

Nov. 17, 1959

W. S. GEISLER, JR
PARTICLE ACCELERATORS

2,913,619

Filed April 29, 1954

3 Sheets-Sheet 1

Fig. 1

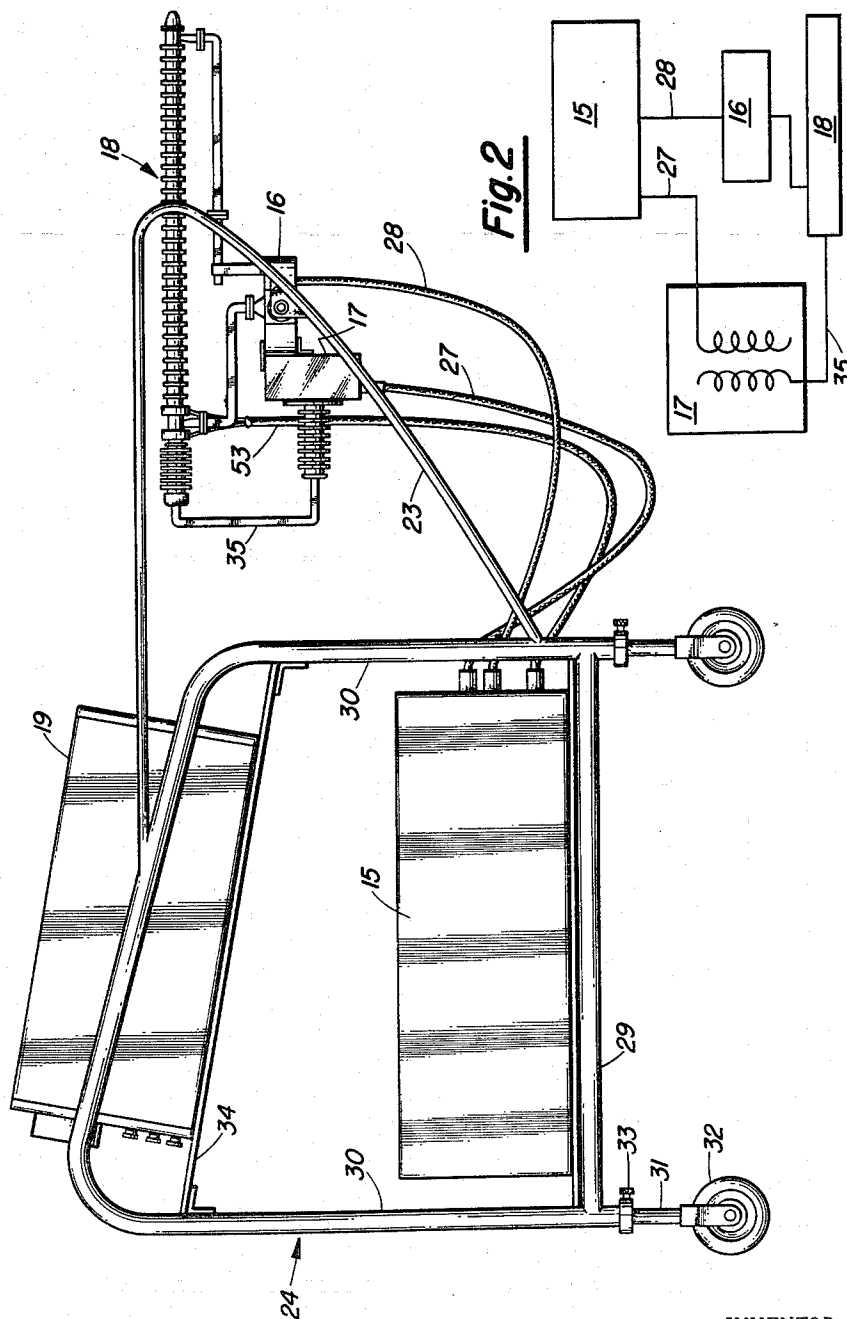
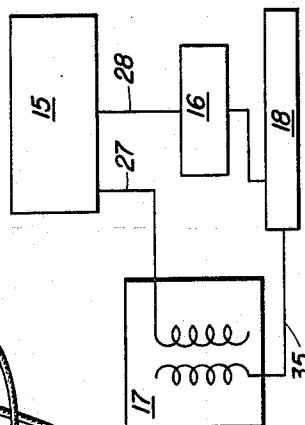


