

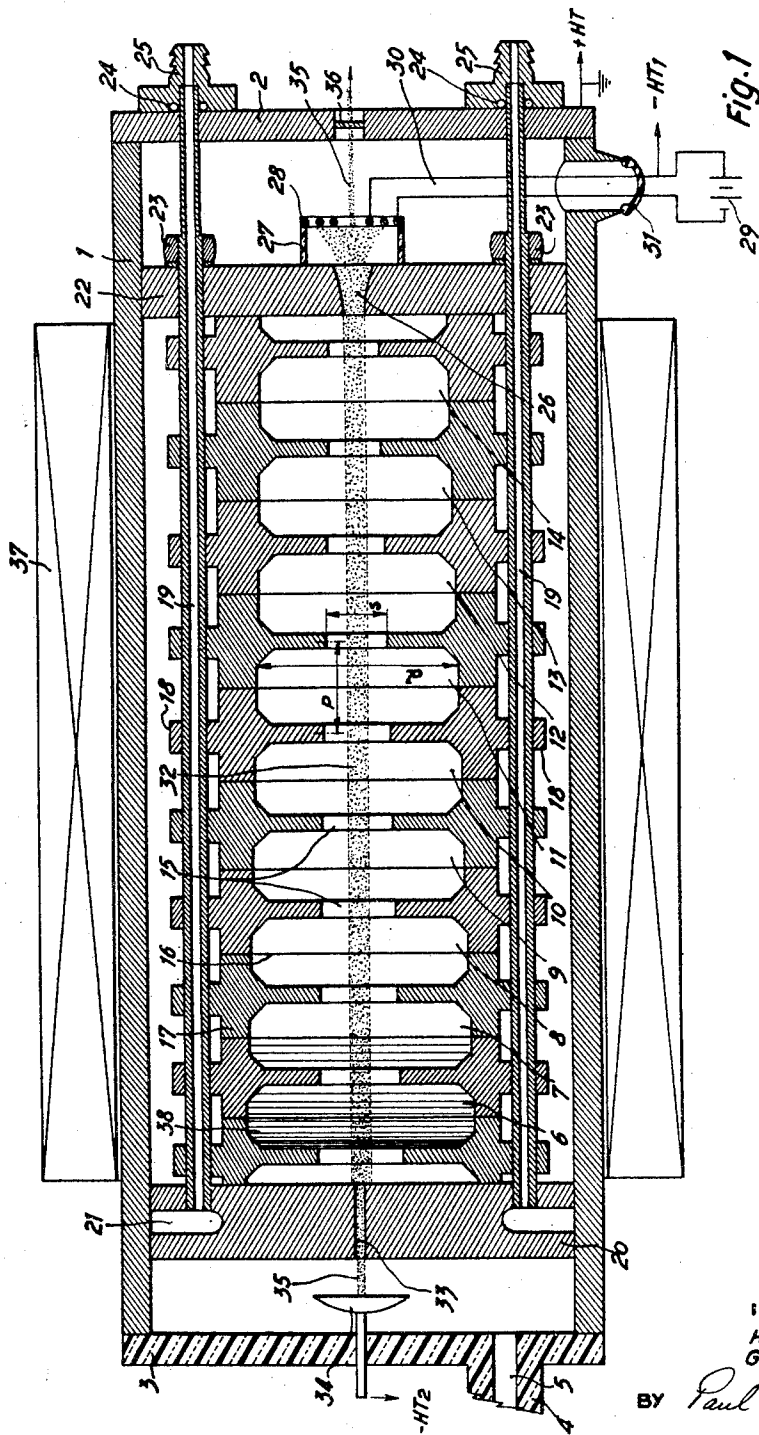
Dec. 11, 1962

H. LE BOUTET ET AL
TRAVELLING WAVE TUBE OSCILLATOR AND ELECTRON
ACCELERATING DEVICE

3,068,425

Filed June 10, 1958

4 Sheets-Sheet 1



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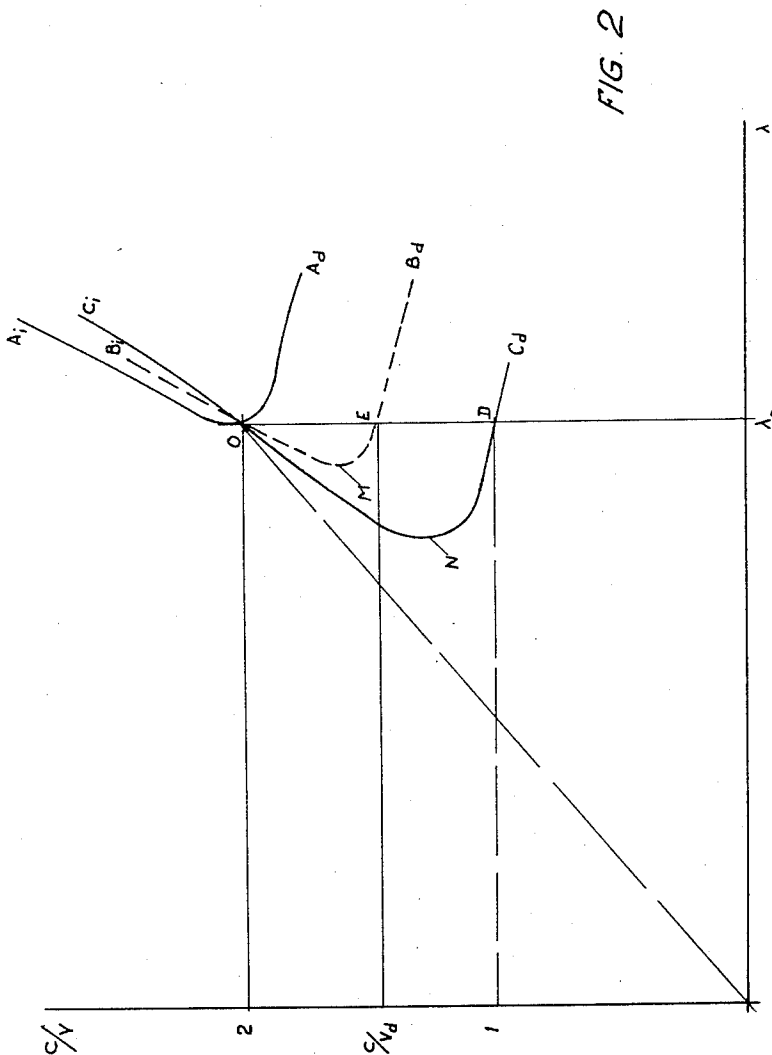
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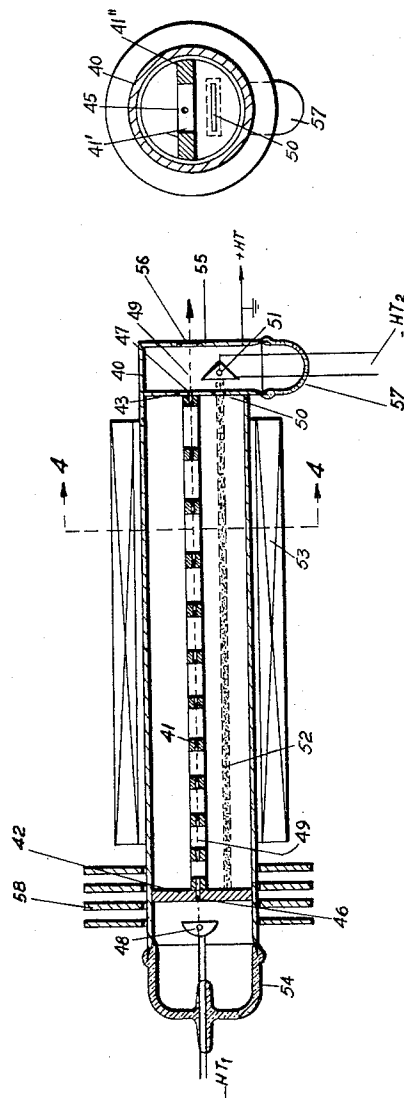


