Aug. 2, 1966 J. HAIMSON 3,264,515

COLLINEAR TERMINATION FOR HIGH ENERGY PARTICLE LINEAR ACCELERATORS

Filed June 29, 1961

FIG. 1

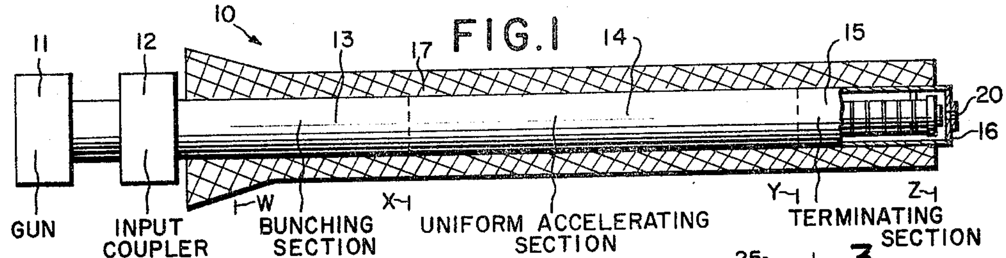


FIG. 2

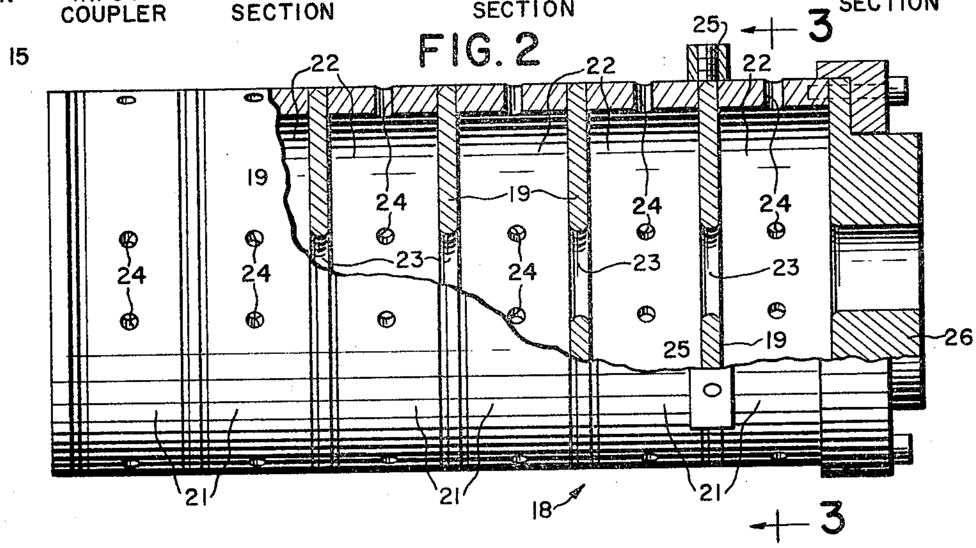


FIG. 3

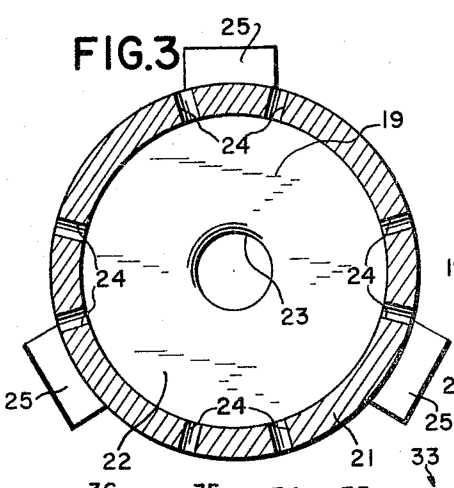


FIG. 4

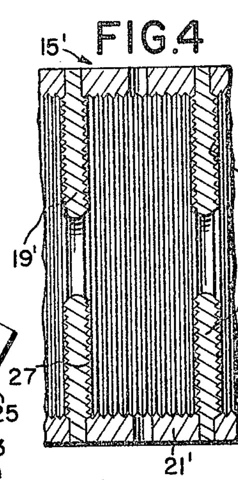


FIG. 5

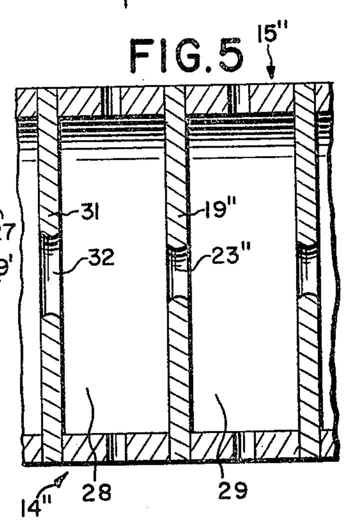
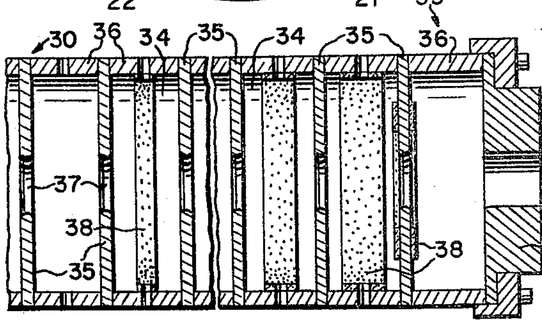


FIG. 6



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COLLINEAR TERMINATION FOR HIGH ENERGY PARTICLE LINEAR ACCELERATORS

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12 Claims. (Cl. 315—5.41)

The present invention relates in general to particle accelerating means and more specifically to a method and apparatus for attenuating radio frequency waves at the end of the particle accelerating structures such as linear accelerators.

In linear accelerators a source of particles such as an electron beam is directed down a slow wave structure which is adapted to propagate a radio frequency electromagnetic wave. The dimensions of the waveguide structure can be arranged such that there is an interaction between the traveling radio frequency wave and the electron beam whereby energy is transferred from the wave to the beam to accelerate electrons in the beam. At the end of the accelerating guide the accelerated electron beam can be directed onto an X-ray target for producing X-rays or can be passed out of the vacuum envelope and directed onto the object being irradiated. In optimizing the design of one type of accelerating structure which is to be utilized for X-ray production it has been found desirable to arrange for approximately ten percent of the radio frequency power to be remanent at the end of the accelerating waveguide after allowance for dissipation losses and beam loading. In other applications greater or less residual radio frequency power may result due to a variety of designs and operational requirements. For example, a greater amount of residual radio frequency power could be due to reduced beam loading caused by a reduction in beam peak current or the dephasing of the radio frequency wave from a synchronous condition in order to reduce the terminal energy of the electrons. Less residual radio frequency power could result from increased beam loading. In particle accelerators for X-ray generation it is sometimes desirable to have even greater percentages of residual power at the end of the accelerating waveguide in the interest of output stability. This residual power is extracted from the accelerating waveguide and is either applied to an external load or fed back to the input of the accelerator. Such structures required a radio frequency transition at the end of the accelerating structure and may also require either an external load for dissipating the power or means for directing the radio frequency power back to the input. Also a radio frequency wave permeable window may be necessary.

