Oct. 22, 1957 C. W. MILLER ET AL 2,810,855

LINEAR ACCELERATORS FOR CHARGED PARTICLES

Filed April 9, 1954 2 Sheets-Sheet 1

Fig. 1.

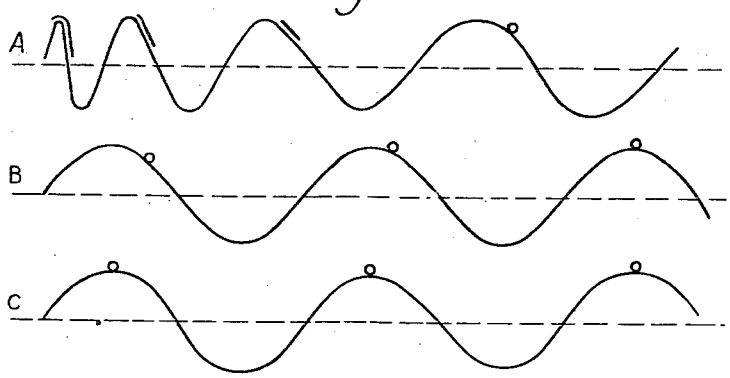


Fig. 2.

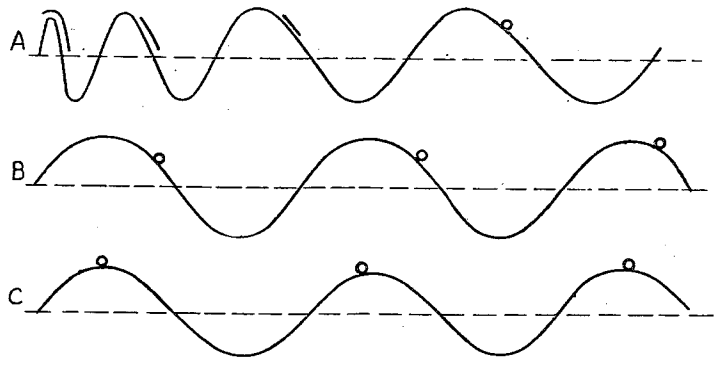
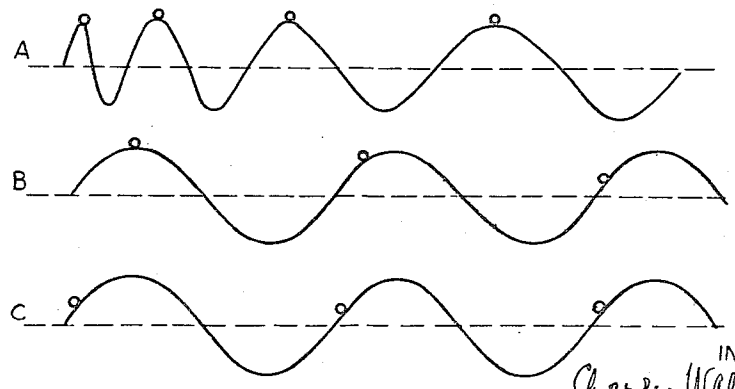


Fig. 3.



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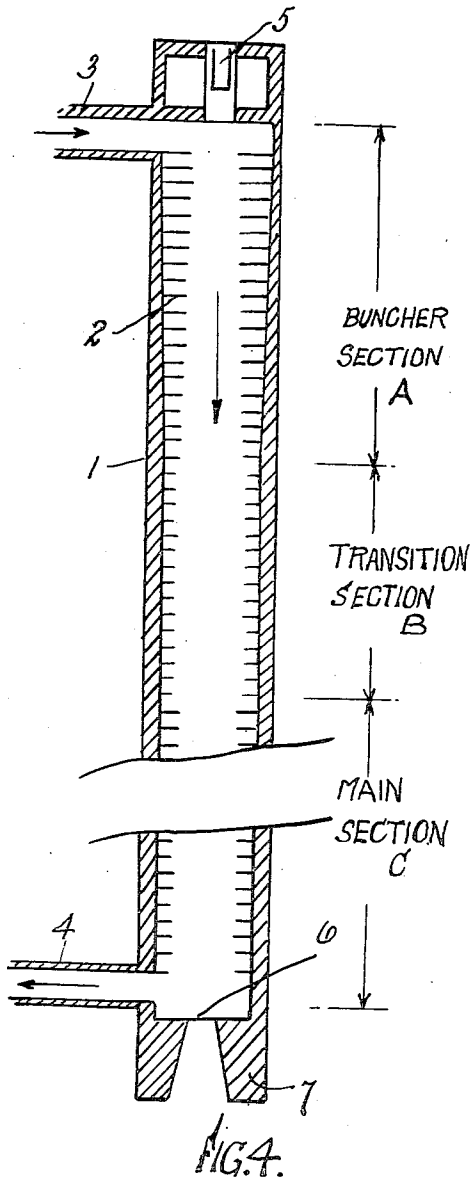


FIG. 4.