FIG. 4

FIG. 3

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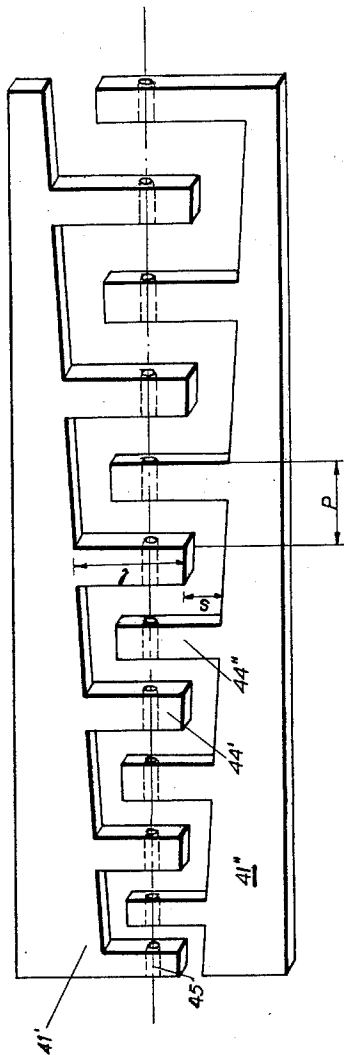


FIG. 5

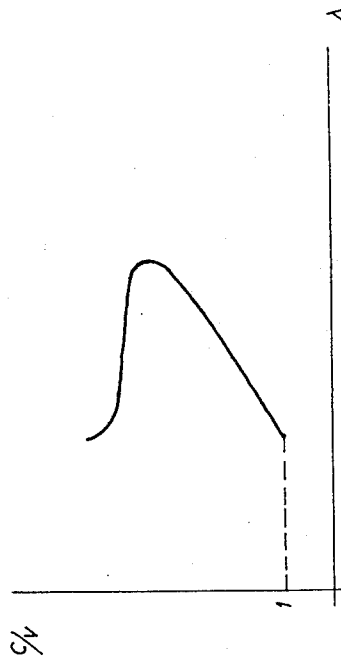


FIG. 6

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3,068,425

TRAVELLING WAVE TUBE OSCILLATOR AND ELECTRON ACCELERATING DEVICE

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Claims priority, application France June 25, 1957

26 Claims. (Cl. 331-82)

The present invention relates to a linear electron discharge system of the traveling wave type, and more particularly to linear electron accelerators of the traveling wave type.

Before describing the present invention, it is believed appropriate to define at first the terminology used in connection with the present application, it being understood that the term "traveling wave" applies in the ensuing text to the accelerators as well as to the oscillators, and encompasses the tubes which operate by the interaction with a direct or forward traveling wave as well as with a reverse traveling wave, the latter being also called a "backward wave." Oscillators which function by the interaction with a backward wave are also known in the art as "Carcinotrons" and are constructed and operate as more fully disclosed in the United States patent application by Bernard Epsztein, Serial No. 281,347, filed April 9, 1952, now Patent No. 2,932,760, entitled "Backward Flow Travelling Wave Oscillators." It might also be appropriate at this time to recall that each geometrically periodical delay line is constituted by a chain of cells coupled with each other, or may be assimilated to such a chain. For convenience of language, it is understood that when speaking of the "pitch" of a line, this term refers to the longitudinal dimension of each cell.

The traveling wave linear electron accelerators of the known type recognized in the prior art include a delay line having a variable pitch, which is coupled for interaction with an electron beam which in turn is accelerated when the line is traversed by a traveling wave of a given frequency and of suitable phase velocity.

This traveling wave is excited or produced in the delay line by a microwave generator, which is disposed either externally or internally of the tube containing the accelerator. In the latter case, particularly with an accelerator operating by the interaction with the forward fundamental space wave, it is known to utilize as generator an auto-oscillator of the traveling wave type, which operates also by interaction with the forward fundamental space wave, this interaction being attained by coupling the beam, to be ultimately accelerated, with a portion of the delay line disposed in extension of the delay line portion which enters into interaction with the beam to accelerate the same.

