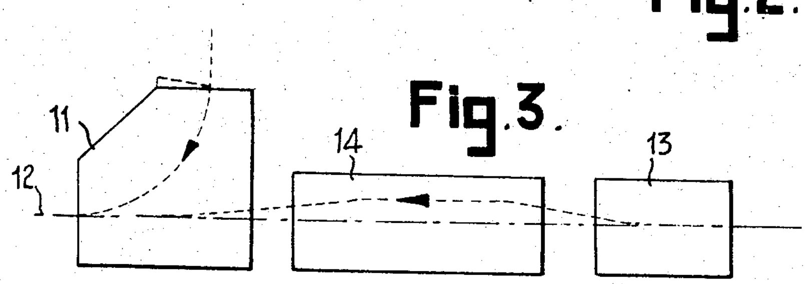

Fig.3.

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Michael Crowley Crowley-Milling, Higher Disley, England, assignor to Associated Electrical Industries Limited, London, England, a British company

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5 Claims. (Cl. 328—233)

ABSTRACT OF THE DISCLOSURE

An electron accelerator comprising a linear accelerator section and deflecting magnets in which fresh electrons are introduced from an electron source laterally into the electron stream at the inlet end of the linear accelerator with means for imparting a forward velocity to the fresh electrons and additional means for imparting a compensating deflection to the main stream of electrons so that all the electrons leave the deflecting magnet in substantially the same direction.

This invention relates to electron accelerators.

The invention has an important application in electron accelerators for generating X-rays for therapeutic purposes but its application is not so limited.

The increasing interest in the use of high-energy electron therapy for the treatment of cancer has created a demand for compact, relatively cheap, accelerators to give electrons with energies up to 30 or 40 mev. at quite low intensity, the mean electron current required being of the order of 1μa. So far electrons from betatrons, or conventional linear accelerators, have been used for this purpose. The betatron has certain disadvantages, and the conventional linear accelerator needed to obtain an electron energy of the order of 40 mev. is unnecessarily large and powerful for this purpose. So the purpose of this invention is to provide a smaller and less expensive electron accelerator for this purpose. It is not of course restricted to this use and such an accelerator would be suitable for any purpose where relatively high energy electrons are required at a relatively low current.

The main object of the invention is to provide an accelerator which is smaller and less expensive than the equipment above referred to but which will give electrons with high energy, i.e. 30 to 40 mev., at a low intensity, i.e. of the order of 1μa.

According to the present invention an electron accelerator comprises a linear accelerating section, deflecting magnets whereby electrons at the outlet are deflected back to the inlet in a re-entrant path and means for introducing fresh electrons from an electron source into the electron stream at the inlet end of the accelerating section.

According to a preferred arrangement the means for introducing electrons into the electron stream passing to the accelerator input comprises a deflecting magnet whereby fresh electrons approaching the stream laterally from an electron source are deflected into it and means are provided whereby the main stream of higher energy electrons is given a compensating deflection prior to entering the field of said deflecting magnet so that all the electrons leave said deflecting magnet in substantially the same direction.

In order that the invention may be more clearly understood reference will now be made to the accompanying drawings, in which:

FIG. 1 shows a prior arrangement for purposes of explanation.

FIG. 2 shows an improved arrangement embodying the invention, and

FIG. 3 explains the action of the inlet magnets shown in FIG. 2.

FIG. 1 is a diagram showing the operation of an accelerator termed a race track microtron.

