June 7, 1960 W. S. GEISLER, JR 2,940,000

LINEAR ELECTRON ACCELERATORS

Filed July 26, 1954 2 Sheets-Sheet 1

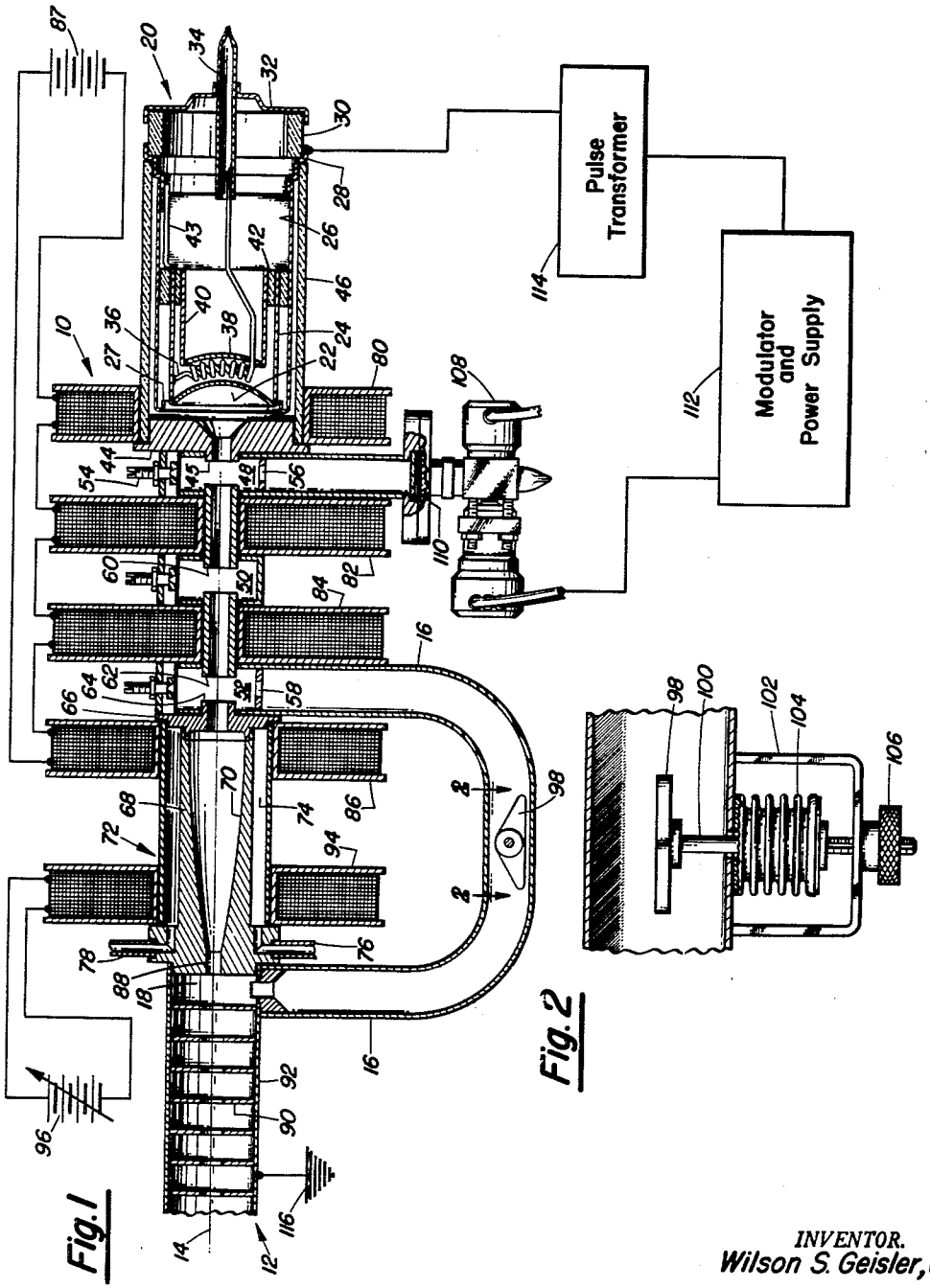


Fig. 1

Fig. 2

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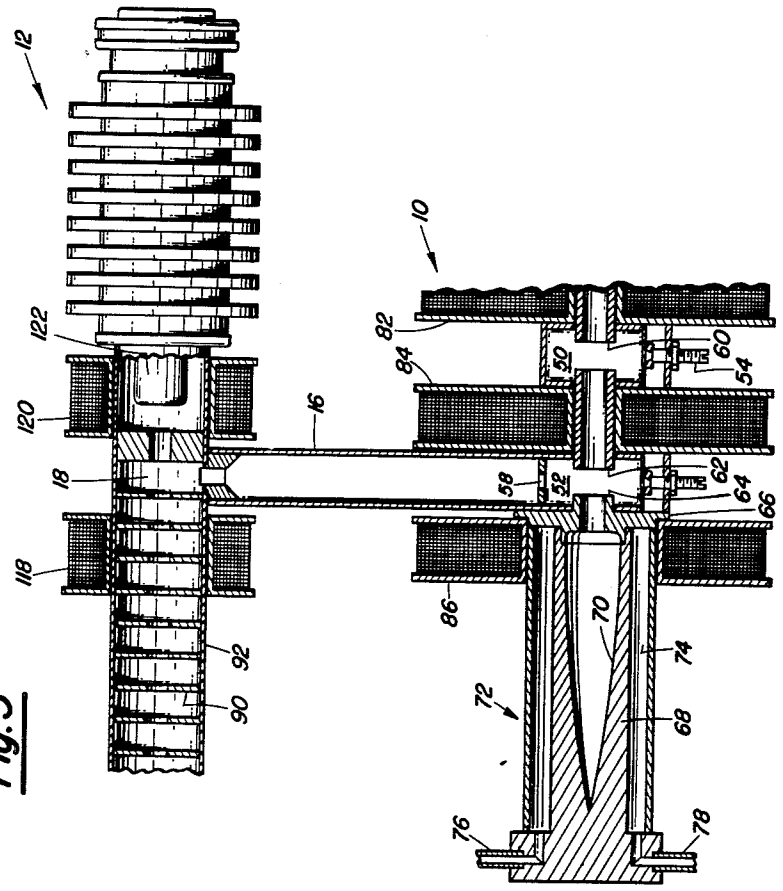


Fig. 3

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LINEAR ELECTRON ACCELERATORS

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10 Claims. (Cl. 315—5.41)

The present invention relates to particle accelerators and, more particularly, to linear electron accelerators.

In order that the desired high velocity of electrons may be obtained in linear electron accelerating structures, it is necessary that a relatively great amount of radio frequency energy be supplied to such accelerating structure so that strong fields will be established. Radio frequency drivers consisting of either klystron amplifiers or magnetron oscillators having a power output as great as one megawatt are conventionally utilized for this purpose. While most of the difficulties with respect to the construction of high power magnetrons and klystrons have been overcome, there yet remain certain difficulties in the injection of the radio frequency energy from the driver into the accelerating structure. As one obvious example, voltage breakdown in the wave guide or other transmission means between the radio frequency driver and the accelerating structure has provided a particularly needling problem. One solution to this exemplary problem is shown in the co-pending application of the present applicant, Serial Number 426,519, filed April 29, 1954, now Patent No. 2,913,619, wherein the coupling wave guide is filled with an inert gas and thereafter sealed.

It is an object of the present invention to provide an improved arrangement for the linear acceleration of electrons which arrangement overcomes many of the difficulties of known devices such as that hereinabove mentioned.