As well as involving a great deal of expense, the additional structure necessary to dispose of the radio frequency power requires a considerable amount of space. In many applications it is necessary to have the particle accelerator fit in as small a space as possible. As a typical example, it is desirable to have particle accelerators which are used for therapy fit within as small a room as possible so that the accelerator can be placed in an existing room in a hospital. Since it is desirable to have the particle accelerator mounted on a gantry for irradiating a patient from many angles, the necessity for space around the end of the accelerating structure for terminating the radio frequency wave prohibits the use of a minimal size gantry.

Also when the residual radio frequency power is ex-

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tracted at the end of the particle accelerator, the particle beam focusing structure is captured between the radio frequency wave coupling structures which are positioned at the ends of the accelerating structures. Since it is desirable to provide a vacuum envelope around the accelerating structure and inside the focusing structure, an assembly and maintenance problem exists. It is usually not possible to complete the vacuum envelope until the focusing structure is positioned around the accelerating structure. This vacuum envelope may have to be opened in order to remove the focusing structure for repairs.

According to the present invention, a termination is provided around the beam axis at the output end of a particle accelerator guide capable of dissipating the residual radio frequency power while permitting the transmission of the particle beam therethrough either without extracting energy therefrom, without altering the beam energy or by deliberately extracting energy therefrom. Such a structure is extremely useful in environments where cost and space are at a premium. Such a termination can be referred to as a collinear termination since it lies in a straight line with the accelerating section.

Therefore, the principal object of the present invention is to provide a termination around the beam axis at the output end of a waveguide structure for propagating a radio frequency wave and capable of dissipating radio frequency power propagating therealong while permitting transmission of the electron beam therethrough.

One feature of the present invention is the provision of a resonant section of loaded waveguide at the end of a radio frequency, phase velocity of light structure wherein the residual radio frequency power at the end of the slow wave structure can be attenuated in accordance with design requirements.

Another feature of the present invention is the provision of a radio frequency wave propagating structure including a waveguide structure comprising a plurality of coupled cavities formed by a series of discs interleaved between a series of hollow cylindrical spacers, at least certain of the spacers and/or discs including a material having a high electrical resistivity.