The prior art tube containing this oscillator and accelerator assembly is, therefore, of relatively great length; for it includes, in extension of one another, two portions of delay line utilized, respectively, for the generation of oscillations and for the acceleration of the beam.

It is an object of the present invention to provide a linear electron accelerator, excited by a generator disposed within the same tube, which enables a reduction of the length of this tube.

According to the present invention, the accelerator, operating by interaction with the fundamental space component of a traveling wave, is excited by an oscillator operating by interaction with the first space harmonic of the same wave, one and the same delay line being utilized with both the oscillator and the accelerator.

Two cases may present themselves in accordance with the present invention, depending on the type of delay line

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used. If the delay line is such that the fundamental space wave is forward, the first space harmonic is backward, and the oscillator for excitation is an oscillator generally known under the term "Carcinotron," i.e., a backward wave type oscillator. If, in contrast thereto, the fundamental space wave is backward, then the first space harmonic is forward and the oscillator may be of the type having a feedback provided by an external circuit or by internal reflection.

The accelerator according to the present invention is constituted by a vacuum tube containing a delay line having a variable pitch, coupled for purposes of interaction with two beams of opposite directions, and of which the cells of the delay line are dimensioned, by acting on the parameters thereof other than the pitch, in such a manner that the phase velocity of propagation of the first space harmonic, for a given frequency, is constant along the delay line and is equal to the constant speed of a beam directed in the sense of decrease of the pitch of the delay line, the second beam thereby being subjected to acceleration by reason of the fact of its interaction with the fundamental space wave which propagates along the line with an increasing speed.

According to one embodiment of the present invention, the beam having an increasing speed is obtained by reflecting, by means of an electrode suitably connected to an appropriate voltage, a portion of the beam having a constant velocity.

Accordingly, it is an object of the present invention to provide a linear electron discharge system for accelerating electrons by means of interaction with a traveling wave which system is of relatively short length in its physical dimension and relatively compact as well as efficient.

Another object of the present invention is to provide a linear electron discharge system for accelerating electrons by the interaction with a traveling wave in which the traveling wave is produced within the tube itself by the generation of suitable oscillations.

Still another object of the present invention is the provision of a delay line which achieves the objects mentioned hereinabove and in which the different cells of the delay line are so dimensioned with respect to each other as to achieve the desired results.

A further object of the present invention is the provision of an electron discharge system having two electron beams in which one beam is operative to produce a traveling wave of predetermined frequency in the delay line and in which the other beam is operative by interaction with this traveling wave to accelerate the electrons thereof.

These and other objects, features and advantages of the present invention will become more obvious from the following description when taken in connection with the accompanying drawing which shows, for purposes of illustration only, several embodiments in accordance with the present invention and wherein:

FIGURE 1 is an axial cross-sectional view of a first embodiment of a linear electron accelerator in accordance with the present invention;

FIGURE 2 is a diagram of the dispersion curves for some of the cells of the delay line used in FIGURE 1;

FIGURE 3 is a longitudinal cross-sectional view through a second embodiment of a linear electron accelerator in accordance with the present invention;

FIGURE 4 is a transverse cross-sectional view taken along line 4-4 of FIGURE 3;

FIGURE 5 is a perspective view of a delay line used in the embodiment of FIGURES 3 and 4; and

FIGURE 6 is a dispersion curve for the delay line of FIGURE 5.

Referring now to the drawing, wherein like reference

numerals are used throughout the various views to designate like parts, and more particularly to FIGURE 1, which shows an accelerator in longitudinal cross section, reference numeral 1 designates an envelope formed by a metallic cylinder containing the accelerator which cylinder is closed on one side thereof by a metallic cover 2 and on the other side thereof by a ceramic cover 3 provided with an extension 4. The extension 4, in turn, is provided with an orifice 5 and is connected with the conduit leading to the vacuum pump which enables maintenance of a high vacuum in the envelope 1 of the tube. A delay line is disposed within the interior of the envelope 1 of which the particulars concerning dimension will be discussed hereinafter. The delay line is constituted by a chain of cylindrical cavities 6, 7, 8, 9, 10, 11, 12, 13 and 14 coupled with each other by apertures 15 which are arranged concentrically with respect to the axis of the accelerator. For convenience of construction, each cavity is separated into two half-cavities by transverse planes 16, and each pair of half-cavities at both coupling apertures is made in practice in the form of a single piece of copper 17. Each piece 17 is provided with two ear portions 18 which are diametrically opposed, all of the pieces 17 being assembled by emplacement or stacking one adjacent another and being aligned by means of two hollow tubes or sleeves 19 on which are mounted the ear portions 18, the tubes 19 being cooled by the circulation therethrough of a cooling liquid at the interior thereof, and the cavities being, as a result thereof, cooled by convection. The tubes 19 are brazed to a collector 20 in such a manner that the extremities thereof terminate in a circular cooling channel 21 provided in the collector 20. The collector 20, of which the diameter is equal to the internal diameter of the cylinder 1, is fixed thereto in any suitable manner, for example, by brazing. On the other end thereof, the tubes 19 pass freely across corresponding apertures provided in the accelerating anode 22 of which the diameter is also equal to the internal diameter of the cylinder 1 but which may freely slide along the interior thereof. After having assembled and emplaced the pieces 17 of the delay line, the anode 22 is thereupon emplaced over the sleeves 19 and the entire assembly is tightened by means of nut members 23, the corresponding portion of the tubes or sleeves 19 being suitably threaded for that purpose. The tubes 19 are each extended by a portion passing through cover 2 and are tightened by an end piece 25 with the interposition of a tight seal 24 of any suitable construction in order to be connected to the circulatory system of the cooling medium.

The first cavities near the end of the delay line adjacent collector 20, for example, cavities 6 and 7, have the surfaces thereof covered with an attenuating layer progressively decreased in the axial direction as indicated in the drawing by the shading 38. However, it is understood that any other suitable equivalent means may be used for the attenuating means shown in FIGURE 1, such as, for example, the use of lossy materials for the first few blocks 17 of the delay line.

