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APPARATUS FOR INJECTING ELECTRONS INTO A TRAVELING WAVE ACCELERATING WAVEGUIDE STRUCTURE

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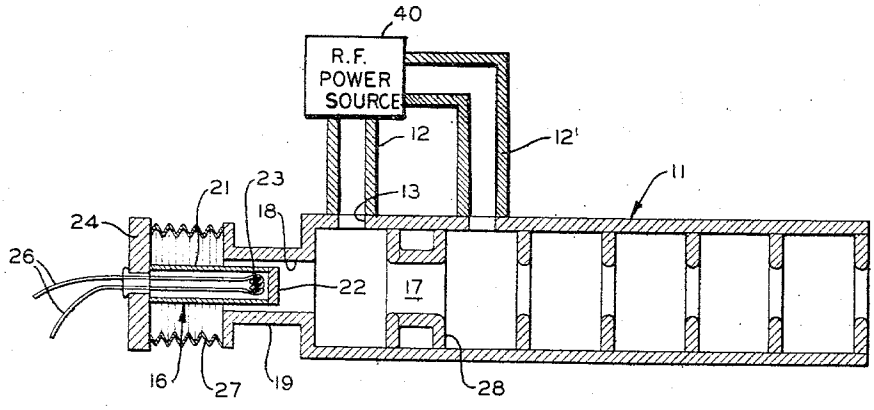


FIG. 1.

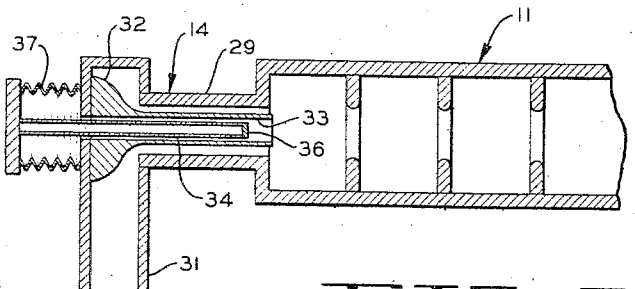


FIG. 2.

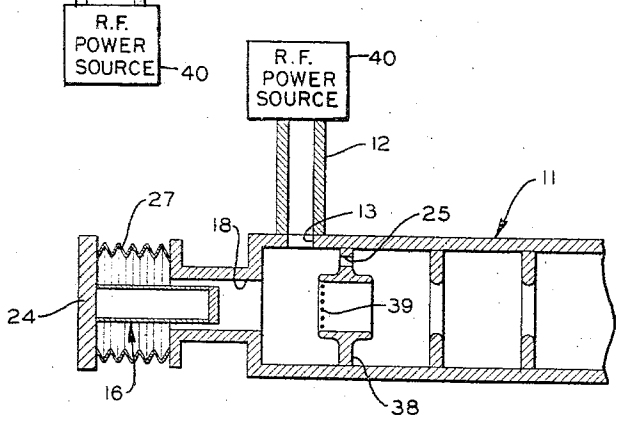


FIG. 3.

INVENTOR.
NEIL J. NORRIS

BY Schapp & Hatch

ATTORNEYS

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APPARATUS FOR INJECTING ELECTRONS INTO A TRAVELING WAVE ACCELERATING WAVEGUIDE STRUCTURE

Neil J. Norris, Walnut Creek, Calif., assignor, by mesne assignments, to High Voltage Engineering Corporation, Burlington, Mass., a corporation of Massachusetts

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10 Claims. (Cl. 315—3.5)

This invention relates to the injection of electrons into the accelerating waveguide of an electron linear accelerator, and is particularly directed to improved method and apparatus for effecting such electron injection where the injection velocity of the electrons is produced by the action of the accelerating field of the waveguide.

Heretofore, the injection of electrons into linear accelerators has generally been accomplished by accelerating the electrons as with a voltage applied to injection electrode structure, prior to entry of the electrons into the accelerating waveguide. Thus the velocity of the electrons as they first enter the field established within the waveguide is greater than their thermal velocity at emission from the cathode of the electron gun or other source of electrons to be accelerated.

I have found that the added injection electrode structure, for accelerating electrons to velocities greater than their thermal velocities prior to introduction to the accelerating field of the waveguide, may readily be eliminated. More specifically, I have found that the axial field produced within an accelerating waveguide may be made very large at the injection end. The large component of field within the accelerating waveguide is employed, in accordance with the present invention, to accelerate the electrons to injection velocities suitably greater than their thermal velocity upon emission from a cathode positioned at the end of the waveguide. The operation is such that, thereafter, the electrons are further accelerated by the remaining portions of the field within the waveguide in the usual manner. The present invention thus facilitates a material simplification of the accelerating system with a consequent saving in construction and maintenance costs by eliminating the electronic circuitry heretofore associated with the establishment of injection voltages.