Fig. 2



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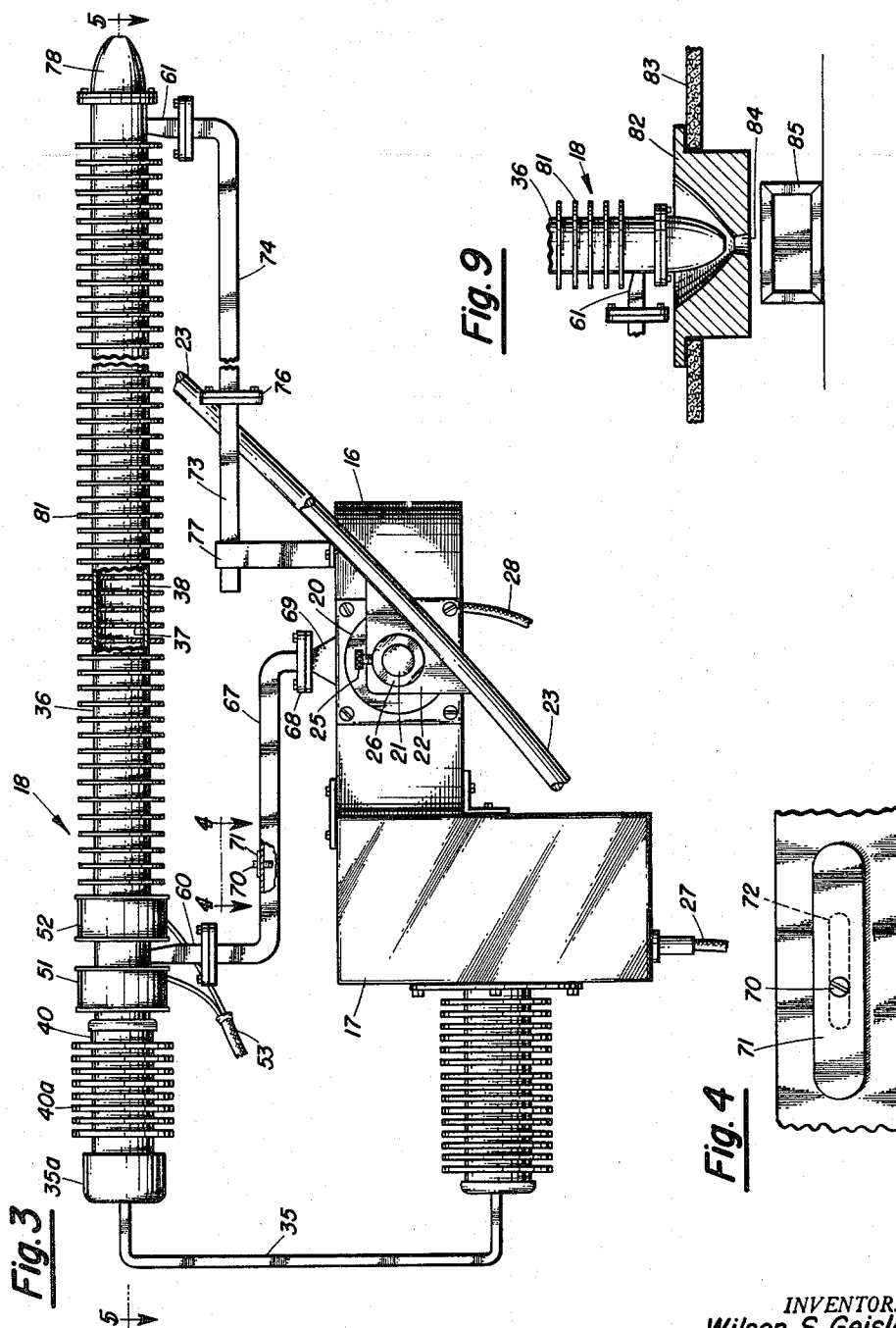
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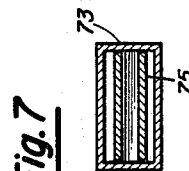
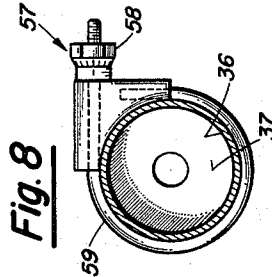
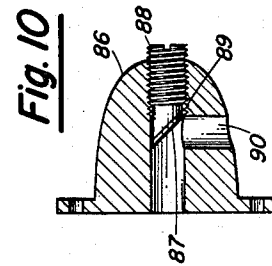
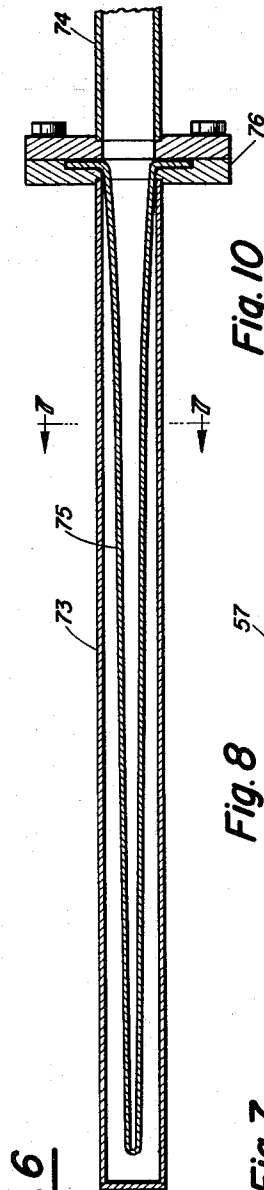
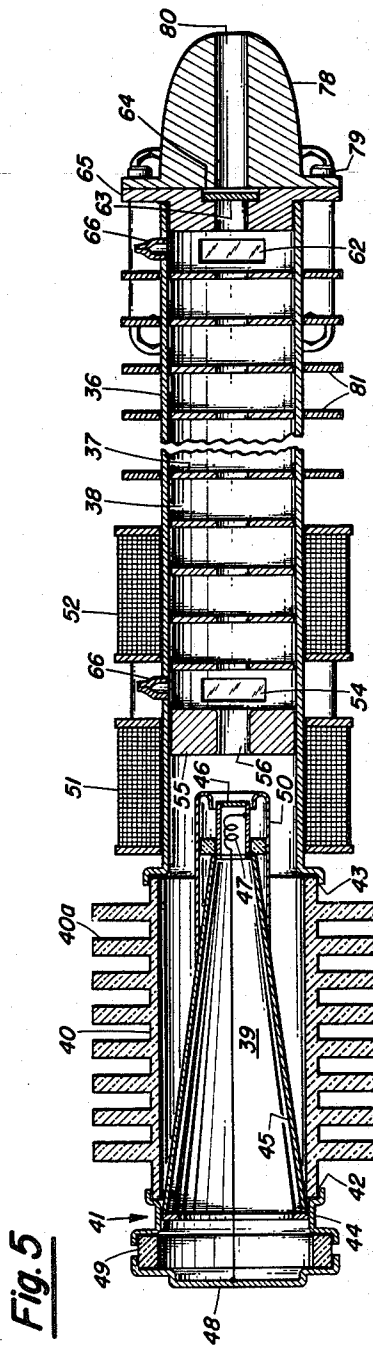
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3 Sheets-Sheet 3



