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APPARATUS FOR ACCELERATING CHARGED PARTICLES, ESPECIALLY ELECTRONS, TO VERY HIGH-VELOCITY

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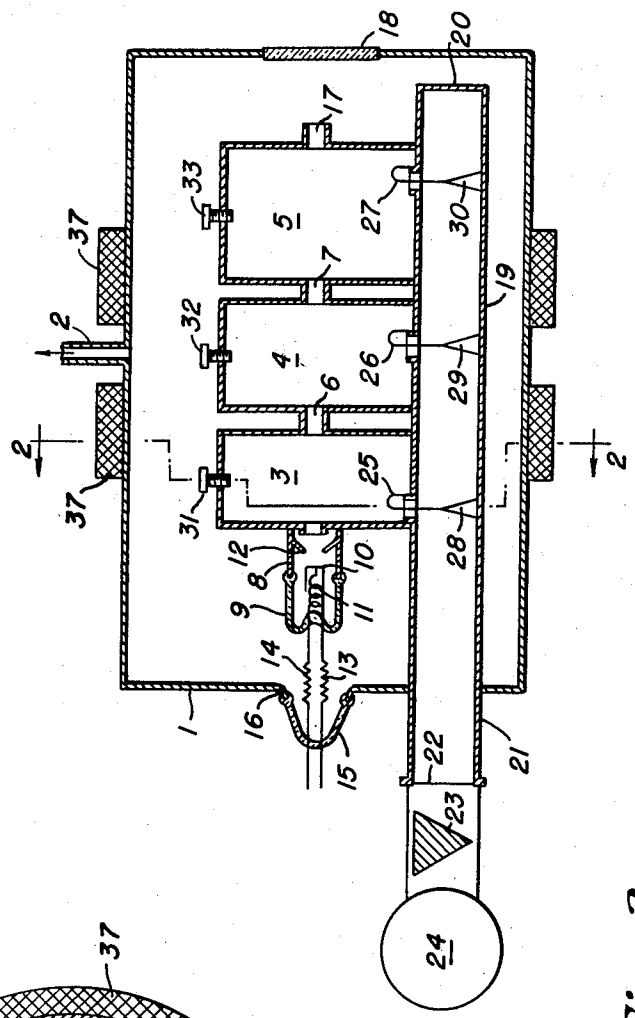


Fig. 1.

Fig. 2.

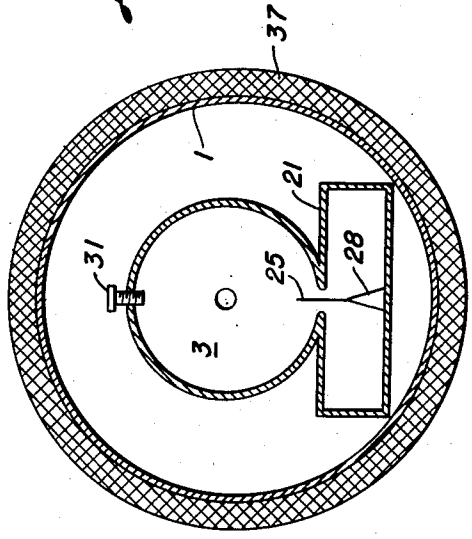
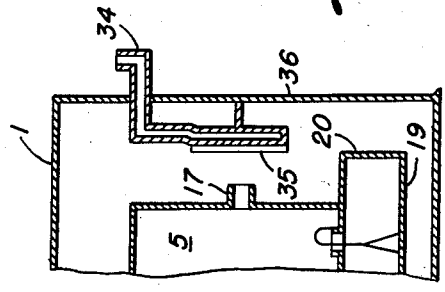


Fig. 3.



INVENTOR
WILLIAM ERNEST WILLSHAW,
BY
ATTORNEY

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APPARATUS FOR ACCELERATING CHARGED PARTICLES, ESPECIALLY ELECTRONS, TO VERY HIGH-VELOCITY

William Ernest Willshaw, Kenton, England, assignor to The General Electric Company, Limited, London, England

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This invention relates to apparatus for accelerating charged particles, such as electrons, or ions, and especially electrons, to very high velocities, and particularly to velocities approaching that of light.

In one known form of apparatus for accelerating charged particles, a stream of the particles is injected into an accelerating system consisting of a succession of cylindrical electrodes having their axes coaxial with the stream; these electrodes are connected alternately to one or other terminal of a source of high frequency potential so that particles passing down the cylinders at the correct velocity pass through a potential step which is always of the same sign when traversing the gaps between adjacent cylinders, so that the particles are progressively accelerated and leave the system having gained energy corresponding to the sum of the potential steps passed through.