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LINEAR ACCELERATORS FOR CHARGED PARTICLES

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Claims priority, application Great Britain April 14, 1953

3 Claims. (Cl. 315—3.6)

This invention relates to linear accelerators for charged particles and has an important application in linear accelerators of the travelling wave type.

A normal linear accelerator of the travelling wave type consists of an initial section known as the buncher section followed by a main section.

In the buncher section the electrons are collected into relatively compact bunches which move along with the travelling wave at some predetermined phase position. At the same time the electron bunches are accelerated and at the end of this section the velocity will normally approach that of light whilst the electron energy will be of the order of 1 MeV.

During the rest of the travel down the main section of the accelerator the bunches of electrons remain relatively compact and may stay at the same phase position with respect to the wave or may be allowed to drift slowly to the peak of the wave in order to obtain maximum energy.

Important factors affecting the operation of the machine are the efficiency of the bunching and the phase position at which the bunches ride on the waves, the maximum energy output being obtained with the bunch riding on the crest of the wave.

Linear accelerators have therefore, in some cases, been so designed that bunching has occurred low down in the wave giving efficient bunching and the bunches then allowed to ride to the crests so as to give maximum energy. Alternatively, if constant energy is aimed at, bunching is effected low down and the bunches then maintained at some point in advance of the crest, in which case they will tend to adjust their phase position automatically if the input power varies so as to tend to minimise variations in output energy for variations in input power.

The main object of the present invention is to provide a linear accelerator in which the output energy is variable at will.

According to the present invention a linear accelerator for charged particles includes a waveguide along which the electrons are accelerated by a travelling electromagnetic wave, which waveguide comprises a buncher section followed by a transition section followed by a main section whereof the buncher section is so designed that the bunching occurs with a phase advance from the wave crests which is dependent upon the power input, and the transition section is designed to retard the electron bunches to the trailing slopes of the waves by substantially constant phase angles and the main section is designed to give negligible phase change of the electron bunches, whereby the distances of the electron bunches form the wave troughs and hence the energy output of the apparatus is dependent upon and controllable by the power input.

It will be appreciated that whereas the phase advance of the bunches leaving the buncher stage is a function of input power, a substantially constant phase retardation will be produced in the transition stage irrespective of the power input.

Preferably, the apparatus is so designed that at full power input the bunches leave the transition section at the crests of the waves and for reduced power input, the bunches will leave the transition section lower down the trailing slope of the wave, thus giving a reduced energy output.

It will be appreciated that the phase position of the bunches will remain substantially constant along the main section and hence the final phase position will be substantially the same as that at the output end of the transition section.

Such an arrangement renders the output energy dependent upon the input power and hence the output energy may readily be controlled by varying the input power.

Reference will now be made to the accompanying drawings, in which:

Fig. 1 illustrates graphically the operation of a known form of linear accelerator, whilst

Figs. 2 and 3 are corresponding graphs illustrating the operation of apparatus embodying the present invention; and

Fig. 4 shows diagramatically one arrangement of apparatus embodying the invention.

Referring first to Fig. 1, the graph A illustrates the conditions obtained in a bunching section, whilst graph B shows the conditions at an intermediate section or the early part of the main section, whilst graph C illustrates the conditions along the major part of the main section.

In the apparatus illustrated, the electrons are collected low down on the wave in the buncher giving efficient collection, as shown by the lines over the waveform, it being appreciated that whilst only a few cycles have been illustrated, it is intended that these should be explanatory of the conditions obtained in this section.

After bunching is completed, the electrons are allowed to ride up to the peak as shown by the graph B and they are then maintained at the peak along the main section of the accelerator as shown by graph C. Such an arrangement is intended to satisfy certain requirements such as maximum collection of electrons and maximum energy.

In an alternative known arrangement the electrons are bunched as shown by graph A, but after bunching, instead of being allowed to ride to the crest, they are maintained in advance of the peak (say at 45° in advance) throughout the remainder of the linear accelerator.

As above explained this gives a machine whose energy is relatively independent of radio frequency power input since in any variation of power input the bunching tends to re-position itself on the wave and this compensates for the change of power input.

As above explained, in arrangements embodying the present invention the electrons are bunched on the forward slope of the wave and then retarded by a substantially constant amount in a transition section after which they remain, during their passage along the main section of the waveguide, in the final position they have reached in the transition section.

Fig. 2 illustrates such an arrangement when the linear accelerator is supplied with the full radio frequency power, and in the buncher (as illustrated by graph A) the electrons are bunched at about 30°, i. e. 60° in advance of the peak, and in the transition section which is the section of guide whose wave velocity is greater than the electron velocity in this part of the path, the electrons are permitted to ride up to the peak, and throughout the remainder of the guide, which may have a uniform phase velocity, the electrons (which by this time have sufficient energy to be regarded as traveling at light velocity) will

be maintained at the peak of the wave and so give maximum energy.

If the power input is reduced, bunching will take place higher up the wave, with the result that after the bunches have retarded at the transition section they will be at a position on the trailing slope of the wave, with a result that the output energy will be reduced.