It is a feature of the invention to provide an electron accelerating structure and an associated radio frequency driver therefor which are together encompassed by a common vacuum envelope.

A further feature of the invention involves the provision of a novel form of beam current control whereby more precise control of the beam current through the accelerating structure is enabled.

A further feature involves the provision of an arrangement of an accelerating structure with a radio frequency driver therefor such that a shift in the frequency of the driver output does not result from a change in the load as presented by the accelerating structure.

These features and others, as well as the advantages stemming from the invention will become more apparent from a perusal of the following description of the accompanying drawings wherein:

Figure 1 is a sectional view of a portion of an accelerating structure together with a three-cavity klystron constituting the radio frequency driver therefor and including the associated circuitry,

Figure 2 is a sectional view taken along line 2—2 of Figure 1, and

Figure 3 is a sectional view of a portion of a modified arrangement of an accelerating structure and a three-cavity klystron.

The present invention generally involves the incorporation of an accelerating structure and a radio frequency driver therefor within a single or common vacuum envelope. As will become apparent from what follows, the radio frequency driver can consist of either an oscillator or amplifier operable at the desired frequency and more particularly, might be a multi-cavity klystron, magnetron, or traveling wave tube. In either case, since the accelerating structure and the radio frequency driver are within a common vacuum envelope, the previously mentioned problem with respect to voltage breakdown in the transmission line (e.g., wave guide), between the driver and the accelerating structure is effectively circumvented.