With this known arrangement, in order to obtain the maximum acceleration in the shortest length it is desirable that the voltage step at each gap should be as large as possible and a transformer is therefore usually used at the voltage source to provide a high voltage for exciting the accelerating electrodes.

It is desirable for compactness to use for exciting the accelerating electrodes oscillations of high frequency, but the difficulties of connecting together the accelerating electrodes, and also the difficulties of designing suitable electrode-feeding transformers, increases rapidly with frequency, and the maximum frequency useable with this known form of apparatus is limited by these considerations; the apparatus has therefore not been used for accelerating electrons which, in view of their high velocities, would require the use of very high frequencies to obtain apparatus of practicable dimensions.

The object of this invention is to provide an alternative form of apparatus in which charged particles are similarly progressively accelerated and which may be designed for accelerating electrons.

According to the invention apparatus for accelerating charged particles such as electrons or ions comprises means for producing a stream of the charged particles, a plurality of hollow resonators spaced along the path of said particles and each arranged to produce when excited an oscillating electric field capable in the appropriate part of the oscillatory cycle of accelerating particles of the stream, and means for exciting said resonators in such phase relationship that some particles of the stream are accelerated at each of the resonators in succession.

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By a suitable design of resonator and exciting means a very high voltage step may be obtained across the parts of each resonator which are traversed by the particles, the resonator acting as a transformer of very high voltage ratio. As a result of the high voltage steps which may be achieved in this way, and by using the very high frequencies which are practicable with this arrangement for exciting the resonators, a relatively compact system may be achieved, since the number of accelerating resonators required to achieve high particle velocity need not be very large and the distance between each may be small, being inversely proportional to the exciting frequency. The latter may be arranged to be so high that the apparatus may readily be designed for accelerating electrons.

Each of the resonators may be arranged to be excited from a separate source, with suitable phase synchronisation between the sources, but preferably all the resonators are fed from a single high frequency source through a waveguide, allowance being made for the fact that the velocity of wave propagation along the guide is greater than the velocity of the particles in the stream; this may be effected, for example, by making the length of waveguide between successive resonators greater than the distance between the resonators along the stream i. e. by kinking the wave guide; alternatively, with cylindrical resonators whose resonant frequency is independent of their axial length, the axial length of the resonators may be arranged to increase progressively from the lower velocity end and the coupling points to the waveguide varied relative to the axial centres of the resonators so that the axial distances between the centres of successive resonators is less than the distances between the coupling points along the waveguide, and increases progressively.

For securing the highest frequencies of excitation of the resonators, which may be for example 3000 megacycles per second or higher for an electron accelerator, it will in general be preferable to excite the resonators intermittently, so as to produce bursts of very high velocity particles, and for this purpose there may be used one or more magnetrons pulse-operated at a suitably high repetitive rate, for example 500 pulses per second.

In order to stabilize the operating frequency, i. e. to reduce the possibility of mode-jumping,

of a pulse-operated magnetron which feeds a resonator via a waveguide in this way, it will in general be desirable to include attenuation in the waveguide and it may be desirable to make the effective electrical length of the waveguide from the magnetron to the first resonator slightly different from the length which is theoretically the optimum for frequency stability i. e. slightly different from an integral multiple of the wavelength in the guide which corresponds to the frequency at which the magnetron is required to operate. It the magnetron feeds a plurality of resonators via a single waveguide, the coupling points of the resonators along the waveguide are preferably arranged to be spaced apart at distances which are half-wavelengths, or multiples thereof, of the wavelength in the guide corresponding to the required operating frequency.

The magnetron should be one capable of operation over a wide range of impedance variation without mode change, since though final operation is to a matched load impedance formed by the attenuating waveguide and the resonators, the impedance presented to the magnetron in the initial stage of the building up of the fields within the resonators at each pulse may be very reactive and different from the matched impedance.

The means for producing a stream of charged particles may be of any convenient form. Thus for producing a stream of electrons a thermionic cathode may be arranged within the first accelerating resonator so that its emission is controlled by the field set up within the resonator; but preferably the electron stream is produced by an electron gun arrangement, which may be pulse-operated in synchronism with a pulse-operated source exciting the resonators, so that a stream of electrons is injected into the first accelerating resonator at a reasonably high speed, for example with about 50 kilovolts energy; this arrangement has the advantage that the electron stream may be initially focussed to counteract to some extent the spreading experienced by the stream in passing through the resonators; alternatively, or additionally, special focussing means such as magnetic coils round the stream between the resonators or grids in the path of the stream, may be used to prevent undue spreading of the stream.