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1

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PARTICLE ACCELERATORS

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Application April 29, 1954, Serial No. 426,519

5 Claims. (Cl. 315-5.42)

The present invention relates generally to particle accelerators and more particularly to a simplified linear accelerator unit adapted for wide utilization, and to the method of its construction.

Previous instruments employed in the production of high energy particles have been excessively restricted in the scope of their utility. As one example, a practical limitation has been established because of the frequencies at which such instruments have been operated, these frequencies being such that the instruments were so ponderous as to be limited to stationary installations. Additionally, the designs, albeit expensive, were specific so as to limit the use even at the point of installation. For any use other than that specifically designed for, a new instrument is required necessitating an additional capital outlay of relatively great proportions.

Accordingly, it is a general object of the present invention to provide a particle accelerator unit which, while adapted for general use as a research tool in nuclear physics, can readily be used for medical purposes such as the treatment of diseased tissue in humans, commercial purposes such as food sterilization, and for other widely variant specific purposes.

A feature of the invention from which the accomplishment of the foregoing object resultantly stems, is the provision of an accelerator designed to operate at a frequency in the neighborhood of 10 kilomegacycles, so that the physical dimensions are relatively small and the accelerator can readily be arranged as a part of a unit which is portable.

Another feature of the present invention is the provision of an improved electron gun structure and the arrangement for its mounting on the body of the accelerator.

Yet another feature is the provision of novel radio frequency input and output couplers for the accelerator enabling an optimization of operating efficacy.

A further feature of the present invention is the provision of an accelerator arranged to be driven by a radio frequency source in a novel fashion, whereby simplification of operation and the circuitry employed are enabled.