As shown in Figure 1, the radio frequency driver consists of a multi-cavity klystron 10 which is preferably arranged in axial alignment with the accelerating structure 12 in a manner such that an axial passage indicated by the line 14 to be traversed by a beam of electrons extends continuously through both the klystron 10 and the accelerating structure 12. A wave guide 16 is arranged to couple the output of the klystron to the initial accelerator cavity 18 and this wave guide, as well as the interior of both the klystron 10 and the accelerating structure 12 lie within a single vacuum envelope.

Since the klystron herein shown as the radio frequency driver can be replaced by, for example, a traveling wave tube, the details of its construction generally constitute no part of the present invention. A general exception, of course, involves the detailed arrangement for coupling the radio frequency energy from the klystron to the accelerator as well as the arrangement for providing the described continuous axial passage 14 through both structures which may be traversed by an electron beam. However, obvious modifications would enable the replacement of the klystron with the traveling wave tube without departure from the scope of the invention.

In order to provide an electron beam, the klystron 10 incorporates an electron gun 20 which itself includes a dished cathode button 22 mounted at the end of a cylindrical support 24 held in insulated relation concentrically within a metal cylinder 26. This metal cylinder 26 is rebent at one end to form a focusing ring 27 surrounding the exterior of the cathode button 22 in close proximity thereto and is supported at its other end upon an annular, stepped, conductive plate 28 to which it is brazed. This stepped plate 28 is secured in vacuum tight relation to a ceramic ring 30 which in turn is secured at its other end to a second annular plate 32 centrally through which a length of tubing 34 protrudes to extend concentrically within the cylinder 26 to a point proximate the cathode button 22. This tube 34 forms one terminal for a heater 36 adapted to lie immediately behind the cathode button 22 and in front of a dished thermal shield 38 mounted on a short cylindrical section 40 secured by a ceramic insulator 42 within the cathode-supporting cylinder 24. The heater 36 is connected at its other end to this cylindrical cathode support 24 which is in turn connected by a suitable lead 43 to the metal cylinder 26 secured to the first annular plate 28 so that the latter constitutes a common heater-cathode terminal.

An annular anode plate 44 is disposed a predetermined distance from the cathode button 22, being supported in this position at the end of a relatively long ceramic tube 46 which encompasses the whole of the gun structure 20 and is secured in vacuum tight relation at its other end to the stepped annular plate 28. Since this ceramic tube 46 is relatively long, voltage breakdown between this stepped annular plate 28 and the anode plate 44 will be precluded.

The central portion of the annular anode plate 44 is provided with a short tubular protuberance 45 that enters the first cavity 48 of the multi-cavity klystron. This cavity 48, as well as the second and third cavities 50, 52, can be formed of sections of wave guide having suitable

diaphragm tuning arrangements 54 secured respectively at the ends of the wave guides. The central cavity 50 is sealed off at its other end while the wave guide sections forming the first and third cavities 48, 52 are extended with suitable iris openings 56, 58 provided therein to permit ingress or egress of radio frequency energy, whichever the case may be. The first and second cavity and the second and third cavity are joined axially by drift tubes 60, 62 and a short tubular protuberance 64, similar to that which enters the first cavity 48, extends into the third resonator cavity 52 from an annular plate 66 so that within each of the three cavities a capacitive gap is formed.

The annular plate 66 from which the protuberance 64 extends into the third cavity 52 supports a generally cylindrical elongated body 68 having a longitudinally and curvilinearly tapering bore 70 axially aligned with the cavities 48, 50, 52 and the electron gun 20 so as to form a collector electrode indicated generally at 72 for the electrons which have been emitted from the gun and have subsequently traversed the three cavities. In order to cool the collector 72, an annular water jacket 74 is arranged around the cylindrical body 68 and is provided with suitable inlet and outlet connections 76, 78. It will be understood that all of the parts are joined in hermetically sealed relation by known brazing techniques so that the electron gun 20 and the cavities 48, 50, 52 can be highly evacuated, such evacuation being accomplished through the previously described central tube 34 in the electron gun, the tube thereafter being pinched off as shown.

Upon application of suitable D.C. potentials, electrons are emitted from the surface of the cathode 22 to move thereafter successively through the three cavities 48, 50, 52. In order to form the electrons into a beam of the desired diameter, suitable focusing coils 80, 82, 84 are disposed around the cathode 22 and each of the described drift tubes 60, 62. After traversal of the three cavities, the electron beam enters the tapered bore 70 of the collector electrode 72 which has an additional focusing coil 86 surrounding the entrance end thereof. The coils 80, 82, 84, 86 are connected in series and supplied with the appropriate D.C. potential from a suitable source indicated at 87.