In any case, the walls of the hollow resonators, or part thereof, may form part of the walls of a vacuum-tight enclosure in which the particles are adapted to move, or the resonators may be totally enclosed within an evacuated outer jacket.

The high velocity charged particles may be arranged to issue from the apparatus through a suitable window or in some cases the particles may be arranged to strike a suitable target contained within the apparatus. Thus X-rays of high energy may be generated by allowing a stream of highly accelerated electrons to strike a target electrode within the apparatus.

The invention will be further described with reference to two forms of it illustrated in the accompanying drawings, in which Figure 1 illustrates schematically apparatus in which a stream of highly accelerated electrons is adapted to emerge from the apparatus through an electron permeable window, Fig. 2 shows a section on the line 2—2 in Fig. 1 looking from the right, and Figure 3 shows how the apparatus of Figuge 1 may be adapted for X-ray generation.

In Figs. 1 and 2 the apparatus comprises a metal outer jacket 1 adapted to be exhausted by the connection of an exhaust tube 2 to an exhaust system.

Within the cylindrical jacket 1 are supported coaxially three centrally apertured cylindrical hollow resonators 3, 4 and 5 which are joined by tubes 6 and 7 coaxial with the resonators. On its side remote from 4, the resonator 3 has fixed to it a tube 8, coaxial with the resonators, which is terminated by a re-entrant glass seal 9 which supports a thermionic cathode 10 and heater 11.

Within the tube 8 is fixed a diaphragm 12 which serves as an accelerating electrode for the electrons emitted from the cathode 10 when the latter is maintained negative to earth in operation; flexible leads 13, 14 for the cathode 10 and heater 11 pass through a further glass seal 15 closing a tubular projection 16 of the jacket 1. The cathode 10 and diaphragm 12, together with the adjacent wall of the resonator 3, constitute an electron gun assembly by means of which a convergent stream of electrons may be injected into the resonator 3 along its axis.

To the end wall of the resonator 5 is fixed coaxially a tube 17 which faces an electron permeable window 18 formed in the jacket 1 and through which electrons from the cathode 10 are adapted to emerge after undergoing successive accelerations in passing through the resonators 3, 4, 5.

For exciting the resonators, a rectangular waveguide 19 is fixed to the lower part of each of the resonators and is sealed through the jacket 1; the end 20 of the waveguide 19 within the jacket is closed and the end 21 emerging from the jacket is connected through a vacuum tight jacket and seal 22 with an attenuating section 23 of waveguide arranged to be fed from a magnetron 24.

The waveguide 19 is coupled to the resonators 3, 4, 5 by means of coupling loops 25, 26, 27 mounted on conical supports 28, 29, 30 extending centrally across the waveguide, the coupling loops extending through cooperating apertures in the abutting wall of the waveguide and resonators. The loops 25, 26, 27 are spaced effectively at half-wavelengths apart along the waveguide 19, the distance between the loop 27 and the closed end 20 being effectively a quarter-length. The resonators 3, 4, 5 are of progressively increasing axial length and are arranged so that the position of the coupling loops relative to the axial centre of the resonators varies so as to ensure the correct relative phase of excitation of the resonators.

Around the jacket 1 in the region of the resonators are fitted magnetic focussing coils 37 for producing a magnetic field along the axis of the resonators which prevents the electron stream from spreading unduly.

The exact dimensions of the system required, including the axial length of the resonators, the position and spacing of the coupling loops, and the amount of attenuation required in the attenuating waveguide section 23 will depend upon the nature of the acceleration required, on the characteristics of the magnetron and waveguide used and in the operating frequency, and must be finally determined by trial for each case.

For guidance it may be said that for operation with a magnetron tuned to a wavelength of 10 cms., the resonators should be chosen to resonate at a frengency about 10 megacycles per second

higher than that of the magnetron; the internal diameter of the cylindrical resonators may be about 3 inches and the exact resonant frequency required secured by adjustment of tuning plugs **31**, **32**, **33**.

If the rectangular waveguide **19** has sides 1 inch by 4 inches, the effective wavelength along the guide will be 12.1 cm., so that the distance between the coupling points **25—26** and **26—27** along the guide should each be 6.05 cms. and the distance between the coupling-point **27** and the closed end **20** should be 3.025 cms.

If the electrons are injected into the resonator **3** by the electron gun with an energy of about 46 kilovolts, the axial lengths of the resonators **3**, **4**, **5** may be about 3.5 cms., **4** cms. and 5.2 cms. respectively with the lengths of the tubes **6** and **7** being 0.7 cm. and 0.6 cm. respectively.