Electrons from a conventional electron gun **1** are accelerated by means of a linear accelerator such as the conventional travelling wave type **2** to an energy of 1 or 2 mev. The electrons then enter the uniform magnetic field set up between two semi-circular pole-pieces **3**. This magnetic field is sufficient to cause the electrons to be deflected through 180° to emerge along the path **4** into a section of linear accelerator **5**. Here they are accelerated further by a few mev., and at the end of the accelerator they enter the uniform magnetic field between a second set of semi-circular pole-pieces **6**. Here they are again bent through 180° but on a larger radius of curvature, following the path marked **7** back to the first bending magnet where they are again deflected through 180° to follow the path of **4** again through the section of linear accelerator **5** where the electrons gain a further increment of energy so that when they emerge from the linear accelerator and again enter the magnetic field between the pole-pieces **6** they follow a path of greater radius of curvature marked **8** and back again for further acceleration, finally leaving the accelerator on the path marked **9**. Certain conditions are necessary for the successful operation of such an accelerator. One condition is that the magnetic field strength between the two sets of pole-pieces shall be the same so that an electron of given energy will perform orbits of the same radius in each magnet. The second condition is that the magnetic field strength and the various dimensions of the equipment should be chosen so that the length of each successive orbit should be an exact multiple of the wavelength at which the linear accelerator is excited. It is assumed that the electrons from the accelerator section **2** have a sufficiently high energy to have a velocity which may be considered to be sufficiently close to the velocity of light so that there is negligible subsequent change in velocity. If, for example, the accelerator section **2** provides electrons with an energy E_0 for injection into the magnetic field between the pole-pieces **3**, and the accelerator section **5** gives an energy increment of E1 for each transit, then the electron energy in orbit **7** will be E_0+E1, in orbit **8** will be E_0+2E1 and in orbit **9** will be E_0+3E1. One of the main disadvantages of this arrangement is the necessity to have an initial accelerator section **2** since the minimum orbit diameter in the magnetic field of electrons leaving section **2** is set by the centre-to-centre distance between accelerator section **2** and **5** and this is made worse by the necessity to have a focussing coil **10** around accelerator section **2** to prevent loss of electrons during the acceleration process. when they are at low energy. This comparatively large radius for comparatively low energy electrons means that the magnetic field between the two sets of pole-pieces has to be kept low and therefore the magnet systems have to be very large if high energies are required. In addition, the accelerator section **2** has to be supplied with R.F. power sufficient to accelerate the electrons up to relativistic energies, and this reduces the efficiency of the equipment.

A diagrammatic view of an accelerator according to the present invention is shown in FIG. 2. In this case, only a single section of accelerator **5** is used. The electrons from the electron gun **1** enter a deflecting magnet **11** which causes them to be bent through a right-angle along the path **12** into the accelerator section. The first part of this accelerator comprises a bunching section in which the phase velocity is increased rapidly up to the velocity of light so that the electrons from the gun 1 at say 50 kev. are bunched and accelerated to an energy of several mev. The accelerator section 5 is surrounded by a solenoid focussing coil 10 to prevent loss of electrons during this process. The electrons then enter the magnetic field between the semi-circular pole-pieces 6 and are deflected through 180° as previously along the path marked 12 and are then deflected again through 180° by the field between the pole-pieces 3 and then pass through the correcting sections 13, 14. The purpose of these correcting sections is to counteract the effect of the bending magnet 11 on subsequent orbits as explained below. The electrons then re-enter accelerator section 5 but the phase velocity at the beginning of this section, the bunching portion, is different from the electrons and so there is a relative phase shift between the electrons and the wave until the electrons reach the portion of the accelerator where the phase velocity is constant and equal to the velocity of light. Along the path where there is a relative phase shift the electrons will be alternately accelerated and decelerated, and gain little net energy in the bunching section, but if the initial phase is adjusted correctly, the electrons will gain energy throughout the constant phase velocity portion of section 5. The electrons are then bent round by the two magnetic fields along orbit marked 15 and back through the accelerator section to gain a further increment of energy. Subsequent orbits follow the paths shown as 16, 17, 18, 19 and 20. It can be seen that the diameter of the first orbit is now determined by the maximum radial dimension of the accelerator section 5 with its focussing coil 10 and that this orbit is for an electron which has experienced the full energy gain of the accelerator section. It is therefore possible to attain a relatively high energy with comparatively small magnets.

FIG. 3 shows a diagrammatic view of the bending magnet for the gun and the correcting or compensation system which is one of the main features of this invention. In order to deflect the beam from the gun into the accelerator section 5 it is necessary to have a bending magnet 11 to deflect the beam. For convenience of placing the gun, the angle of deflection in the example shown is 90° although the invention is not limited to this and this could be any angle convenient between about 30° and 120°. A 90° magnet as shown is focussing in the plane of the orbit but not in the plane at right-angles. Inclination of the entrance face as shown by the chain dotted line may be preferable, since this enables the focussing in the two planes to be adjusted. The presence of the bending magnet 11 would cause a deflection of the beam at this point on subsequent orbits which would upset the required conditions and lead to loss of current. In this invention the bending magnet 11 is preceded, for subsequent orbits, by the magnetic elements 13 and 14. 13 and 14 represent, pole-pieces, preferably rectangular though not necessarily so, between which a uniform magnetic field is maintained. The magnetic field in magnet 13 is in the same direction as in the bending magnet 11 but the magnetic field in the magnet 14 is in the opposite direction. In the example shown the magnetic field in each of the elements has the same value, element 13 has the same axial length of element 11 and element 14 has twice the axial length of element 11. Under these conditions, it can be seen that a relatively high energy particle, which is deflected with a large radius of curvature in the elements, follows a symmetrical path through the three elements and emerges on the same axial line as it enters. Higher energy particles will follow a similar symmetric path, but with a smaller maximum deflection in element 14. In a practical case, for an electron gun producing a beam of electrons with an energy of 46 kev., the electrons would be bent on a radius of 2″ in element 11 for a magnetic field of approximately 150 gauss. If accelerator section 5 accelerates the electrons to 5 mev., then the maximum displacement in element 14 on the next orbit will be just over ⅛″. Thus it can be seen that the change in path length introduced by the bending