It is therefore an object of the present invention to provide a method and apparatus for deriving electron injection voltage from the accelerating field established within an accelerating waveguide without requiring auxiliary injection voltage circuitry.

Another object of the invention is the provision of an electron linear accelerator wherein the electron source is positioned within the traveling wave accelerating structure.

Yet another object of the invention is to provide for the emission of electrons at an end of an accelerating waveguide and further to provide for the acceleration of these electrons by the traveling wave field established in the waveguide in such a manner that the electrons approach the velocity of light in the injection end region of the guide with a phase relationship to the field that allows them to gain energy during the rest of the time they are in the guide.

Further objects and advantages of my invention will be apparent as the specification progresses, and the new and useful features of my apparatus for injecting electrons into a traveling wave accelerating waveguide structure will be fully defined in the claims attached hereto.

The preferred forms of my invention are illustrated in the accompanying drawing forming part of this application, in which:

FIGURE 1 is a schematic longitudinal sectional view

at the axis of disc loaded accelerating waveguide structure as modified to accomplish electron injection in accordance with the present invention;

FIGURE 2 is a cross sectional view of the injection end portion of an accelerating waveguide structure incorporating a modified arrangement for electron injection; and

FIGURE 3 is a view similar to FIGURE 2 depicting another modified arrangement for electron injection.

While I have shown only the preferred forms of my invention, it should be understood that various changes or modifications may be made within the scope of the claims attached hereto without departing from the spirit of the invention.

Considering now the invention in some detail and referring to the drawing, there is shown a generally conventional disc loaded accelerating waveguide **11** energized with radio frequency energy from R.F. power source **40** to establish an electromagnetic traveling wave having an axial component of electric field conducive to the acceleration of electrons through the waveguide. The radio frequency driving energy may be variously introduced to the waveguide, as for example by means of an input waveguide **12** communicating radially with the interior of waveguide **11** through a coupling iris aperture **13** adjacent one end as depicted in FIGURES 1 and 3. Alternatively, the radio frequency energy might be, for example, introduced coaxially to the end of waveguide **11** by means of a door knob coupler **14** as depicted in FIGURE 2.

Conventionally, irrespective of the particular means employed to establish the accelerating field within the waveguide **11**, the electrons are injected coaxially to the waveguide through a beam inlet aperture in its end. In order that the electrons will be properly trapped by the traveling wave for acceleration through the waveguide, the electrons are usually accelerated to velocities substantially greater than their thermal velocity prior to introduction to the inlet aperture. More specifically, auxiliary accelerating electrode structures energized with voltages in the range of, for example, 50 to 200 kv. have been provided between the electron emissive cathode and beam inlet aperture to facilitate acceleration of the electrons prior to introduction to the traveling wave accelerating field within the waveguide.

I have found that the auxiliary electrode structure and associated circuitry may be eliminated to provide a simplified and more compact accelerator. In accordance with my invention, the traveling wave accelerating field within waveguide **11** is utilized to accelerate the electrons from their thermal emission velocity to a suitable injection velocity, as well as to accelerate the electrons thereafter in the usual manner.

The waveguide **11** is provided with a closed injection end, and the axial electric field produced by the radio frequency power coupled to the waveguide is made very high at the input end of the guide by eliminating the usual beam inlet aperture. Electrons are then introduced axially to the field within the waveguide from a position interiorly thereof and adjacent to the closed injection end. This is accomplished by disposing an electron emissive cathode structure **16** within the waveguide coaxially adjacent to the injection end.

The very high axial electric field at the closed injection end of the waveguide is effective to accelerate the electrons emitted from the cathode structure **16** to injection velocities substantially greater than their thermal velocity during the accelerating phase of the field. In this connection, the point of electron injection, viz., the axial position of the cathode structure **16**, and the strength of the field at the injection end of the guide, are preferably selected such that the electrons are ac-

celerated to substantially the velocity of light during the first half cycle of the traveling wave field and are positioned essentially near the crest of the wave thereafter. Thus some of the electrons emitted from the cathode during the accelerating phases of the field are accelerated in such a way that they approach the velocity of light under the action of the traveling wave field with a phase relationship to that field that allows them to gain energy during the rest of the time they are in the waveguide.