Additional features involve the provision of an accelerator construction and techniques of assembly designed to facilitate obtaining of the close tolerances required for operation of an accelerator at the specified high frequency.

These and other more specific features of the invention, as well as the advantages thereof, will become apparent from the following description of a preferred embodiment shown in the accompanying drawings wherein:

Figure 1 is a side elevational view of a portable accelerator unit embodying the present invention,

Figure 2 is a block diagram of the electrical components of the unit,

Figure 3 is an enlarged side view of the accelerator illustrating the manner of its mounting in association with a pulse transformer and a magnetron which is the specific

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type of radio frequency source herein utilized, parts being broken away to illustrate details of construction,

Figure 4 is a fragmentary view of an input susceptance tuner, as viewed from line 4-4 in Figure 3.

5 Figure 5 is a central fragmentary section through the accelerator taken along line 5-5 of Figure 3,

Figure 6 is a fragmentary longitudinal sectional view of an output load arrangement for the accelerator,

10 Figure 7 is a transverse section taken along line 7-7 of Figure 6,

Figure 8 is a transverse section of the accelerator with a final tuning or trimming arrangement thereon,

Figure 9 is a view in section of an improved shielding arrangement adapted for use with the accelerator unit and,

15 Figure 10 is a sectional view of a target which may be utilized with the accelerator when it is desired to produce X-rays or other radiations of a specific character.

As shown in Figure 2, the accelerator unit generally includes a modulator 15 adapted to supply 30 kilovolt pulses directly to a magnetron 16 as well as to a pulse transformer 17 having a step-up ratio of approximately 7 to 1. The output of the pulse transformer 17, which is then approximately 200 kilovolts, is fed to the accelerator itself, as generally indicated at 18, to provide a D.C. potential to initiate electron motion and the radio frequency output of the magnetron 16 supplies accelerating force to the moving electrons within the accelerator.

The accelerator 18 is an elongated vacuum tube and 30 is designed, in accordance with the present invention, to operate at a frequency, as previously mentioned, in the neighborhood of 10 kilomegacycles and, accordingly, has an overall length of only 2½ feet. As shown in Figures 1 and 3, it is centrally supported from beneath, in a manner to be described in detail hereinafter, by the magnetron 16 which also provide a support laterally for the mentioned pulse transformer 17. Tubular horizontally-disposed extensions 20 are bolted to opposite sides of the magnetron 16, substantially in line with its 40 axis and mount at their outer ends stub shafts 21 resting in suitable bearings (not shown) in brackets 22 secured to spaced frame members 23 supported and extending laterally from a wheeled carriage or cart 24. As a consequence of the described pivotal mounting on the stub shafts 21, the unit including the magnetron 16, the pulse transformer 17 and the accelerator tube 18 may be selectively tipped so that the accelerator tube may be directed horizontally, as illustrated in Figure 1, or at any desired angle. A set screw 25 in a collar 26 is adapted to engage the one stub shaft 21 to maintain the desired pivotal disposition.

Cables 27, 28 which connect the magnetron 16 and pulse transformer 17 to the modulator 15 are of sufficient length to permit the described pivoting and are actually connected to the modulator at one end thereof, the modulator 15 being supported at a low level on cross members or braces 29 extending between and supported by vertical tubular legs 30 forming the uprights of the frame of the previously mentioned carriage 24. Each of these 60 tubular legs 30 is mounted in telescoping fashion on a bar 31 which mounts at its lower end a suitable small wheel 32 and a set screw 33 enables individual vertical adjustment of the carriage legs 30. A shelf 34 is secured between the tubular legs 30 of the carriage adjacent their 65 upper ends to provide support for an oscilloscope 19 adapted to facilitate monitoring of the accelerator operation. For this purpose, the oscilloscope 19 can be connected by suitable leads (not shown) to enable observation of the magnetron or cathode pulses, the radio frequency input or output pulses, or the beam current pulse.

The modulator 15 is of a commercially available type

and in and of itself constitutes no part of the present invention. It is designed to provide the required 30 kilovolt pulses previously mentioned and to provide such pulses at variant repetition rates, preferably enabling a variation of from 200 to 5,000 pulses per second. It also incorporates a source of current for the accelerator focusing coils, to be described hereinafter.