The anode 22 which is provided at the center thereof with an orifice 26 of suitable cross section supports, on the external face thereof, by the intermediary of insulating columns 27, a cathode 28, for example, in the form of a spiral of thoriated tungsten, which leaves at the center thereof a hole or aperture. The spiral of the cathode 28 is heated by means of a source 29 and the connections 30 therefor pass through an insulating passage 31 provided therefor in tube 1.

The cover 2 is pierced in the center thereof and the orifice is obturated or closed by a very thin window 36 of aluminum or platinum brazed to the support thereof.

The cathode 28 is connected by the connection $-HT_1$ thereof to the negative terminal of the high voltage source of any suitable construction of which the positive terminal as well as the assembly of the tube 1 and all the

other parts electrically connected therewith are connected to ground.

The cathode 28 emits electrons which, during passage through the orifice 26 of the anode 22 carried at a relatively high voltage with respect to the cathode 28, are focused into a cylindrical beam 32 which propagates along the axis of the system through the coupling apertures 15. At the end of the trajectory or path thereof, the beam 32 is absorbed by collector 20 with the exception of a small portion thereof which passes through an axial channel 33 provided in the collector 20 and having a much smaller diameter than the beam 32. A small portion of the beam 32 thus traverses through the collector 20, and the electrons of this small portion of the beam 32 return back under the action of a reflector 34 fed by a connection $-HT_2$ passing through the insulating cover 3, the potential of this connection $-HT_2$ being equal or less (more negative) than that of the cathode 28 and being also adjustable. The electrons repelled by reflector 34 thus form a beam 35 of weak intensity which passes again through the channel 33, thereupon propagates through the beam 32 and in the axis thereof in a direction opposite with respect thereto, passes through the coupling apertures 15, the orifice 26, the hole in the center of the cathode 28 and finally through the output window 36.

The beams 32 and 35 are focused by a longitudinal magnetic field furnished by coil 37 or by an equivalent permanent magnet of suitable construction.

The considerations which lead to the rules concerning the dimensions of the chain of cavities 6 to 14 will be more readily understood by reference to FIGURE 2 which indicates a family of dispersion curves, that is,

$$\frac{c}{v}$$

as a function of λ , c being the speed of light, v being the phase velocity, and λ being the wave length of the propagated wave, for a delay line of the forward fundamental type. It is well known that the line with cavities which has been illustrated as an example in FIGURE 1, belongs to this class of delay lines.

Three dispersion curves A_1OA_0 , B_1MB_0 , and C_1NC_0 have been shown in FIGURE 2 of which the position in the coordinate system depends on the structural parameters of the delay line. Each curve comprises a branch of a so-called direct or forward dispersion, namely branches OA_0 , MB_0 and NC_0 which corresponds to the fundamental space wave, and a branch having an inverse or backward dispersion, namely OA_1 , MB_1 and NC_1 which corresponds to the first space harmonic. The common points of the two branches O, M and N correspond to the π mode operation thereof.

It is always possible to establish in the plane of the coordinates a point O corresponding to a desired wave length λ_0 and with a desired value of

$$\frac{c}{v}$$

for example,

$$\frac{c}{v_1} = 2$$

The delay line of the accelerator in accordance with the present invention is constituted by chaining together cells which are dimensioned in a different manner and each of which has a dispersion curve occupying a different position in the coordinate system, the common characteristic of these curves being the fact that the inverse or backward branches thereof all pass through the point O. In other words, the delay line in accordance with the present invention is such that though the individual cells are made of different physical dimensions, the dispersion curves thereof all intersect in a common

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point with the backward branches thereof, for example, the point O of FIGURE 2.

It should be noted that the position of each of the curves in FIGURE 2 can only be disposed between two limits of which one is determined by the condition that the point O corresponds to the π mode, namely the curve A_1OA_d , and the other by the condition that the direct or forward branch thereof passes through the point D defined by the coordinates λ_0 and

$$\frac{c}{v}=1$$

the speed of $v=c$ representing in effect the upper limit of acceleration which may be realized. This latter curve corresponds to curve C_1NC_d .

It is preferably, though this is not absolutely necessary, to construct the end cavities of the line such as, for example, cavities 6 and 14 in such a manner that for cavity 6 a dispersion curve corresponding to the curve A_1OA_d is obtained and for the cavity 14 a dispersion curve corresponding to the curve C_1NC_d . The intermediate cavities of the delay line such as cavities 7, 8, 9, 10, 11, 12 and 13 are realized so as to obtain dispersion curves intermediate these two last-mentioned curves of which the curve B_1MB_d , shown in FIGURE 2 in dash lines, is an example. The direct or forward branch of this curve intersects the abscissa λ_0 in a point E having an ordinate corresponding to

$$\frac{c}{v_d}$$

It is known that in lines having a periodic structure with a pitch p , the phase velocity is given by the general expression:

$$v = \frac{2\pi \cdot cp}{\lambda_0(\psi_d + 2k\pi)} \quad (1)$$

wherein ψ_d is the phase shift per cell for the fundamental, $0 < \psi_d < \pi$, if the fundamental mode is forward.

From Equation 1, one obtains, for the fundamental mode, if v equals v_d and k equals 0:

$$\frac{c}{v_d} = \frac{\psi_d \lambda_0}{2\pi p} \quad (2)$$

and for the first harmonic mode in which $v = -v_1$, the phase velocity being backward, and $k = -1$:

$$-\frac{c}{v_1} = \left(\frac{\psi_d}{2\pi} - 1 \right) \frac{\lambda_0}{p} \quad (3)$$

Equation 3 gives immediately the relation between the phase shift ψ_d and the pitch p which must be satisfied for each cell of the line for a given

$$\frac{c}{v_1}$$

$$\psi_d = 2\pi \left(1 - \frac{c}{v_1} \cdot \frac{p}{\lambda_0} \right) \quad (4)$$