Fig. 3 shows an extreme case in which the R. F. input power is reduced to one quarter of full power, that is, the R. F. field is reduced to one half amplitude.

It will be appreciated that in the transition section in which the bunch is retarded it will be moved down the trailing slope of the wave to a position say 60° behind the peak and it will remain at this position throughout the remainder of the accelerator. The field at a point 60° behind the peak is obviously half the peak field, and since the peak field is already half of that obtained in the full power condition, the acceleration given to the electrons in the main section of guide is only one quarter of that obtained in the full power case. Thus, if we neglect the energy received in the buncher and transition section as being small compared with the total, it will be seen that in this design a change of output energy over a 4:1 range can be obtained. Clearly, whilst Figs. 2 and 3 show extreme conditions, intermediate conditions can be obtained in which the bunches down the main section of wave travel at positions intermediate these shown in graph C of Figs. 2 and 3.

Referring now to Fig. 4 which shows one form of apparatus embodying the invention, the apparatus shown consists of a waveguide wall **1** having apertured diaphragms or plates **2** spaced apart along the interior of the waveguide. A waveguide inlet **3** is provided at the inlet end and a waveguide outlet **4** at the output end.

At the top end of the waveguide as shown in the drawing there are provided electron gun means **5** and electrons projected into the waveguide from the gun means **5** will be accelerated along the waveguide by a travelling electromagnetic wave until they strike a target or window **6** at the opposite end.

This may allow the electrons to pass out through an opening **7** or it may intercept the electrons sufficiently to cause the generation of X-rays.

The invention consists in providing the waveguide with a buncher section A, a transition section B, and a main section C in that order.

In the drawing the variations in size both of the waveguide diameter and of the iris diameters have been greatly exaggerated for explanatory purposes, it being appreciated that in actual operative apparatus the variations in dimensions are relatively small.

In accordance with the invention, the buncher section A is designed with the iris diameters progressively increasing and the waveguide diameters progressively reducing in such a manner that the electrons will bunch on the forward slopes of the travelling electromagnetic wave and with a phase advance from the peak which depends upon the input power.

In the transition section B, the iris aperture diameters and waveguide diameters both remain substantially constant, the iris aperture diameters being slightly larger than in the main section, the design being such as to retard the electrons by a substantially constant amount.

Finally, in the main section C the iris aperture diameters and waveguide diameters both remain substantially constant, but the iris aperture diameters are reduced in comparison with those in the transition section B.

For further information regarding the design of such waveguides, reference may be made to the Proceedings of the Physical Society (Great Britain, 1948, volume 61, at page 246).

What we claim is:

1. In a linear accelerator for charged particles, a waveguide structure, means for injecting charged particles into said waveguide structure, means for propagating an electro-magnetic wave along said waveguide structure so as to impart energy to said charged particles, said waveguide structure comprising three consecutive sections, namely; an initial bunching section for bunching and accelerating the charged particles to a velocity approaching the speed of light and having means for causing the phase of the bunch relative to the electro-magnetic wave to be dependent on the input power of said wave, a transition section having means for retarding the phase of the bunched particles by a constant amount, and a main section having means for imparting energy to the bunch at substantially constant velocity by an amount dependent on the phase of the bunch, whereby the output power of the charged particles is dependent on the input power of the electro-magnetic wave.

2. In a linear accelerator for electrons, a waveguide structure, means for injecting electrons into said waveguide structure, means for propagating an electro-magnetic wave along said waveguide structure so as to impart energy to said electrons, said waveguide structure comprising three consecutive sections, namely; an initial bunching section for bunching and accelerating the electrons to a velocity approaching the speed of light and having means for causing the phase of the bunch relative to the electro-magnetic wave to be dependent on the input power of said wave, a transition section having means for retarding the phase of the bunched electrons by a constant amount, and a main section having means for imparting energy to the bunch at substantially constant velocity by an amount dependent on the phase of the bunch, whereby the output power of the electrons is dependent on the input power of the electro-magnetic wave.

3. In a linear accelerator for electrons, a waveguide structure, means for injecting electrons into said waveguide structure, means for propagating electro-magnetic waves along said waveguide structure so as to impart energy to said electrons, said waveguide structure comprising three consecutive sections, namely; an initial bunching section for bunching the electrons and having means for causing a phase of the bunch relative to the electro-magnetic wave to be dependent on the input power of said wave, said means comprising a circular waveguide of progressively decreasing diameter and containing spaced irises having apertures of progressively increasing diameter, a transition section having means for retarding the phase of the bunched electrons by a constant amount, said means comprising a circular waveguide of constant diameter and containing spaced irises having apertures of constant diameter, and a main section having means for imparting energy to the bunch by an amount dependent on the phase of the bunch, said means comprising a circular waveguide of constant diameter containing spaced irises having apertures reduced in diameter in comparison with the irises in said transition section whereby the output power of the electrons is dependent on the input power of the electro-magnetic wave.

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