The pulse transformer 17 and the magnetron 16 are also by themselves not part of the present invention and will not be described in detail. As shown herein, the magnetron 16 is a strapped magnetron with a power output of $\frac{1}{2}$ megawatt, but other magnetrons or klystrons can be employed as substitutes. The pulse transformer 17, in addition to providing the required step-up for the high voltage pulses, also contains a suitable filament supply winding. A cable 35 terminating in a suitable socket 35A provides both high voltage and filament voltage connections between the pulse transformer 17 and the accelerator 18.

The accelerator 18, constructed in accordance with the invention and as clearly shown in Figure 5, includes a body 36 formed of an elongated copper tube, having a relatively thin wall within which a number of annular discs 37 are secured, in a manner to be described in detail hereinafter, to form therebetween a plurality of cavities 38 enabling, when radio frequency energy is supplied, the acceleration of particles injected axially into the body 36 at one end. The particle injecting means herein shown constitutes an electron gun 39 secured to one end of the tube body 36 by an insulator 40. This insulator 40 is of generally tubular configuration substantially corresponding in diameter to the copper tube body 36 and is secured to both the body 36 and the cup-shaped base 41 of the electron gun 39 in vacuum-tight relation by known metal-to-ceramic sealing techniques as indicated at 42 and 43. On the exterior of the tubular ceramic insulator 40, a plurality of integral radial ceramic fins 40A are formed to provide a long leakage path between the copper tube body 36 and the electron gun 39 to prevent breakdown at the operating D.C. potential of 200 kilovolts. From an annular metal ring 44 constituting part of the cup-shaped base 41 of the electron gun, a frusto-conical support 45, brazed to the ring, extends within the ceramic insulator 40 to mount a cathode button 46 at a point adjacent the first accelerator cavity 38 within the copper tube body 36 and in axial alignment therewith. A heater or filament 47 is supported behind the cathode button 46 to provide for electron emission therefrom and is connected between the cathode and the metal cap portion 48 of the cup-shaped base 41, the cap being insulated from the described ring 44 by a ceramic spacer 49. A corona focusing ring 50 is also secured, as by brazing, on the frusto-conical support 45 to surround the cathode button 46 so that the emitted electrons will be injected into the first cavity 38 as a parallel beam of the desired diameter. To supplement this focusing effect, a pair of magnetic focusing coils 51, 52 can be positioned as shown on the exterior of the copper tube adjacent the first accelerator cavity, current being supplied to these coils from the described modular unit 15 through a suitable cable 53.

The radio frequency energy is supplied to this first cavity 38 through an iris opening 54 in the wall of the copper tube 36, and such energy is restricted to transmission toward the distal or output end of the tube because the wall of this cavity is formed by a thick annular disc or plug 55 whose central aperture 56 is of such diameter and length as to preclude the passage of radio frequency energy of the applied frequency in the opposite direction towards the electron gun 39.

Since the beam of electrons is subjected to an original accelerating potential of 200 kilovolts, the individual electrons are moving at approximately .7C where C is the velocity of light (3×10^{10} cm./sec.), when they enter the first cavity. Thereafter, as the electrons pass suc-

cessively through the cavities 38 in the proper phase relationship with the applied radio frequency wave, their velocity increases to approximately .996C. As a result of relativistic considerations, the length of the path of the electron beam through the tube 36, as seen by each electron, is tremendously foreshortened and rather than being the actual length of something over 2 feet, appears as a length of approximately $\frac{1}{4}$ inch. Consequently, the previously described corona ring 50 and magnetic focusing coils 51, 52 are more than adequate to overcome any de-focusing and spreading of the electron beam during its passage through the tube.

In order that the proper phase relationship be maintained between the moving electrons and the radio frequency wave during the complete traverse of the beam through the accelerator cavities 38, it is necessary in operating at a frequency of 10 kilomegacycles, that special construction of the tube and special techniques of assembly be employed. In point of fact, in spite of the increased shunt impedance obtainable at the high frequency herein employed, and it will be understood that shunt impedance is a measure of the merit of an accelerator, it has been considered impractical with previously used construction techniques to operate at this frequency.

Preferably, the described annular discs 37 are formed from high purity copper bar stock. The stock is first machined to an accurate outside diameter and a bore is drilled axially through the bar stock; thereafter, the two sides of the disc 37 are machined simultaneously, this simultaneous cutting operation enabling the maintenance of .0001 tolerance in the thickness of the disc. The aperture in the disc is then machined to provide a rounded surface. Finally, to complete the discs, their outer edges are silver or gold plated, such plating controlling the ultimate outside diameter.

Spacer elements composed of aluminum are machined in much the same fashion as the discs to approximately the same outside diameter and having a longitudinal dimension accurately machined to correspond to the ultimately desired axial dimension of the cavities.