The pitch for the end cells may be determined by noting that if cavity 6 is established to function in the π mode, corresponding to the point O of the curve A_1OA_d , one has

$$\frac{c}{v_d} = \frac{c}{v_i}$$

and Equation 2 becomes:

$$p = \frac{\lambda_0}{2 \cdot \frac{c}{v_i}} \quad (5)$$

If the cavity 14 is constructed to propagate in direct or forward mode with

$$\frac{c}{v_d} = 1$$

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corresponding to the point D of the curve C_1OC_d , one obtains, by eliminating ψ_d between Equations 2 and 3

$$p = \frac{\lambda_0}{1 + \frac{c}{v_i}} \quad (6)$$

For the intermediate cavities, intermediate the outermost or end cavities 6 and 14, the pitch p varies between the values given by the Equations 5 and 6, according to a law such that the variation in phase velocity experienced by the traveling wave coincides as continuously as possible with the variation in speed to which the electrons of the accelerated beam are subjected. After having determined, on this basis, the pitch p of each cell, one may find from Equation 4 the phase shift to be realized by this cell, which may be realized by acting on the structural parameters thereof other than the pitch. In the cavities of the present invention, these other structural parameters are the diameter of the cavity and the diameter of the coupling aperture.

For example, by giving

$$\frac{c}{v_i} = 2$$

and $\lambda_0 = 10$, one obtains: for cavity 6, $p = 2.5$ cm. and $\psi_d = \pi$, and for cavity 14, $p = 3.33$ cm. and $\psi_d = 0.667\pi$.

The pitch p corresponds to the distance between the average planes of the separating partitioning of two adjacent cavities.

For the intermediate cavities 7 to 13, the values of p and ψ_d are intermediate the two values given hereinabove for cavities 6 and 14.

It has been found that the desired characteristics could be realized in the particular embodiment of the present invention by reducing very slightly the diameter d of the cavity, in passing progressively from a value of 8.3 cm. for the cavity 6 to a value of 8.2 cm. for the cavity 14, and in reducing the diameter s of the aperture 15 from a value of 3 cm. for the cavity 6 to a value of 1.85 cm. for the cavity 14 at the rate at which the pitch increases.

OPERATION

Having thus described completely the structure and dimension of the accelerator in accordance with the present invention, as well as the manner of obtaining the same mathematically, the operation thereof will now be described in greater detail:

Voltages are applied to cathode 28 and to reflector 34 determined by the selected value of

$$\frac{c}{v_1}$$

For example, for a value

$$\frac{c}{v_i} = 2$$

that is, v_1 equal to 150,000 km./sec., a negative potential is applied to the connection $-HT_1$ which corresponds to this speed expressed in volts, taking into account the relativistic correction, that is, a potential near $-80,000$ volts. A lower potential or voltage is applied to the connection $-HT_2$, for example, approximately $-81,000$ volts. The potentials at $-HT_1$ and $-HT_2$ are given with respect to the cylinder 1 and collector 20 which are grounded at the terminal $+HT$. The cathode 28 emits then a beam 32 which propagates with this constant velocity of 150,000 km./sec. between the anode 22 and the collector 20, that is, in the direction of a decrease of the pitch of the delay line. The interaction between the beam 32 and the line produces a starting or build-up in the latter, according to the well-known mechanism of backward wave oscillators, of an oscillation at the selected wave length λ_0 in the mode corresponding to the first backward space harmonic which propagates with a constant phase velocity since all of the cells of the delay line function at the point O of FIGURE 2. This back-

ward wave propagates in a direction opposite to the direction of propagation of the beam 32, that is, from the collector 20 to the anode 22 whereas the phase velocity is directed in the same direction as the beam 32 and remains in synchronism therewith. The attenuation 38 disposed on the line at the end thereof adjacent the collector 20 plays its usual roll as is well known in connection with "Carcinotrons," and furthermore, it being given that this delay line, contrary to those of "Carcinotrons," is not provided with an output at the cathode end thereof but is left thereat open-ended, the energy which is not transferred to the beam is reflected thereat and returns along the line in order to be absorbed by the attenuation 38.

The return beam 35 enters into the delay line with the same speed corresponding to the accelerating voltage of the order of 80,000 volts between the collector 20 and the reflector 34. The return beam 35 then propagates along the axis of the delay line in which propagates, in the same direction, the wave induced by the oscillator mechanism of λ_0 wave length, of which the fundamental mode is forward. The phase velocity of propagation of this mode, directed in the same direction as the beam, is variable and increases in the direction of the beam 35; the point of operation in the forward mode displaces itself in effect between points O and D in FIGURE 2, with the position of the point under consideration on the line. The beam 35 thereupon synchronizes itself with the traveling wave, that is, the velocity thereof varies in a manner to remain constantly in interaction and receive the transfer of energy carried by the wave. It may thus be seen that the beam 35 is accelerated and its speed attains at the end of its traversal at the passage of the cavity 14 a speed v_d equal to c or very close to that value, in conformity with the characteristics realized for that cavity.

This accelerated beam 35, having a large energy, at the output of the channel 26 is only very slightly decelerated by the retarding field due to the difference in potential between the cathode 28 and the anode 22; furthermore, after passage through the cathode 28, it is again accelerated by the same difference in potential between the cover 2 and the cathode 28 and reaches the output window 36 with the same energy which it possessed at the output of the line. Owing to this energy, it readily traverses the window 36 and is available for utilization at the outside of the accelerator.

FIGURES 3 and 4 represent, respectively, a longitudinal cross section and a transverse cross section along line 4—4 of FIGURE 3, of another embodiment of an accelerator in conformity with the present invention. The modified embodiment of the accelerator of FIGURES 3 and 4 includes, at the interior of a tubular evacuated envelope 40, an interdigital delay line 41 with a pitch, width of the line and length of the fingers which are variable, and shown in perspective in FIGURE 5. The delay line is composed of two comb-like structures 41' and 41'' fixed or secured in any suitable manner to the metallic envelope 40. The delay line is terminated at both ends thereof by reflecting planes formed by two circular plates 42 and 43. The fingers 44' and 44'' of the two comb-like structures 41' and 41'', respectively, are pierced longitudinally in such a manner as to form a channel 45 with which are aligned the orifices 46 and 47 pierced into the plates 42 and 43. An electron gun 48 having a point-like cathode, provided with a Wehnelt electrode is disposed suitably with respect to orifice 46. This gun 48 emits through plate 42, operating in the manner of an accelerating anode, a linear beam 49 of weak intensity, which passes through the channel 45 and the orifice 47, in the direction of increase of the pitch of the delay line 41.