In accordance with the present invention, the tapering bore 70 within the collector 72 is not closed at its extreme end in the normal manner but is provided with a small passage 88 adapted to register axially with the previously mentioned accelerating structure 12 which generally includes a series of annular discs 90 within an elongated tube 92 as disclosed in detail in my previously mentioned co-pending application. As a consequence, although the majority of the electrons entering the collector 72 of the multi-cavity klystron 10 are actually collected upon the surface of its tapered bore 70, a few pass into the accelerating structure 12 to move thereafter successively through the accelerating cavities formed between the described annular discs 90. In order to control the number of electrons which pass into the accelerating structure 12, a focusing coil 94 is disposed around the collector 72 adjacent its output end and this coil is connected to a variable supply 96 which enables the strength of the magnetic focusing field to be varied at will. In this manner is provided an exceedingly simple but precise means for controlling the amount of beam current injected into the accelerating structure 12.

To supply the radio frequency energy to the accelerating structure 12 so that the electrons which enter the same will actually be speeded during their successive traversal of the accelerating cavities, the radio frequency output from the third klystron cavity 52 is transmitted through the previously mentioned wave guide 16 to enter the first cavity 18 in the accelerating structure, the full length of such guide being, as previously mentioned, included within the vacuum envelope common to both the klystron 10 and the accelerating structure 12. In an intermediate position within the wave guide 16, a generally triangular piece of quartz 98 is disposed, being supported, as best shown in Figure 2, at the end of a rod 100 which passes through the wall of the wave guide 16 and is mounted upon a suitable bracket 102. A bellows 104 is hermetically sealed to the rod 100 and to the exterior of the wave guide wall so that the vacuum within the wave guide 16 will be maintained, the bellows at the same time enabling the rod to be moved longitudinally when a suitable adjustment nut 106 is turned. When the nut 106 is turned, the quartz 98 within the wave guide 16 is shifted transversely of the guide to provide for adjustment of the phase of the transmitted radio frequency wave so that the phase relationship of the wave as it enters the first accelerator cavity 18 and the electron beam will be proper.

To drive the three-cavity klystron 10, a small klystron oscillator 108 is coupled to the first cavity 48 through the entering section of wave guide which is provided with a suitable vacuum window 110. This klystron oscillator 108 is supplied for pulsed operation in a well-known manner from a suitable power supply 112 which is also adapted to supply through a pulse transformer 114, D.C. pulses of the proper voltage to the conjoined three-cavity klystron 10 and accelerating structure 12. As shown, the cathode 22 is preferably provided with a negative pulse while the body of the klystron 10 and the accelerating structure 12 is maintained at ground potential, the ground connection being indicated at 116.

When the described pulses are supplied to the small klystron oscillator 108 and the cathode 22 and the latter is energized by the supply of voltage to the heater 36 from a suitable source (not shown), electrons will be emitted from the cathode 22 to be directed axially of the structure and maintained in a pencil-like beam by the described focusing coils 80, 82, 84, 86. As the electrons pass through the capacitive gap in the first cavity 48 of the three-cavity klystron, they will be velocity modulated by the radio frequency energy supplied from the klystron oscillator 108 and will subsequently arrive at the third cavity 52 in bunched relation so as to impart amplified radio frequency energy thereinto. The amplified radio frequency energy will be coupled from the third cavity 52 of the klystron through the wave guide 16 and into the first accelerator cavity 18. Subsequently, radio frequency fields will be established in all of the cavities of the accelerating structure 12, the time required for this establishment of the fields being commonly referred to as the "fill time." The electrons, after producing the radio frequency energy in their traversal of the capacitive gap in the third cavity 52, enter the tapering bore 70 of the collector 72. Depending upon the strength of the magnetic field produced by the variable strength magnetic focusing coil 94 surrounding the collector adjacent its far end, a predetermined amount of the electron beam will be caused to pass through the small axial passage 88 at the end of the collector 72 to thereafter pass successively through the accelerator cavities and thus gain in velocity through interaction with the established radio frequency fields. Typical operation in the manner described can consist of the application of a D.C. pulse of approximately 120 kilovolts to the cathode 22 of the three-cavity klystron 10 and having a duration of approximately one microsecond. The klystron oscillator 108 can be arranged to provide a pulsed output of approximately one kilowatt with an amplification through the klystron amplifier such that approximately one megawatt of radio frequency output will be obtained. To provide this amount of amplification, a beam current of approximately 50 amperes is required and the beam current control at the end of the klystron 10 is arranged so that approximately 50 milliamperes of beam current enter the accelerating structure 12 for acceleration by the radio frequency fields therein

so that an ultimate output from the accelerator of approximately six million electron volts can be expected.