Another feature of the present invention is the provision of a novel structure of the last aforementioned feature wherein the last cavity of said structure is resonant and adapted for reflecting any radio frequency wave power at the end of said structure, whereby the radio frequency power is attenuated in the forward and backward directions.

Another feature of the present invention is the provision of a radio frequency wave propagating structure comprising a loaded waveguide at least a portion of which is provided with an uneven surface, for example, rough surface finish, for attenuating a wave propagating therein.

Another feature of the present invention is the provision of a particle accelerator structure including an accelerating section and a terminating section, both the accelerating and terminating section being comprised of loaded waveguide defining a plurality of cavity resonators, the cavity resonators of said terminating section having a much lower Q than the cavity resonators of said accelerating section.

Another feature of the present invention is the provision of a particle accelerator structure including an accelerating section and a terminating section, both the accelerating and terminating sections being comprised of loaded waveguide defining a plurality of cavity resonators, the cavity resonators of said terminating section being adapted to propagate a radio frequency wave therethrough with a much lower group velocity than the cavity resonators of said accelerating section.

Still another feature of the present invention is the provision of a particle accelerating structure including an accelerating section and a terminating section, both the accelerating and terminating sections being comprised of disc loaded waveguide, the apertures in the discs of the terminating section being smaller than the apertures in the discs of the accelerating section.

Still another feature of the present invention is the provision of a particle accelerating structure including an accelerating section and a terminating section, both the accelerating and terminating sections comprised of disc loaded waveguide, the thickness of the discs of the terminating section being greater than the thickness of the discs of the accelerating section.

Other features and advantages of the present invention will become more apparent upon a perusal of the following specification taken in connection with the accompanying drawing wherein:

FIG. 1 is a schematic view of a particle accelerator utilizing the features of the present invention,

FIG. 2 is an enlarged side view, partially broken away, of a portion of the structure shown in FIG. 1,

FIG. 3 is a cross sectional view of a portion of the structure shown in FIG. 2 taken along the line 3—3 in the direction of the arrows,

FIG. 4 is a side view, similar to a portion of FIG. 2, of an alternative embodiment of the present invention,

FIG. 5 is a side view, similar to FIG. 4, of another alternative embodiment of the present invention, and

FIG. 6 is a side view, similar to FIG. 4, of still another alternative embodiment of the present invention.

Referring now to FIG. 1 of the drawing, there is shown a schematic view of an evacuated, linear, particle accelerator **10** adapted for accelerating a particle beam. While the particle accelerators shown and described below are especially designed for accelerating a beam of electrons, the features of the present invention are equally applicable to apparatus for accelerating beams of other particles such as, for example, positrons. Also, the apparatus is adaptable for use with both pulsed and continuous beams.

The particle accelerator **10** includes a particle source **11** such as an electron gun and an accelerating structure including, for example, a bunching section **13**, a uniform accelerating section **14** and a terminating section **15** all of which are adapted to pass the electron beam directed thereinto by the source **11**.

Typically for pulsed operation of a particle accelerator a squared high voltage pulse is applied to electrodes within the gun assembly **11** which serve to pulse the emission of the electron beam.

A high power, radio frequency source (not shown), for example, a klystron amplifier, serves to provide to the accelerating structure by means of an input coupler **12** peak radio frequency beam acceleration power as, by way of illustration, on the order of 1.75 megawatts at a certain high frequency as of, for example, 2,998 megacycles. The high frequency source is pulsed on in synchronism with the pulses applied to the electrodes of the electron gun.

In the bunching section **13** which can typically be a disc loaded waveguide certain dimensions, such as the waveguide inside diameter, the beam aperture diameter, the disc spacing and the disc thickness, can be varied along the length thereof whereby the electron beam passing therethrough will be velocity modulated such that the beam will be formed into bunches of electrons as is passes into the uniform accelerating section **14**. Also the bunching section may take a number of different forms, or may not even be utilized under certain conditions.

The accelerating section **14** is typically a length of disc-loaded waveguide forming a plurality of coupled cavities wherein the discs have a constant size aperture therein and are uniformly spaced along the length of the waveguide. In the buncher section **13** the electrons in the beam are bunched, and these bunches ride up to the crest of the radio frequency wave propagating through the accelerating structure. As these electron bunches pass through the uniform accelerating section **14**, energy is continuously given up by the radio frequency wave to the electron bunches and the bunches are thereby greatly accelerated.