magnet and corrector system for the subsequent orbits is negligible. It is not necessary that the clements 11, 14 and 13 should all have the same magnetic field strength as long as the length and magnetic field strength are chosen appropriately. For example, elements 11, 14 and 13 can all be the same length if element 14 has twice the magnetic field strength of elements 11 and 13.

The special features of this accelerator are thus: (i) the use of low energy injection with a special bending and compensating system; (ii) the use of a single accelerator section of which the first part can be a bunching section; and (iii) the relatively high field that can be used in the bending magnet systems 3 and 6 due to the small radius of the lower energy orbits, thus allowing the high energy to be obtained with small magnets.

The injection and compensating system shown is not limited to use with this type of accelerator but may be applied to any cyclic accelerator where low energy injection is desired and the energy gain per turn is high compared with the injection energy.

What I claim is:

1. An electron accelerator comprising a linear accelerator section, deflecting magnets adapted to deflect electrons leaving the outlet end of the linear accelerator section back to the inlet in re-entrant paths, means for introducing fresh electrons from an electron source laterally into the main electron stream approaching the inlet end of the linear accelerator, deflecting means for imparting a forward velocity component to said fresh electrons, compensating magnet means adapted to impart a compensating deflection to a main stream of electrons prior to said electrons entering the field of said deflecting magnets to cause all the electrons to pass from said deflecting magnets in substantially the same direction.

2. An electron accelerator comprising a linear accelerator section, a first magnet system adapted to deflect the electrons leaving the accelerator section substantially through 180°, a second magnet system adapted subsequently to deflect the electrons from the first magnet system through a further 180° and to direct the electrons towards the inlet end of the linear accelerator section, means for introducing fresh electrons from an electron source laterally into the electron stream at the linear end of the electron accelerator, deflecting means for imparting a forward velocity component to said fresh electrans and compensating magnet means adapted to impart a compensating deflection to the main stream of electrons prior to said electrons entering the field of said deflecting magnets.

3. An electron accelerator comprising a linear accelerator section, deflecting magnets adapted to deflect electrons leaving the outlet end of the linear accelerator section back to the inlet in re-entrant paths, means for introducing fresh electrons from an electron source laterally into the electron stream at the inlet end of the linear accelerator, deflecting means for imparting a forward velocity component to said fresh electrons entering the main stream, means for applying a compensating deflection to the main stream prior to the main stream entering said deflecting means for the fresh electrons, the length of each successive orbit of the electrons being a multiple at the wavelength of which the linear accelerator is excited.

4. An electron accelerator comprising a linear accelerator section, a first magnet system adapted to deflect the electrons leaving the accelerator section substantially through 180°, a second magnet system adapted subsequently to deflect the electrons from the first magnet system through a further 180° and to direct the electrons towards the inlet end of the linear accelerator section, means for introducing fresh electrons from an electron source laterally into the electron stream approaching the inlet end of the linear accelerator, deflecting means for imparting a forward velocity component to said fresh electrons and compensating means for imparting a compensating deflection to the high velocity electrons prior to

said electrons entering the deflecting means for fresh electrons, said compensating means comprising a first stage in which the high velocity electrons are deflected laterally towards the electron source and a second stage in which said high velocity electrons are subsequently deflected laterally in the opposite direction to the deflection of the electrons entering the main stream from the electron source.

5. An electron accelerator comprising a linear accelerator section, deflecting magnets adapted to deflect electrons leaving the outlet end of the linear accelerator section back to the inlet in re-entrant paths, means for introducing fresh electrons from an electron source laterally into the electron stream at the inlet end of the linear accelerator, deflecting means for imparting a forward velocity component to said fresh electrons, means for imparting a compensating deflection to the main stream of

electrons prior to these electrons entering the field of said deflecting means, with the dimensions of the elements of the system, the magnitude of the magnetic field in the deflecting magnets and the energy gain in the linear accelerator section being such that the length of each successive orbit of the electrons is a multiple of the wavelength at which the linear accelerator is excited.

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JAMES W. LAWRENCE, *Primary Examiner.*

V. LAFRANCHI, *Assistant Examiner.*