On the other hand, plate 43 includes a slot 50, parallel to the plane of the delay line. Behind the slot 50 is aligned a second electron gun 51 having a linear cathode and provided with a Wehnelt electrode. The electron gun 51 emits through the plate 43, operating as anode, a

laminar beam 52 which propagates parallel to the delay line 41, in the direction of decrease of the pitch thereof, and is absorbed by the plate 42 functioning as collector. The beams 49 and 52 are focused by a longitudinal magnetic field furnished, for example, by the winding 53 or by an appropriately constructed equivalent permanent magnet.

The envelope 40 is terminated on one side thereof by a glass seal 54, across which extend the connection —HT₁ of the electron gun 48. On the other end, the envelope 40 is closed by a metallic cover 55 in which is brazed a thin output window 56, aligned with the channel 45 and the orifice 47. The connections —HT₂ of the electron gun 51 extend toward the outside through the glass seal 57 provided along the lateral surface of the envelope 40.

Cooling fins 58 are fixed to the outer surface of the envelope 40 in the vicinity of the plate 42.

The line illustrated in FIGURE 5 is of the type having a backward fundamental space wave, and a first harmonic space wave which is forward. The general form of dispersion curve for this line is shown in FIGURE 6.

The phase velocity may be expressed in this case by a general formula analogous to that of equation 1:

$$v = \frac{2\pi c p}{\lambda_0(\psi_1 + 2k\pi - 2\pi)} \quad (7)$$

in which $2\pi > \psi_1 > \pi$, and ψ_1 is the phase shift per cell for the fundamental backward mode.

By analogous consideration to those pointed out in connection with FIGURE 2 and with the line utilized in the accelerator of FIGURE 1, one may readily determine the length l of the fingers and the pitch of the line of FIGURE 5, by establishing as condition that all cells function in the first direct harmonic mode with the same ratio of delay

$$\frac{c}{v_d}$$

and at a same wave length λ_0 .

By utilizing the same considerations as hereinabove, one obtains:

$$l = \frac{\lambda_0}{2} \frac{\frac{c}{v_d} - 1}{\frac{c}{v_d} + \frac{c}{v_1}} \quad (8)$$

$$p = \frac{\lambda_0}{2} \frac{1}{\frac{c}{v_d} + \frac{c}{v_1}} \quad (9)$$

The dimensions of the line are such that these expressions are valid for each cell of the delay line,

$$\frac{c}{v_1}$$

varying, for example, between

$$\frac{c}{v_d}$$

at the narrow end to 1 at the large end of the line.

The width of each individual finger being constant, and the distance s between the extremity of each finger and the comb opposite thereto being taken as average of the widths of the intervals between contiguous fingers to the finger in question, it may be readily seen that the length $l+s$ of the line is also determined in such a manner that it increases at the same time as the length l and the pitch p .

As in the case for the delay line of FIGURE 1, the line illustrated in FIGURE 5 is such that the parameters thereof other than the pitch have been modified in order that, after having selected the law of variation of the latter, the phase velocity of the first space harmonic is constant along the line whereas that of the fundamental increases in the direction of increase of the pitch.

OPERATION

The operation of the accelerator of FIGURES 3 to 6

is inverse to that of FIGURE 1, that is, the acceleration takes place by interaction with a backward mode, and the generation of the microwave by interaction with a forward mode. After the application to the connections —HT₂ of the high voltage necessary to obtain the desired speed v_d , the electron beam 52 propagates with this constant speed v_d , and it is known that under these conditions the structure of the type described hereinabove in connection with FIGURES 3 through 5 is capable of breaking into oscillation. Consequently, a traveling wave propagates along the line 41 which undergoes multiple reflections in the planes 42 and 43. The oscillator is, therefore, in fact of the stationary wave type which may be decomposed into a traveling wave which propagates in one direction and a traveling wave which propagates in the opposite direction, of which only the former propagates in the same direction as the beam 52 and enters into interaction on its forward (harmonic) mode of which the phase velocity is directed in the same direction as the beam 52 and is constant along the line.

With the high voltage applied to the connections —HT₁ in such a manner that the beam 49 enters the channel 45 with a speed v_b , preferably equal or close to the speed of v_d , there will be interaction between this beam 49 and the forward traveling wave mentioned hereinabove, that is, the wave propagating in a direction opposite to the beam 49. This interaction will take place on the backward (fundamental) mode of which the phase velocity is opposite to that of propagation, that is, directed in the same direction as the beam 49. As this phase velocity increases in the direction under question, the interaction will take place if the beam is synchronized with the phase velocity, that is, when it is accelerated. It may, therefore, be seen that the final result remains the same as in connection with the tube of FIGURE 1 and the accelerated beam leaves across the output window 56.

The devices described hereinabove enable the use, on the outside of the tube, of the beam of electrons. If only a beam of γ rays is to be used, the end of the tube, i.e., of the trajectory of the accelerated electron beam, is advantageously closed by a sheet, for example, of copper or gold. The assembly may also be mounted directly as a source of rapid neutrons by fastening a block of beryllium directly in contact with the output window.

The present invention is not limited to the embodiments shown in the drawing. For example, the arrangement of the two electron guns in FIGURE 3 may be utilized in place of the system with reflection of FIGURE 1 and vice versa. However, the presence of the reflector is advantageous; for by varying the voltage thereof it is possible to regulate the input phase into the high-frequency field of the reflected bunches of electrons. The fact that the electrons admitted to subsequent acceleration are already grouped into bunches renders the control of acceleration more easy and leads to a spectrum of energy of the apparatus which is very narrow.

It is also equally obvious that the source of the accelerated beam could be constituted, instead of by means of a reflector or a gun, by a plate with secondary emission.

The embodiments of delay lines described hereinabove also are not limitative but are only shown herein for illustrative purposes, and it is understood that they may also be varied, for example, any kind of a line may be used which presents the general characteristics specified for that of FIGURE 1 as well as that of FIGURE 5 and dimensioned according to the considerations indicated hereinabove.