In typical linear electron accelerators when the accelerated electron beam emerges from an accelerating structure the particles making up the beam will have obtained extremely high energies such as anywhere from a few to very many million electron volts. Also, for maximum efficiency of X-ray production the radio frequency power remaining in the accelerating guide when the traveling radio frequency wave has reached the end of the accelerating structure may typically be on the order of 10% of the injected radio frequency power. This power is usually passed through an output transformer and either through radio frequency vacuum window assembly to a water cooled load or through a waveguide to be fed back into the input of the accelerating structure.

The terminating section **15** according to the present invention and more fully described below is positioned at the output end of the uniform accelerating section **14** and not only acts as a radio frequency wave terminating section but also as a means for continuing to accelerate the electron beam after it enters from the accelerating section **14** to the desired energy level, or leaving the entry energy unaltered or reducing the beam energy as required by the particular application. It is usually desirable to continue to impart energy to the beam in the terminating section.

The external wall of the waveguide of the bunching section **13**, the accelerating section **14** and the terminating section **15** can, itself, constitute the vacuum envelope for the particle accelerator **11** or, as is shown in the illustrated embodiment of the present invention, a vacuum envelope **16** can enclose the radio frequency waveguide which is then provided with pump out holes whereby the waveguide can be evacuated.

The high energy bunched particle beam emanating from the terminating section of the particle accelerator **10** can either be passed through a continuation of the evacuated envelope or as shown for convenience directly through a particle permeable vacuum window **20** into open atmosphere. In either case the particle beam can be bent, scanned, or directed onto a target for emitting X-rays, or utilized in any one or more of a number of schemes.

A beam focusing solenoid **17** circumscribes the accelerating structure to prevent the beam from spreading as it travels along the length of the particle accelerator **10**. Since with the present invention a radio frequency wave coupler is not provided at the output end of the particle accelerator **10**, the focusing solenoid **17** can conveniently be slipped over the output end of the accelerating structure onto the accelerating structure. This is a most desirable advantage of the present invention and reduces the cost and complexity of the vacuum envelope **16**. Another great advantage of this arrangement owing to the absence of external connections is the capability of the acceleration structure to freely expand and contract within the vacuum vessel as described in detail below.

Referring now to FIGS. 2 and 3 there is shown a typical embodiment of the terminating section **15** of the present invention. The structure of the terminating section **15** includes a disc loaded waveguide **18** forming a slow wave structure for the radio frequency power in the accelerating structure and having the same dimensions as the disc loaded waveguide of the uniform accelerating section **14**. The loaded waveguide **18** is made up of a plurality of centrally apertured conductive disc members **18** as of, for example, copper, each disc member **19** being spaced from the adjacent disc member **19** by a hollow cylindrical spacer wall **21** of high, electrically resistive magnetic material such as, for example, magnetic stainless steel.

The alternatively stacked disc members **19** and spacer walls **21** form a plurality of cavity resonators **22** coupled together through the central apertures **23** in the disc members **19**. A plurality of pump out holes **24** are provided in each of the spacer walls **22** to assist in the evacuation of the waveguide **18** positioned within the envelope **16**.

Waveguide cooling means such as water cooling tubes (not shown) are provided on the exterior surface of the waveguide for cooling the waveguide since a large amount of heat is generated in the terminating section wherein residual radio frequency power is attenuated. If the wall of the waveguide **18** were the vacuum envelope it could be completely surrounded by a cooling fluid. A plurality of radial supports **25** are provided for supporting the waveguide **18** within the envelope **16**.

A radio frequency cut-off device **26** is provided at the end of the waveguide **18** of the terminating section **15** for preventing the passage of radio frequency waves through the end of the waveguide **18**. However, this cut-off device **26** can be removed from the end of the guide for extracting or introducing radio frequency power during the testing of the accelerating structure.

The last cavity resonator **22** in the terminating section **15** provides a reflection for the radio frequency waves traveling along the accelerating structure whereby the residual radio frequency wave power at the end of the particle accelerator **10** is reflected back down the accelerating structure in a direction opposite to the direction of the particle beam.

By the construction of the particle accelerator described above the accelerating structure can be positioned within the vacuum envelope **16** with only the input end of the accelerator structure **13** anchored to the vacuum envelope **16** whereby the remainder of the accelerating structure including the length of the bunching section **13**, the accelerating section **14**, and the terminating section **15** is free to move lengthwise within the envelope **16** when the accelerating structure expands as it becomes hot.