The points where the coupling loops **25**, **26**, **27** pass through the aperture in the abutting walls of the resonators and waveguide **19** may then be distant about 0.9 cm., 2.8 cms., and 4.2 cms. respectively from the end face of the resonator nearer the electron gun, but it will be appreciated that these distances will depend on many factors, such as the size and shape of the coupling loops and the energy fed into the resonators so that the optimum distances must be determined by trial for each particular case; the figures quoted are for a magnetron pulse-operated with 2 micro-second pulses at a repetition rate of 500 per second, the power in each pulse reaching the resonators being about 1.4 megawatts. After three accelerations at the resonators the electrons may reach an energy of about 2 to 3 x 10^6 electron volts.

The apparatus may, after final assembly and adjustment, be evacuated and sealed off via the tube **2** or it may be arranged to be continually exhausted through the tube **2** in operation.

Figure 3 shows the modification of Figure 1 required to adapt the apparatus of Figure 1 for X-ray generation, the electron permeable window **18** not being present and the end wall **36** of the envelope supporting instead, via water-cooling means **34**, a target electrode **35** arranged to be struck by the highly accelerated electrons emerging from the tube **17**, the X-rays thereby generated passing out through the end wall **36**.

In either embodiment of the invention the resonators **3**, **4**, **5** may also be arranged to be water-cooled if required.

I claim:

1. Apparatus for accelerating electrons to energy exceeding 1,000,000 electron volts, comprising an electron gun for producing a stream of electrons along an axis, a plurality of hollow resonators, each resonant at the same frequency, spaced along said axis and each disposed to produce when excited a high frequency alternating electric field having a component along said axis, a generator of high frequency energy for exciting said resonators, and a wave-guide for conveying said high frequency energy to said resonators, the distance apart along the wave-guide of the coupling points to said resonators being greater than the distance between the corresponding resonators along said axis for compensating for the excess of the phase velocity of the exciting energy along the wave-guide over the velocity of the electrons along said axis to produce progressive acceleration of the electrons.

2. Apparatus for accelerating electrons to energy exceeding 1,000,000 electron volts, comprising an electron gun for producing a stream of electrons along an axis, a plurality of hollow resonators, each resonant at the same frequency, spaced along said axis and each disposed to produce when excited a high frequency alternating electric field having a component along said axis, a generator of high frequency energy for exciting said resonators, and a wave-guide for conveying the exciting energy from said generator to said resonators, the couplings from said wave-guide to said resonators being spaced apart along the wave-guide at a distance electrically equivalent to one half-wave length of the oscillations in the wave-guide, and the distance between the centres of said resonators along said axis being less than this equivalent half-wave length and increasing progressively to maintain synchronism of excitation of the resonators with the electron stream for progressive acceleration of the electrons.

3. Apparatus for accelerating electrons to energy exceeding 1,000,000 electron volts, comprising an electron gun for producing a stream of electrons along an axis, a plurality of cylindrical hollow resonators coaxial with and spaced along said axis and each resonant at the same frequency, the axial length of successive resonators increasing progressively away from the electron gun and the resonators being apertured axially for the passage of the electron stream, a generator of high frequency energy for exciting said resonators and a wave-guide for conveying the exciting energy from said generator to said resonators, the couplings from said wave-guide to said resonators being spaced apart along the wave-guide at a distance electrically equivalent to one half-wave length of the oscillations in the wave-guide, and the distance between the centres of said resonators along said axis being less than the equivalent half-wave length and increasing progressively to maintain synchronism of excitation of the resonators with the electron stream for progressive acceleration of the electrons.

4. Apparatus according to claim 3 wherein the electron gun and hollow resonators are contained within an evacuated enclosure which is provided with an electron-permeable window for the emergence of the highly accelerated electrons.

5. Apparatus according to claim 3 comprising an electron intercepting electrode lying across the axis of the electron stream on the side of the resonators away from the electron gun so as to be struck by the highly accelerated electrons for the generation of X-rays.

6. Apparatus according to claim 3 wherein the said generator of high frequency energy comprises a resonant cavity magnetron.

7. Apparatus for accelerating charged particles to very high velocity comprising means for producing a stream of the particles along an axis, a plurality of hollow resonators, each resonant at the same frequency, spaced along said axis and each disposed to produce when excited a high frequency alternating electric field having a component along said axis, a generator of high frequency energy for exciting said resonators, and a wave-guide for conveying said high frequency energy to said resonators, the distance apart along the wave-guide of the coupling points to said resonators being greater than the distance between the corresponding resonators along said axis for compensating for the excess of the phase velocity of the exciting

energy along the wave-guide over the velocity of the particles along said axis to produce progressive acceleration of the particles.

WILLIAM ERNEST WILLSHAW.

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