The discs and spacers are then assembled alternately on a tie-rod which then holds all of the discs and the spacers in tight abutting relation. This disc-spacer assembly is then placed in a liquified gas, such as liquid nitrogen, to provide substantial shrinkage thereof, and while so shrunk, is inserted into the copper tube 36 which has been previously machined and polished to the proper interior dimensions and has been subsequently heated to, for example, 300 degrees centigrade. The cooled disc-spacer assembly and the heated tube are then allowed to come to room temperature whereby the discs 37 are brought into tight engagement with the interior of the tube 36. The tie-rod is removed and the aluminum spacers are at this point etched out of the assembly by means of, for example, a suitable caustic solution, leaving the accurately machined discs 37 in precisely spaced parallel relation with their interior apertures in exact alignment.

While the described machining and assembly techniques produce a number of cavities which vary but slightly in resonant frequency as determined by radio frequency measurements on each cavity individually, a pretuning or trimming means is provided, in accordance with the present invention, to even further reduce such variance and optimize operation at the high frequency. As shown in Figure 8, a tuning clamp 57, which is similar to the well-known hose clamp, is applied to the exterior of the copper tube 36 at a point substantially mid-way between adjacent discs 37. While the cavity 38 between these discs is measured as to resonant frequency, a micrometer 58 is turned to tighten the thin metallic band 59 of the clamp 57 so as to deform the copper tube 36 and thus reduce the volume of the cavity 38. By this or any equivalent means for accurately de-forming the thin

copper tube 36, all of the cavities 38 may be tuned or "peaked" to the desired frequency. It should be pointed out that this tuning or trimming of the cavities 38 is only made possible because of the structure of this accelerator and more particularly, the utilization therein of a copper tube 36 whose wall is relatively thin and thus deformable.

The tube 36 with the discs 37 secured therein is then mounted on the electron gun 39 by means of the previously described ceramic insulator 40 and wave guide stubs 60, 61, within each of which a radio frequency window (not shown) is sealed, are brazed over the input iris 54 in the first cavity and a second or output iris 62 in the last accelerator cavity. Each wave guide stub 60, 61 is tapered as it approaches the copper tube 36 to establish the proper impedance match. To complete the vacuum envelope, a beryllium window 63 is vacuum-brazed to the central aperture 64 of an annular plug 65 at the output end of the copper tube 36, this plug aperture, like that adjacent the electron gun 39, being of a length and diameter such that no radio frequency energy of the applied frequency can pass therethrough, but permitting the transmission of the high energy particles.

When the tube 36 is baked out, the described silver or gold plate on the outer edge of the discs 37 fuses or alloys with the copper to form a clean and rigid junction between the tube 36 and the discs. When the accelerator 18 is thus assembled, it can be evacuated through exhaust tubulations 66 which are subsequently pinched off, these being disposed at opposite ends of the copper tube 36 to expedite the evacuation.

After assembly of the accelerator 18 has been completed, it is mounted on the magnetron 16 as best shown in Figure 3. For this purpose, a wave guide section 67 is secured by coupling flanges 68 to the output wave guide 69 of the magnetron 16 and to the input wave guide stub 60 of the accelerator 18. In this manner the input coupling means which supplies radio frequency energy to the accelerator 18 simultaneously functions as a physical support for the latter.

In order that the magnetron 16 will experience a substantially constant load during operation of the accelerator, a susceptance tuner is arranged within the wave guide section 67 which couples the magnetron 16 and the accelerator 18. This tuner can take the form of a screw 70 which is mounted in a small plate 71 and projects through a slot into the guide, as shown in Figures 3 and 4. The screw 70 is turned to vary the amount of its projection into the guide upon first operation of the unit and its position lengthwise of the slot 72 is adjusted by sliding of the plate 71. The proper position having been ascertained, the screw 70 and the plate 71 are then brazed so as to remain stationary or fixed thereafter. Although the magnetron 16 will see a substantially constant load, loss of radio frequency energy is minimized by use of the described tuner. To preclude breakdown in the input wave guide section 67, an inert gas, such as argon, is inserted into the wave guide during assembly to displace the air and completely fill the same. Suitable seals (not shown), such as O-rings, are placed between the coupling flanges 68 to preclude leakage.