The particle accelerator **10** operates in the following manner. As the radio frequency waves coupled into the accelerating structure through coupler **12** travel through the bunching section **13** and the accelerating section **14** the waves impart energy to the electrons passing therethrough to bunch and accelerate the particles of the beam. From the accelerating section **14** the radio frequency wave propagates into the terminating section **15** wherein it continues to interact with the particle beam and impart energy thereto. Furthermore, as the radio frequency wave propagates through the terminating section it is greatly attenuated, especially by the highly resistive spacer walls **21**. Thus, the radio frequency wave continues to give up energy to the electron beam as it is being attenuated itself. In the last cavity resonator **22** of the terminating section **15** the radio frequency wave is reflected and travels backward in the terminating section **15** in the opposite direction to the direction of the electron beam and is again attenuated as it passes therethrough. The length of the terminating section is selected such that the attenuating characteristics of the terminating section **15** in the forward direction plus the attenuating characteristics of the terminating section **15** on the reflected wave traveling in the backward direction provide the proper amount of attenuation for the residual radio frequency wave power entering the terminating section **15** from the accelerating section **14** in order to prevent interference by the reflected wave with the bunching and accelerating characteristics of the bunching section **13** and the accelerating section **14**, and to prevent undue frequency pulling of the radio frequency generator.

In a typical particle accelerator of the type herein described the electron phase positions commence to deviate undesirably from their design orbits within the buncher section when the available forward power is reduced by 8%. Also, the capability of the buncher section to produce an energy focus is effected when the reflected power is at a high level.

Even though the terminating section **15** attenuates the residual power of the radio frequency wave in the forward direction, under some conditions it is undesirable to have the residual radio frequency power at the end of the terminating section so low that the particle beam will regeneratively provide radio frequency power and will give up energy to the radio frequency structure. According to the present invention the length of the termination can be arranged such that the attenuation in the forward direction can be reduced to zero if necessary but for practical purposes this attenuation is selected such that in combination with the attenuation in the backward direction the level of the reflected power is sufficiently reduced whereby the bunching and accelerating characteristics of the accelerating structure are not impaired and the radio frequency generator is not pulled.

The following two tables show the manner in which the residual radio frequency power in a typical particle accelerator can be attenuated within the accelerating structure. The specific particle accelerator is especially adaptable for therapy. The injected peak radio frequency power is approximately 1.75 megawatts and electron energies on the order of about 6 million electron volts are produced. However, much greater energies can be produced. The tables show the attenuating characteristics of particle accelerators of equal length wherein along the accelerator axis the lengths of the accelerating section **14** and the terminating section **15** are varied to vary the amount of attenuation presented to the residual radio frequency power.

TABLE I

Distance along accelerator axis in Fig. 1	In cms.	Forward Power, mw.		Reflected Power, mw.		Electron Beam Energy (mev.)
		Unloaded	Loaded, 100 ma. pk.	Unloaded	Loaded	
	0	1.75	1.75	0.176	0.091	0.08
W	10	----------	1.60	----------	*0.095	----------
X	55	1.41	1.15	0.225	0.112	2.8
Y	130	1.07	0.61	0.30	0.147	5.9
Z	150	0.56	0.28	0.56	0.28	6.5

*i.e., 6% of forward power.

TABLE II

Distance along accelerator axis in Fig. 1	In cms.	Forward Power, mw.		Reflected Power, mw.		Electron Beam Energy (mev.)
		Unloaded	Loaded	Unloaded	Loaded	
	0	1.75	1.75	.064	.027	.08
W	10		1.60		*.028	
X	55	1.41	1.15	.079	.034	2.8
Y	110	1.15	0.73	.096	.041	5.3
Z	150	0.32	0.15	0.32	0.150	6.4

*i.e., 1.75% of forward power.

The amount of attenuation presented to the residual radio frequency power leaving the uniform accelerating section **14** can be varied in several different ways. Attenuation, I, is determined by the following formula:

$$I=\frac{\pi c}{QVg\lambda}$$

wherein c is the velocity of light, Q is 2π times the ratio of the energy stored in the cavity resonators of radio frequency propagating structure to the energy lost in the cavity resonators of the structure per cycle, Vg is the group velocity of the radio frequency wave traveling along the structure and λ is the free space wavelength of the radio frequency wave. Therefore, for a given operational frequency the attenuation in the terminating section **15** can be increased over the attenuation presented in the uniform accelerating section **14** by decreasing Q and/or Vg. Q can be decreased by decreasing the ratio of effective cavity volume to effective electrical surface area. Another way of reducing the Q of a cavity is to increase the permeability and/or resistivity.

In the embodiment described above the cavity walls of high resistivity magnetic material, such as magnetic stainless steel greatly increased the attenuation of a terminating section having cavities of the same dimensions as those of the accelerating section. For example, accelerating sections having copper spacer walls would have a Q on the order of 12,500 whereas the cavities of the terminating section **15** described above of similar size as those of the uniform accelerating section but with magnetic stainless steel walls **21** would have a Q on the order of 1400. Even if the walls were of high resistivity non-magnetic material instead of magnetic material the Q would still be on the order of 2500.