In the event the electrons are not accelerated sufficiently during the first accelerating half cycle of the field to be thereafter carried along by the traveling wave, provision may be made to shield the electrons from the field during the first decelerating half cycle thereof. To this end a field-free region **17** may be established within the waveguide at a position relative to the cathode structure that corresponds to the positioning of the electrons at the end of an accelerating half cycle of the field. The drift distance of the field-free region is selected to correspond to the distance through which the electrons drift during the time interval of the decelerating half cycle of the field. The electrons then emerge, at the beginning of the next accelerating half cycle, from field-free region **17** unaffected by the decelerating field and are further accelerated during such accelerating half cycle to a speed approaching the velocity of light at a position near the crest of the accelerating field. Thereafter, the electrons and wave travel in concert at very nearly the velocity of light through the remainder of the waveguide. Alternatively, a small voltage of the order of 5–10 kv. maximum may be applied to the cathode structure to enable the electrons to be sufficiently accelerated during the first accelerating half cycle of the field so that a field-free region is not required.

In order that the foregoing injection method may be readily conducted in the accelerating waveguide **11**, suitable injection structure is provided. As illustrated in FIGURE 1, the cathode structure **16** is preferably arranged to be axially movable within a recess **18** provided at the injection end of the waveguide, the configuration being such that the gradient of the field at the cathode can be adjusted to provide an optimum acceleration of the electrons and phase relationship thereof to the traveling wave. It is to be understood, however, that the cathode may be fixed in position rather than movable and the cathode temperature or field strength in the accelerating waveguide controlled to provide the desired injection field gradient at the cathode. Similarly, for some applications the cathode may be fixed in position and the cathode temperature and field strength maintained constant to provide a constant electron current.

More particularly as regards the preferred movable cathode structure, the injection end of waveguide **11** is provided with a axially projecting cylindrical extension **19** defining the recess **18**. The cathode structure **16** here comprises a tubular housing **21** having a cathode **22** secured in closing relation to its inner end. Cathode **22** may be of the field emissive variety, a filament, or as illustrated, an indirectly heated cathode which is brought to the desired temperature by means of a filament **23** mounted within the housing adjacent the cathode.

The outer end of housing **21** is secured to a metallic mounting plate **24** and the leads **26** to filament **23** are extended through the plate in insulated vacuum sealed relation thereto. The housing **21** is disposed coaxially within the waveguide extension **19** with the plate **24** spaced from the outer end of the extension. To complete the assembly, a metallic bellows **27** is secured in vacuum sealed relation coaxially between the mounting plate **24** and the outer end of the extension. The cathode structure **16** is thus axially movable within the waveguide recess **18**, movement of the mounting plate **24** being accommodated by the bellows **27**. Accordingly, the cathode structure may be moved to a position wherein the field gradient at cathode **22** is compatible with optimum operation, viz., a position which is productive of acceleration of the electrons to approach the velocity of light at a position near the crest of the accelerating field in the first accelerating half cycle thereof.

Where the field-free region **17** is provided in the waveguide **11**, as by means of a drift tube **28** coaxially secured therein in spaced relation to cathode structure **16**, the axially movable nature of the cathode structure also facilitates adjustment of the electron drift time within the field-free region. The position of cathode **22** may be readily adjusted to coincide with a field gradient that will accelerate the electrons to positions within the field-free region at the beginning of a decelerating half cycle and to velocities that are commensurate with traversal of the field-free region during the same half cycle. The electrons are thus shielded from the field during the deceleration half cycle and are exposed to the field during the second accelerating half cycle to approach the velocity of light and be appropriately phased relative to the field for continued energy gain.

Where the drift tube **28** is included in the accelerating waveguide, it will be appreciated that in some instances it is difficult to couple the radio frequency power introduced by input waveguide **12** to the first cavity of the accelerating waveguide through the drift tube hole to the cavity following the drift section. Accordingly, it is preferable that the radio frequency power be coupled to the cavity following the drift section by auxiliary means such as a second input waveguide **12'** coupled thereto (see FIGURE 1), by coupling slots **25** provided through the drift tube support structure (see FIGURE 3), or by like means.

Although the cathode structure was described hereinbefore as being movable in a recess **18** provided in the input end of the waveguide **11**, it will be appreciated that where the radio frequency driving energy is applied coaxially to the input end of the guide, as shown in FIGURE 2, the cathode structure may be beneficially translatably mounted in the input coupler **14**. More particularly, the outer member **29** of the coupler projects from a rectangular radio frequency driving waveguide **31** into coaxial communication with the input end of accelerating waveguide **11**. The inner doorknob member **32** of the coupler then projects from the interior wall of driving waveguide **31** to extend concentrically through the outer member **29**, and the inner member **32** is provided with an axial bore **33**.