The oscillator of the direct wave type which functions by internal reflections, described in connection with the embodiment of FIGURE 3, could also be replaced by any other suitable equivalent oscillator, for example, utilizing a feedback by an external line, conduit or channel.

The object of the present invention, that is, an accelerator of the traveling wave type excited by an oscillator

of the traveling wave type is realized in any case if the same delay circuit is utilized for the acceleration as well as for the oscillation thereby reducing the length of the assembly of the construction in accordance with the present invention with respect to tubes in which these circuits, located in the same envelope, are separate from one another.

Thus, it is quite obvious that the present invention is not limited to the described embodiments but is susceptible of many changes and modifications within the spirit and scope of the present invention, and we intend, therefore, to cover all such changes and modifications as encompassed by the appended claims.

We claim:

1. A traveling wave linear electron accelerator, having a source of a first electron beam and means for accelerating the electrons thereof, said means comprising a variable pitch delay circuit coupled with said first beam and generating means for generating ultra-high-frequency energy and for exciting a traveling wave in said delay circuit to thereby accelerate said electrons by interaction between said beam and the ultra-high-frequency field of said wave, said variable pitch delay circuit being dimensioned so that the propagation characteristics thereof on a predetermined wave length include a first space harmonic propagating along one direction with a substantially constant phase velocity through differently dimensioned elements of said circuit and a fundamental space component propagating along the opposite direction with phase velocities increasing along said delay circuit, said generating means including a source of a second electron beam and means for propagating said beam opposite said first beam and in coupled relationship with said delay circuit to thereby generate oscillations by the interaction between said beam and the ultra-high-frequency field of said wave propagating in said circuit, and means for abstracting for utilization at least a part of said first beam from said accelerator.

2. An accelerator as claimed in claim 1, further comprising means for propagating said first and second beams with velocities respectively substantially equal at each point of said delay circuit to the phase velocities of said fundamental and harmonic components.

3. An accelerator as claimed in claim 1, wherein said delay circuit is of a structure having propagation characteristics comprising a positive space fundamental and a negative first space harmonic of said wave.

4. An accelerator as claimed in claim 3, wherein said delay circuit is a chain of coupled cavities with the axial dimensions thereof gradually decreasing in the direction of said second beam, and with the diameters and coupling openings between two adjacent cavities gradually decreasing in the direction of said first beam.

5. An accelerator as claimed in claim 1, wherein said delay circuit is of a structure having propagation characteristics comprising a negative space fundamental and a positive first space harmonic of said wave.

6. An accelerator as claimed in claim 5, wherein said delay circuit is an interdigital delay line having a pitch gradually decreasing in the direction of said second beam, and the finger length as well as line width gradually increasing in the direction of said first beam.

7. An accelerator as claimed in claim 1, wherein said first beam source is a negatively biased electrode facing said second beam, thereby repelling at least a fraction of electrons thereof to form said first beam.

8. An accelerator as claimed in claim 1, having two distinct electron guns for generating respectively said first and second beams.

9. An accelerator as claimed in claim 1, wherein said delay circuit is of a structure having propagation characteristics comprising a positive space fundamental and a negative first space harmonic of said ultra-high-frequency field of said wave, means for propagating said first beam

with a velocity substantially equal to and in the same direction as the said space fundamental phase velocity and for propagating said second beam with a velocity substantially equal to and in the same direction as said first space harmonic phase velocity, and ultra-high-frequency energy absorbing means coupled to said delay circuit near said first beam source, said generating means forming thereby a backward wave oscillator.

10. A traveling wave linear electron accelerator as claimed in claim 1, wherein said delay circuit is dimensioned so that a substantially π -mode condition is established therein for said ultra-high-frequency energy near said first beam source.

11. A traveling wave linear electron accelerator as claimed in claim 1, wherein electrons of said first beam have a velocity substantially equal to the velocity of light near said second beam source.

12. An electron discharge system constituting an electron accelerator, comprising delay line means, means producing two electron beams, and means for propagating electrons of both of said two beams in energy transfer relationship with said delay line means to produce oscillatory traveling wave energy of predetermined frequency in said delay line means by interaction of one of said beams with said delay line means and for accelerating at least some of the electrons of the other beam by interaction between said traveling wave energy and said other beam, and means for abstracting for utilization at least a part of the accelerated electrons of said other beam from said accelerator.

13. An electron discharge system according to claim 12, wherein said two beams travel in opposite directions.

14. An electron discharge system for accelerating electrons comprising a single delay line structure, means producing two electron beams in energy-transfer relationship with said single delay line structure to produce oscillatory energy having at least a traveling wave component by the interaction between one of said beams and said single delay line structure and for accelerating the electrons of the other beam by the interaction thereof with the oscillatory energy of said component, and means for abstracting for utilization at least a part of the accelerated electrons of said other beam from said electron accelerating systems.

15. An electron discharge system according to claim 14, wherein said single delay line structure is linear.

16. An electron discharge device for accelerating electrons comprising a delay line structure, means for producing traveling wave oscillatory energy in said delay line structure by the interaction of a first electron beam traveling in energy-transfer relationship along said delay line structure, means for accelerating the electrons of a second beam by the interaction thereof with said oscillatory traveling wave energy in said delay line structure, and means for abstracting for utilization at least a part of the accelerated electrons of said second beam from said electron accelerating device.

17. An electron discharge device according to claim 16, wherein said delay line structure includes a plurality of periodic elements having parameters varying in such a manner as to produce a gradual increase in the phase velocity of one of the components of said traveling wave energy consisting of the fundamental or the first space harmonic thereof.