As an alternative embodiment of the present invention the disc members **19** as well as the spacer walls **21** can be made of high, electrically resistive material to provide even greater attenuation for the radio frequency wave in the terminating section **15**. However, in such a structure the heat dissipated in the disc members **19** cannot be conducted out to the cooling means surrounding the waveguide **18** as easily as in the embodiment described above wherein the disc members **19** are made of highly conductive material such as copper. In this present embodiment cooling means such as water channels can be provided into the disc members **19** to more adequately cool these disc members **19**.

Referring now to FIG. 4, there is shown another embodiment of the present invention wherein a plurality of grooves **27** providing an uneven surface are provided across the current path along the surface of the disc members **19'** and the spacer walls **21'** whereby the residual radio frequency power in the waveguide can be attenuated to a much greater degree within the same axial length of waveguide. The grooves cut in this manner across the current path decrease the cavity Q by decreasing the ratio of effective cavity volume to effective electrical surface area. The cavities of a termination constructed in such a manner with disc members **19**, as of copper, and spacer walls **21'** as of non-magnetic stainless steel have a Q on the order of 1600. If the spacer walls are also magnetic the Q would be on the order of 1100.

In the terminating section a great deal more power is absorbed per unit length than in the accelerating waveguide and even though the structure is cooled the temperature of the structure will rise, the cavities will expand, and the waveguide wave length of the cavities will change thereby causing a phase shift between the electron beam and the radio frequency wave. This results in undesirable contributions to electron beam energy spread.

It is therefore advantageous to have a very high attenuation factor so that the termination can be very short in length thereby considerably minimizing the spectrum spreading contribution to the electron beam due to operational fluctuations.

If the material of the terminating section is made of a material with a lower coefficient of expansion and/or if the terminal Vg is lower than that of the uniform accelerating section so that the frequency change is not so great for a given rise in temperature, then the phase shift will be even less.

Still a further alternative embodiment of the present invention is illustrated in FIG. 5 which shows the last cavity resonator **28** of the uniform accelerating section **14** and the first cavity resonator **29** of the terminating section **15''**. In this embodiment the central apertures **23''** of the disc members **19''** are smaller than the central apertures **32** of the disc members **31** in the uniform accelerating section whereby the cavity resonators in the terminating section propagate a radio frequency wave therethrough with a reduced group velocity than do the cavity resonators of the accelerating section **14''**.

As still a further embodiment of the present invention, the desirably low Q of the cavities in the terminating section can be achieved while still utilizing properly treated cavity spacer walls and disc members of the same dimensions and same materials as those of the uniform accelerating section. This greatly facilitates the fabrication of the particle generator. Referring to FIG. 6, a terminating section **33** secured to the end of a uniform accelerating section **30** includes a plurality of cavity resonators **34** comprised of alternately stacked apertured disc members **35** such as copper and spacer walls **36** such as copper, adjacent cavities being coupled through the apertures **37** in the disc members **35**. The last spacer wall **36** which is adapted to support a radio frequency cut-off device **40** at the end thereof can be made of stainless steel for added strength as well as to increase the attenuation of the last cavity. High resistive metal powder **38** is sprayed onto parts of the termination thereby increasing the attenuation. A good material for this purpose is metal powder sold under the trademark Kanthal. In many ways, such a material is ideal for increasing the attenuation of the cavity structure. I has a high resistivity ρ and high magnetic permeability μ. Furthermore, the Kanthal sprayed on the cavity surfaces leaves a very uneven surface whereby the ratio of cavity volume to effective surface area is reduced. A cavity of the same dimensions as those of the cavities described above and with copper spacer walls sprayed with Kanthal has a Q of 300. An even lower Q can be provided by spraying the Kanthal on the disc members **35** as well as the spacer walls **36**.

Typically as shown in the FIG. 6, the amount of Kanthal provided in successive cavities along the length of the terminating section **33** is gradually increased such that a very large thermal discontinuity will not be provided at the front end of the terminating section **33** of the accelerating structure due to an extremely large difference between the attenuation in the last cavity of the uniform accelerating section **30** and the attenuation in the first cavity of the terminating section **33**.

Also Kanthal can be applied to portions of the terminating section by first sandblasting the region where the Kanthal is to be applied. This presents an even rougher surface and permits the Kanthal to stick to the structure better.

Other materials besides Kanthal that can be sprayed onto the terminating structure are high loss materials such as stainless steel, iron, Kovar, etc.

The following table shows the manner in which the residual radio frequency power can be attenuated in a typical particle accelerator of the construction shown in FIG. 6.