Inasmuch as the input coupler defines a recess at the input end of the accelerating waveguide, such recess is utilized to good advantage to house the cathode structure. More particularly, as depicted in FIGURE 2, cathode structure comprising a tubular housing **34** and cathode **36** secured in closing relation to the inner end of the housing is movably mounted concentrically within the bore **33**. The outer end of the housing **34** projects through the wall of waveguide **31** in freely slidable relation thereto and is secured to the end wall of a bellows **37** sealed to the exterior of waveguide **31**. Thus, upon axial movement of the bellows, the housing **34** and cathode **36** secured thereto are axially translated within the bore **33** of the coupler inner member **32**. The position of cathode **36** relative to the accelerating field within waveguide **11** may thus be optimumly adjusted in accordance with the considerations advanced hereinbefore.

Considering now one further modification that may be made in the injector structure of the present invention it will be appreciated that a drift tube **38** having a grid **39** across its leading end may be mounted within waveguide **11**, in coaxially spaced relation adjacent to its input end (as illustrated in FIGURE 3) in place of the open ended drift tube **28** of FIGURE 1.

The drift tube **38** establishes a field-free region therein in a manner similar to that established by drift tube **28**. The grid **39**, however, appropriately contours the

accelerating field in the input end of the waveguide to minimize defocussing of the electrons accelerated from the cathode structure.

From the foregoing it will be seen that I have provided a novel method and apparatus for injecting electrons into an accelerating waveguide of an electron linear accelerator without recourse to auxiliary accelerating devices and wherein the injection velocity of the electrons is produced by the action of the accelerating field of the waveguide.

I claim:

1. Apparatus for injecting electrons into a traveling wave accelerating waveguide structure driven by radio frequency energy, comprising in combination: means for establishing a large axial component of traveling wave electric field adjacent the input end of said waveguide structure including a conductive closure thereat, and means conductively carried by said waveguide structure for releasing electrons axially into said traveling wave field from a position within said waveguide structure adjacent said input end.

2. Apparatus for injecting electrons into a traveling wave accelerating wave guide structure driven with radio frequency energy comprising in combination: means for establishing a large axial component of traveling wave electric field adjacent the input end of said waveguide structure including a conductive closure thereat, and means conductively carried by said waveguide structure for releasing electrons axially into said traveling wave electric field in the region of large axial field component from a position where the field gradient accelerates the electrons to a velocity approaching that of light during the accelerating half cycles of the field and which are attained at positions in space near the crests of the field.

3. Apparatus for injecting electrons into a traveling wave accelerating waveguide structure driven with radio frequency energy comprising in combination: means for establishing a large axial component of traveling wave electric field adjacent the input end of said waveguide including a conductive closure thereat, means conductively carried by said waveguide structure for releasing electrons axially into said traveling wave field from a position within said waveguide structure adjacent said input end, and means for shielding said electrons from said field during the initial decelerating half cycle thereof following introduction of the electrons to the field.

4. An electron linear accelerator comprising a traveling wave accelerating waveguide having a conductively closed input end, means driving said waveguide to establish a radio frequency traveling wave field therein, and a cathode directly connected to said waveguide mounted adjacent and within the input end of said waveguide, said traveling wave field being adapted to accelerate electrons from said cathode axially along said waveguide.

5. An electron linear accelerator according to claim 4, further defined by said waveguide having a drift tube mounted therein in coaxially spaced relation to said cathode.

6. An electron linear accelerator according to claim 5, further defined by said drift tube having a grid across its proximal end relative to said cathode.

7. An electron linear accelerator comprising a disc loaded accelerating waveguide having an outwardly coaxially projecting tubular extension at its input end defining a recess, cathode structure including a cathode secured to a support member concentrically disposed within said recess, a mounting plate secured to said support member and spaced exteriorly from said extension, a bellows secured coaxially between said extension and mounting plate in vacuum sealed relation thereto and concentrically disposed about said support member, and radio frequency driving means coupled to said waveguide to establish a traveling wave field therein.

8. An electron linear accelerator according to claim 7, further defined by a drift tube concentrically mounted within said waveguide in spaced adjacent relation to said cathode.

9. An electron linear accelerator comprising a disc loaded accelerating waveguide having a centrally apertured input end, an outer tubular coupler member coaxially sealably secured to said input end in communication with the aperture thereof, a driving waveguide having a coupling aperture, said outer coupler member sealably secured to said driving waveguide in communication with said coupling aperture, an inner tubular coupler member secured to the inner wall of said driving waveguide and projecting through said coupling aperture in concentric relation to said outer coupler member, cathode structure mounted within said inner coupler member for adjustable translation coaxially thereof, and a source of radio frequency driving energy coupled to said driving waveguide to establish a traveling wave accelerating field within said accelerating waveguide.

10. An electron linear accelerator according to claim 9, further defined by a drift tube mounted concentrically within said accelerating waveguide in coaxially spaced adjacent relation to said coupling aperture.

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GEORGE N. WESTBY, *Primary Examiner.*