It is known that accelerator tubes can be operated as standing wave or traveling wave devices, the type of operation being determined for the most part by the input and output coupling arrangements. In the present instance and as shown particularly in Figures 3 and 6, the output coupler provides a matched load and the tube provides a loaded-line structure and consequently operates as a traveling wave device, such operation being frequently analogized to the action of a surf board (the electrons) upon a breaking ocean wave (the radio frequency wave). However, it will be understood that by suitable changes, particularly in the input and output couplers, the accelerator 18 may be readily converted for use as a standing wave device, still incorporating many features of the present invention.

To provide the matched load for traveling wave operation, a wave guide section 73 closed at its outer end is secured by a conventional wave guide elbow 74 to the output wave guide stub 61 so that the closed guide section 73 extends in substantial parallelism with the tube 36. Lossy material which in accordance with the present invention, takes the form of an iron strap 75, is secured within the wave guide section 73. The ends of the strap 75 are clamped between opposite points of the coupling flanges 76 which connect the guide sections, as clearly shown in Figure 6, and the intermediate portion of the strap 75 is disposed in hairpin-like configuration in the guide section 73. More specifically, the legs of the hairpin approach one another exponentially to provide a substantially reflectionless load. A rigid brace 77 secured between the load wave guide 73 and the magnetron 16 provides added support for the accelerator 18.

Over the end of the tube 36, a small lead cap 78 is secured, as by screws 79, so that a central bore 80 provided in the cap 78 is aligned with the cathode button 46 and the apertures in the discs 37. This cap 78 serves to maintain the electrons in substantially a narrow beam as they emerge from the tube 36 and to preclude the return of any radiation back around the tube.

To maintain the accelerator tube 36 throughout its length at the same temperature so as to avoid de-tuning of the cavities, radial fins 81 are brazed at spaced intervals on the tube exterior and a controlled flow of air can be directed thereover. While this method of temperature control has been found to be adequate, it is not intended that more complex arrangements, including heating elements as well as cooling fluid, be eliminated from possible utilization. Air can also be directed over the load wave guide section 73 to provide cooling thereof.

The operation of the accelerator unit is quite simple. The modulator 15 is energized to provide 30 kilovolt pulses of substantially one microsecond duration to both the magnetron 16 and the pulse transformer 17. The output of the pulse transformer 17, consisting of 200 kilovolt pulses, is applied between the cathode 46 and the body 36 of the tube which, in effect constitutes the anode, so that upon energization of the cathode when the filament supply is turned on, and subsequent energization of the focusing coils 51, 52, electrons are emitted from the cathode 46 thereafter to be focused into a pencil-like beam having a velocity of approximately .7C upon entering the first accelerator cavity 38.

The pulsed radio frequency output of the $\frac{1}{2}$ megawatt magnetron 16 is simultaneously applied through the input wave guide 67 to the accelerator cavities 38 to interact with the electrons so that the beam velocity at the output end of the tube 36 which, in the present instance, consists of 72 cavities, is quite close to the speed of light, being .996C and the total output energy is approximately 4 million electron volts.

In the present accelerator tube, the "fill-time," which is the time for the radio frequency output of the magnetron 16 to establish the equilibrium or the steady-state electromagnetic fields in all of the cavities 38, is approximately .2 microsecond. Since this fill-time is but a fraction of the complete pulse length, that is, one microsecond, the necessity for providing a delay between the firing of the magnetron 16 and the application of the voltage pulse to the cathode 46 is obviated. As a consequence, the circuitry required to produce such delay is eliminated and in its place appears merely the pulse transformer 17.

Usually it has been the practice to utilize an accelerator having an electron gun which is arranged as a triode to enable current control. In the described accelerator 18, the gun 39 obviously operates as a diode and for the purpose of current control, a novel technique is employed in accordance with the present invention. Such technique constitutes the variation of the pulse repetition rate from the described modulator 15. As has been men-

tioned previously, this repetition rate can be varied continuously between 200 and 5,000 pulses per second. Such variation in the pulse repetition rate provides a variation in the current output of the accelerator 18 of from approximately 1 to 100 microamperes.

The portable accelerator unit can, because of its portability, be used conveniently as a research tool in nuclear physics and because of its relatively small size, is easily shielded. A particular shielding arrangement which may be conveniently utilized with the unit and as shown in Figure 9, comprises a generally cup-shaped lead bucket 82 which may be mounted in a suitable opening in a floor 83. A central aperture 84 is formed in the lead bucket 82 and elements to be bombarded, as indicated at 85, can conveniently be placed thereunder. The portable accelerator unit can be moved on its wheeled carriage 24 to a position over the lead bucket 82 and the accelerator tube 18 is pivoted into a vertical position as indicated in Figure 9, so as to extend into the lead bucket 82 in alignment with its aperture 84. When operated in this position, any electrons which do not pass through the aperture are absorbed by the lead bucket 82 or by the lead cap 78 on the tube. Consequently, danger to the machine operators is simply eliminated.