18. A traveling wave electron accelerator comprising a chain of delay elements of similar shape and slightly differing dimensions predetermined in such a manner that for a given wave one spatial wave component propagates along one direction of said chain with a common phase velocity v_0 on all said elements, whilst another spatial wave component propagates along the opposite direction with phase velocities increasing from substantially v_0 at one end of the chain to a considerably higher value at the other end of the chain, means for producing

and projecting in energy transfer relationship with said chain a first beam of electrons propagating in said one direction with a speed substantially equal to v_0 , thereby to set up and sustain in said delay elements ultra-high frequency oscillatory energy, means for producing and projecting in energy transfer relationship with said chain a second beam of electrons propagating in said opposite direction with an initial speed substantially equal to v_0 , near one end of the chain for synchronizing said second beam with said other spatial wave component, thereby to accelerate the electrons thereof up to said higher value near said other end of the chain, and means for abstracting for utilization at least a part of said second beam from said accelerator.

19. For use in an electron discharge device, a delay circuit for providing interaction between microwave traveling wave energy propagating along said delay circuit and beamed electrons passing along said delay circuit, said delay circuit comprising a chain of interconnected delay element means provided with means of slightly differing dimensions and operative to cause for a given wave one spatial wave component to propagate along said circuit in one direction of said chain with a constant phase velocity at all said element means, while another spatial wave component propagates along the delay circuit in the opposite direction with phase velocities increasing from one end of the chain to the other.

20. Apparatus according to claim 19, wherein said delay circuit consists of comb structures with interdigitated fingers forming said elements means.

21. In a charged particle accelerator, a wave interaction circuit comprising a variable pitch chain of cascade coupled cells of the kind which is characterized in that a wave propagating therealong gives rise to a first spatial component thereof with progressively variable phase velocity along said chain and to a second spatial component thereof with substantially constant phase velocity directed opposite said first spatial component phase velocity, first means for forming a first electron beam for flow past said interaction circuit for interaction with said second spatial component thereby generating in said circuit microwave energy of desired frequency, second means for forming a second electron beam for flow past said interaction circuit in the direction of the increasing pitch and opposite to that of said first beam for interaction with said first spatial component thereby yielding said microwave energy by said circuit to said second beam and accelerating electrons thereof, and means for abstracting for utilization at least a part of second beam from said accelerator.

22. In a charged particle accelerator, a wave interaction circuit comprising a variable pitch chain of cascade coupled cells of the kind which is characterized in that a wave propagating therealong gives rise to a first spatial component thereof with progressively increasing phase velocity directed in the direction of wave propagation therefore being termed forward component and to a second spatial component with substantially constant phase velocity directed in the direction opposite to that of wave propagation therefore being termed backward component, first means for forming a first electron beam for flow past said interaction circuit for interaction with said backward component thereby generating in said circuit microwave energy of desired frequency propagating opposite to said first beam direction, second means for forming a second electron beam for flow past said interaction circuit in the direction opposite to that of said first beam for interaction with said variable phase velocity forward component thereby yielding said microwave energy by said circuit to said second beam and accelerating electrons thereof, and means for abstracting for utilization at least a part of said second beam from said accelerator.

23. In a charged particle accelerator, a wave interaction circuit comprising a variable pitch chain of cascade

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coupled cells of the kind which is characterized in that a wave propagating therealong gives rise to a fundamental spatial component thereof with progressively increasing phase velocity directed in the direction of wave propagation therefore being termed forward fundamental and to a first harmonic spatial component with substantially constant phase velocity directed in the direction of wave propagation therefore being termed forward fundamental and to a first harmonic spatial component with substantially constant phase velocity directed in the opposite direction to that of wave propagation therefore being termed backward harmonic, first means for forming a first electron beam for flow past said interaction circuit for interaction with said backward component thereby generating in said circuit microwave energy of desired frequency propagating opposite to said first beam direction, second means for forming a second electron beam for flow past said interaction circuit in the direction opposite to that of said first beam for interaction with said variable phase velocity forward fundamental thereby yielding said microwave energy by said circuit to said second beam and accelerating electrons thereof, and means for abstracting for utilization at least a part of said beam from said accelerator.

24. In a charged particle accelerator, a wave interaction circuit comprising a variable pitch chain of cascade coupled cells of the kind which is characterized in that a wave propagating therealong gives rise to a first spatial component thereof with progressively increasing phase velocity directed in the direction opposite to that of wave propagation therefore being termed backward component and to a second spatial component with substantially constant phase velocity directed in the direction of wave propagation therefore being termed forward component, first means for forming a first electron beam for flow past said interaction circuit for interaction with said forward component thereby generating in said circuit microwave energy of desired frequency propagating in said first beam direction, second means for forming a second electron beam for flow past said interaction circuit in the direction opposite to that of said first beam for interaction with said variable phase velocity backward component thereby yielding said microwave energy by said circuit to said second beam and accelerating electrons thereof, and means for abstracting for utilization at least a part of said second beam from said accelerator.

25. In a charged particle accelerator, a wave interaction circuit comprising a variable pitch chain of cascade coupled cells of the kind which is characterized in that a wave propagating therealong gives rise to a fundamental

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spatial component thereof with progressively increasing phase velocity directed in the direction opposite to that of wave propagation therefore being termed backward fundamental and to a first harmonic spatial component with substantially constant phase velocity directed in the direction of wave propagation therefore being termed forward harmonic, first means for forming a first electron beam for flow past said interaction circuit for interaction with said forward harmonic thereby generating in said circuit microwave energy of desired frequency propagating in said first beam direction, second means for forming a second electron beam for flow past said interaction circuit in the direction to that of said first beam for interaction with said variable phase velocity backward fundamental thereby yielding said microwave energy by said circuit to said second beam and accelerating electrons thereof, and means for abstracting for utilization at least a part of said second beam from said accelerator.

26. For use in an electron discharge device, a delay circuit for providing interaction between microwave traveling wave energy propagating along said delay circuit and beamed electrons passing along said delay circuit, said delay circuit comprising element means defining a chain of cylindrical cavities of progressively changing dimensions, said element means providing a central passage through all said cavities for passage of said beamed electrons interacting with wave energy at said delay circuit, and the element means of said delay circuit being operative in such a manner that for a given wave one spatial wave component propagates along said circuit in one direction of said chain with a constant phase velocity at all said element means while another spatial wave component propagates along the delay circuit in the opposite direction with phase velocities increasing from one end of the chain to the other.

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