In Figure 3 is shown a modified embodiment of the invention wherein the accelerating structure **12** and the klystron **10** constitute in and of themselves distinct units or entities which, however, are still within a single or common vacuum envelope, the two units being joined vacuum-wise by a wave guide section **16** which couples the radio frequency output from the klystron **10** to the accelerating structure **12**. The accelerating structure **12** is generally similar to that shown in Figure 1 and like parts are designated by like numerals. Added are focusing coils **118**, **120** and an electron gun **122** which can be of the type specifically disclosed in my co-pending application previously referred to. The klystron **10** is likewise similar to that shown in Figure 1, differing only in that the final axial passage **88** leading from the collector **72** is eliminated, and additionally, in the elimination of the variable magnetic focusing coil **94** which functions as a beam current control in the structure shown in Figure 1. It will be obvious that the klystron **10**, as shown in the arrangement of Figure 3, might well be replaced by a magnetron which could be coupled to the accelerating structure by the wave guide section **16** so that the common vacuum envelope arrangement can be preserved. The operation of this arrangement is relatively conventional, the output of the klystron **10** being fed to the accelerating structure **12** so that the electrons traversing the latter will be accelerated and the output and general operating characteristics will be similar to those described with respect to the embodiment shown in Figure 1.

It should be pointed out that the embodiment of the invention shown in Figure 1 and that shown in Figure 3 are not only similar in that they each incorporate the accelerating structure **12** and the klystron **10** within a single vacuum envelope, but in each case, the second or middle cavity **50** of the klystron serves as a "buffer." As a consequence, regardless of the level of operation of the accelerating structure **12** or any change therein, the klystron **10** will not be detuned from the required operating radio frequency, but will always function at its peaked level.

Various modifications and alterations other than those hereinabove mentioned may be made without departing from the spirit of the present invention. As a consequence, the foregoing description of the accompanying drawings is to be considered as purely exemplary and not in a limiting sense; rather reference is made to the appended claims which are indicative of the scope of the present invention.

What is claimed is:

1. A linear electron accelerating device comprising an electron accelerating structure adapted to be traversed by a beam of electrons, a klystron amplifier having an electron gun and a collector secured in axial alignment with said accelerating structure, and means forming an axial passage at the end of said collector whereby electrons can be injected axially into said accelerating structure.

2. A linear electron accelerating device according to claim 1 comprising means for controlling the amount of electrons injected into said accelerating structure from the collector end of said klystron.

3. A linear electron accelerating device according to claim 2 wherein said control means includes a focusing coil encompassing said collector, and means for varying the current through said coil.

4. A linear electron accelerating device comprising an electron accelerating structure of generally tubular form and having an axial passage therethrough adapted to be traversed by a beam of electrons, a multi-cavity klystron having an electron gun and a collector with an axial passage through the end thereof, and means for securing said klystron in hermetically sealed relation to said accelerating structure in axial alignment therewith so that a continuing electron path through said klystron and said accelerating structure is provided.

5. A linear electron accelerating device according to claim 4 comprising a wave guide section coupling the radio frequency output of said klystron to said accelerating structure.

6. A linear electron accelerating device according to claim 5 wherein said electron accelerating structure, said multi-cavity klystron, and said coupling wave guide section are within a common vacuum envelope.

7. A linear electron accelerating device comprising an electron accelerating structure of generally tubular form and having an axial passage therethrough adapted to be traversed by a beam of electrons, a multi-cavity klystron having an electron gun and a collector with an axial passage through the end thereof, means for securing said klystron to said accelerating structure in axial alignment therewith so that a continuing electron path through said klystron and said accelerating structure is provided, and a focusing coil encompassing said collector to control the number of electrons injected into said accelerating structure through the axial passage in the end of said collector.

8. A linear electron accelerating device according to claim 7 comprising means for varying the current through said focusing coil.

9. A linear electron accelerating device which comprises means for producing an electron beam, means for velocity modulating the electrons in said beam whereby bunching of the electrons is effected, and means disposed beyond said velocity modulating means a predetermined distance in the direction of electron motion for establishing a radio frequency field in interacting relationship with the bunched electrons and in a phase such that the bunched electrons are accelerated, said velocity modulating means including a structure forming a resonator cavity and a drift tube disposed between said cavity and said electron accelerating means.

10. A linear electron accelerating device which comprises means for producing an electron beam, means for velocity modulating the electrons in said beam whereby bunching of the electrons is effected, and means disposed beyond said velocity modulating means a predetermined distance in the direction of electron motion for establishing a radio frequency field in interacting relationship with the bunched electrons and in a phase such that such electrons are accelerated, said velocity modulating means including a structure forming at least two resonator cavities.

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