TABLE III

Distance along axis in Fig. 1	In cms.	Forward Power, Mw.		Reflected Power, Mw.		Electron Beam Energy (mev.)
		Unloaded	Loaded 100 ma. pk	Unloaded	Loaded 100 ma. pk.	
	0	1.75	1.75	0.031	0.0143	0.08
W	10		*1.60		*0.015	
X	55	1.41	1.15	0.038	0.018	2.80
Y	140	1.04	0.55	0.050	0.024	6.25
Z	150	0.23	0.11	0.230	0.110	6.47

*0.94% of forward power.

VSWR at RF generator without ferrite isolator and without beam loading=1.31

VSWR at RF generator without ferrite isolator and with 100 ma. pk. loading=1.186

VSWR at RF generator with 5 db isolation and with 100 ma. pk. loading=1.106

VSWR at RF generator with 10 db isolation and with 100 ma. pk. loading=1.060

Alternatively, the attenuation provided by the terminating section **15** to the residual radio frequency power at the end of the uniform accelerating section can be increased by loading the cavity resonators of the terminating section with loading members such as resistive coated ceramic members or by increasing the thickness of the disc members in the terminating section over the thickness of those in the uniform accelerating section.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A particle accelerating structure comprising, in combination, an accelerating section including a disc loaded waveguide comprised of a plurality of coupled cavity resonators adapted to pass a particle beam therethrough and to propagate a radio frequency wave for interaction with and acceleration of said particle beam, and a collinear terminating section including a disc loaded waveguide comprised of a plurality of coupled cavity resonators adapted to pass a particle beam therethrough and to propagate a radio frequency wave for interaction with and acceleration of said particle beam, said cavity resonators of said termination section adapted to progagate a radio frequency wave therethrough with a reduced group velocity than said cavity resonators of said accelerating section whereby any residual power of a radio frequency wave emanating from said accelerating section is greatly attenuated in said termination section.

2. A particle accelerating structure comprising, in combination, an accelerating section including a disc loaded waveguide comprised of a plurality of coupled cavity resonators adapted to pass a particle beam therethrough and to propagate a radio frequency wave for interaction with and acceleration of said particle beam, and a collinear terminating section including a disc loaded waveguide comprised of a plurality of coupled cavity resonators adapted to pass a particle beam therethrough and to propagate the radio frequency wave for interaction with and acceleration of said particle beam, the apertures in the discs of said terminating section being smaller than the apertures in the discs of said accelerating section whereby any residual power of a radio frequency wave emanating from said accelerating section is greatly attenuated within said terminating section.

3. A particle accelerator comprising, in combination, an accelerating section including a disc loaded waveguide comprised of a plurality of coupled cavity resonators adapted to pass a particle beam therethrough and to propagate a radio frequency wave therethrough for interaction with and acceleration of said particle beam, and a collinear terminating section including a disc loaded waveguide comprised of a plurality of coupled cavity resonators adapted to pass a particle beam therethrough and to propagate a radio frequency wave therethrough for interaction with and acceleration of said particle beam, the discs of said terminating section being thicker than the discs of said accelerating section whereby residual power of a radio frequency wave emanating from the end of said accelerating section is greatly attenuated in said terminating section.

4. A particle accelerating apparatus comprising, in combination, an accelerating waveguide means for propagating a radio frequency wave for interaction with and acceleration of a particle beam passing therethrough from an input end at which the particles in the beam are introduced at an initial velocity to an output end at which the particles in the beam are discharged at an accelerated velocity higher than said initial velocity and a collinear termination section having a termination input end located at the output end of said accelerating waveguide means for receiving the accelerated particles discharged from the output end of said accelerating waveguide means and a termination output end for passing the accelerated particles for utilization, said collinear termination section including cavity resonators apertured for passing particles from the output end of said accelerating waveguide to the termination ouput end in interacting relationship with the radio frequency wave traveling from the output end of said accelerating waveguide through said termination section, said cavity resonators having wall means for providing high attenuation to the radio frequency wave passing therethrough with said wall means positioned to insure transfer of energy from the radio frequency wave to the particles traveling along the length of said termination section whereby within the termination section the radio frequency wave is attenuated as it gives up energy to accelerate the particles.

5. The particle accelerating apparatus in accordance with claim 4 including means at the termination output end for causing residual radio frequency power remaining at said termination to be reflected back toward said termination input end whereby the radio frequency wave reflected at the termination output end is attenuated while traveling through said termination section in the backward direction.

6. The particle accelerating apparatus in accordance with claim 4 wherein said termination section includes a loaded waveguide defining a plurality of cavity resonators and at least a portion of the walls of said cavity resonators including a high, electrically resistive material for attenuating the radio frequency wave traveling therethrough.