For medical use such as, for example, the treatment of cancerous tissue, the high energy electrons are directed toward the diseased area. Since radiation is produced in quantity only after a pre-determined slow down of the electrons has occurred, control of the amount of acceleration within the accelerator by varying the radio frequency accelerating potential, will determine the depth within the patient's body at which tissue destruction will occur. The total beam current as determined by the selected pulse repetition rate will control the amount of radiation and consequently the exposure time required for destruction of the tissue. Consequently, by judicious selection of accelerating potential and pulse repetition rate, a cancerous growth can be quickly destroyed with a minimum destruction of surrounding healthy tissue.

For commercial utilization such as food sterilization, one or more of the portable accelerator units may be moved to a position adjacent a moving belt carrying, for example, in continuous sequence, cans of food. As the cans move successively by the portable accelerator unit, the food is immediately purged of harmful bacteria. It will be understood that a suitable lead shield must be provided in such utilization, again to preclude danger to the cannery operators.

For the production of X-rays, the lead cap 78 on the end of the accelerator is removed and a substitute cap, as shown in Figure 10, in the form of a lead cap 86 having a removable target therein is secured on the end of the tube. This target takes the form, as shown, of a small plate 87 composed of gold, tungsten, copper, or the like, which is supported at somewhat of an angle on the end of a screw 88 threaded into an axial opening 89 in the cap. A lateral opening 90 in the target cap provides for egress of the radiation. In view of the fact that the accelerator is part of a portable unit and furthermore that it is pivotally mounted, the application of the X-rays is facilitated. For example, the rays can readily be applied to metal castings to search out imperfections therein.

It will be appreciated that many variations and modifications of the described structure may be made without departing from the spirit of the invention. For example, as previously mentioned, it is obvious that the radio frequency source for the accelerator might constitute, rather than a magnetron, a klystron of the desired operating frequency. Additionally, although the invention has been explained with particular reference to the acceleration of electrons, it is applicable as well in many respects to the acceleration of other particles, such as protons. Since such variations are possible, it is not intended that

the present invention be limited to the particular structure described and shown in the drawings, but its scope instead is indicated by the appended claims.

What is claimed is:

1. A linear electron accelerator comprising a metal tube, means forming a plurality of accelerator cavities within said tube, an electron gun adapted to inject electrons into said tube so as to traverse successively said cavities, an input wave guide coupler associated with the first of said cavities, to enable application of radio frequency energy to said cavities, an output wave guide section coupled to the last of said cavities to extract radio frequency energy, and means in said output wave guide section including lossy material in the form of an iron hairpin-shaped strap for absorbing radio frequency energy extracted from said cavities in a manner providing a substantially reflectionless load for the accelerator.

2. A linear electron accelerator unit comprising means forming a plurality of accelerator cavities, an electron gun adapted to direct a beam of electrons for passage successively through said accelerator cavities, a source of radio frequency energy, and means for coupling radio frequency energy from said source into said cavities in a manner providing acceleration of the electrons, said coupling means including a susceptance tuner adapted to provide substantially a constant load for said radio frequency source.

3. An accelerator unit comprising an accelerator for charged particles, a magnetron, means coupling radio frequency energy from said magnetron to said accelerator and rigidly connecting the same, a transformer supported rigidly on said magnetron and adapted to step up a pulsed direct current voltage supplied thereto, and means for coupling the transformer output to said accelerator.

4. An accelerator unit comprising an accelerator for charged particles, a magnetron, means coupling radio frequency energy from said magnetron to said accelerator and rigidly connecting the same, a transformer supported rigidly on said magnetron, means for coupling said transformer output to said accelerator, a carriage, and means supporting said magnetron on said carriage for pivotal movement.

5. An accelerator unit comprising an accelerator for charged particles having a predetermined radio frequency fill-time, a magnetron coupled to said accelerator for supplying pulsed radio frequency energy thereto, a pulse transformer coupled to said accelerator for supplying direct current voltage pulses thereto, and a modulator coupled to said magnetron and said pulse transformer for supplying input pulses of a duration long compared to the fill-time of said accelerator to said magnetron and said pulse transformer simultaneously.

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