7. The particle accelerating apparatus in accordance with claim 4 characterized further in that said termination section includes a loaded waveguide defining a plurality of cavity resonators, at least a portion of said cavity resonators being provided with an uneven surface which increases the attenuating characteristics of said resonators to radio frequency waves for attenuating radio frequency waves traveling therealong.

8. The particle acceleraing apparatus in accordance with claim 7 characterized further in that said uneven surface is Kanthal sprayed onto the surface of a portion of said cavity resonators.

9. A particle accelerating structure comprising, in combination, an accelerating section including a disc loaded waveguide constructed to pass a particle beam therethrough from an input end at which the particles in the beam are introduced at an initial velocity to an output end at which the particles in the beam are discharged at an accelerated velocity higher than said initial velocity and to propagate a radio frequency wave for interaction with and acceleration of said particle beam from said input end to said output end, means for directing a particle beam into the input end of said accelerating section for acceleration therealong, means for introducing into said accelerating section at the input end thereof a radio frequency wave for interaction with and acceleration of said particle beam, a collinear termination section at the output end of said accelerating section including a disc loaded waveguide adapted to pass a particle beam and to propagate a radio frequency wave from a termination input end adjacent the output end of said accelerating section to a termination output end for beam-wave interaction and acceleration of said particle beam, the attenuation of said termination section presented to the radio frequency wave therein being greater than the attenuation of said accelerating section presented to a radio frequency wave passing therethrough for greatly attenuating the residual power of radio frequency waves passing from the output end of said accelerating section through said termination section while maintaining a high axial accelerating electric field in at least the initial portion of said termination section, and means for passing accelerated particles out of said termination output end for utilization.

10. A particle accelerating structure comprising, in combination, an accelerating section including a disc loaded waveguide means having an input end at which the particles in the beam are introduced at an initial velocity and an output end at which the particles in the beam are discharged at an accelerated velocity higher than said initial velocity and comprised of a plurality of coupled cavity resonators for passing a particle beam therethrough from said input end to said output end and propagating a radio frequency wave for interaction with and acceleration of said particle beam from said input end to said output end, means for directing a particle beam into said input end of said accelerating section for acceleration therealong, means for introducing a radio frequency wave into said accelerating section for interaction with and acceleration of said particle beam therein, a collinear termination section having a termination input end and a termination output end, said termination input end located adjacent the output end of said accelerating section, said termination section including a disc loaded waveguide comprised of a plurality of coupled cavity resonators for passing a particle beam therethrough from said termination input end to said termination output end and propagation of radio frequency waves therethrough for interaction with and acceleration of said particle beam while said radio frequency waves travel from said termination input end to said termination output end, the Q of the cavity resonators of said termination section being much less than the Q of the cavity resonators of said accelerating section whereby any residual power of a radio frequency wave emanating from said accelerating section is greatly attenuated in said termination section, and means for passing accelerated particles out of the termination output end for utilization.

11. The method of accelerating a beam of charged particles to a high velocity comprising the steps of:

passing a beam of charged particles in synchronism with a radio frequency wave whereby energy is given up by the wave to accelerate the particles of the beam; then after the beam is partially accelerated, greatly attenuating the residual power of the radio frequency wave along the beam path while providing continuous, simultaneous interaction between the wave and the particles of said beam to continue to accelerate the beam of charged particles; then reflecting the radio frequency wave back in the opposite direction to the direction of said accelerating beam; and again greatly attenuating the residual power of the radio frequency wave as it travels along the beam path in the direction opposite to the direction of the accelerating beam.

12. A termination for particle accelerating structures for terminating radio frequency power adjacent the output end of the accelerating structure at which the accelerated beam of charged particle emerges comprising, in combination, means for coupling radio frequency power into the termination, a plurality of apertured discs, a plurality of hollow, cylindrical spacer walls, one of said spacer walls interposed between each adjacent pair of apertured discs whereby said discs and said walls form cavity resonators adapted to propagate a radio frequency wave coupled into said termination at a first end thereof; a highly resistant material provided on at least certain of the surfaces of said cavity resonators, said cavity resonators phase tuned for propagating the radio frequency wave, the amount of said resistant material provided in each of said cavities increasing from said first end of said termination to the second end of said termination, the cavity resonator at the second end of said termination positioned as to reflect any residual power of said radio frequency wave traveling therein back toward said first end of said termination section whereby the radio frequency wave is attenuated both as it travels in the forward direction from said first end to said second end of said termination and in the backward direction from said second end to said first end of said termination and means for connecting said first end of said termination section to the output end of an accelerating structure at which the accelerated beam of charged particles emerges.

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