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ELECTRON DISCHARGE APPARATUS

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FIG. 1

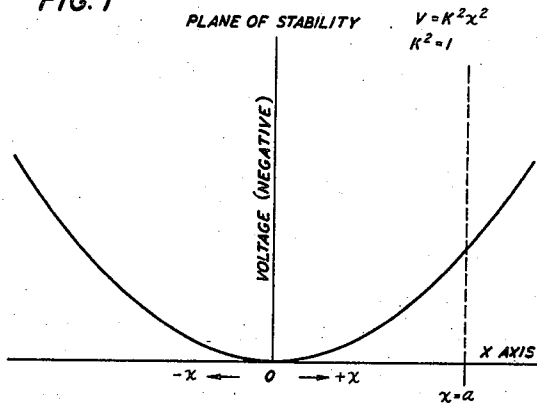


FIG. 3

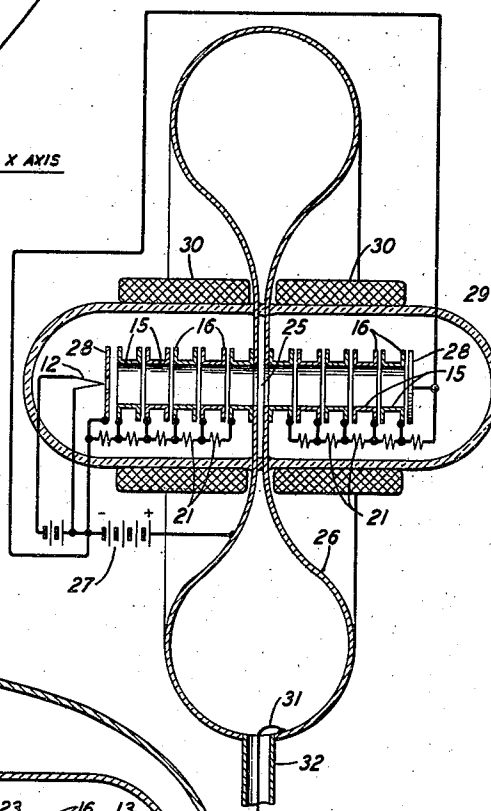
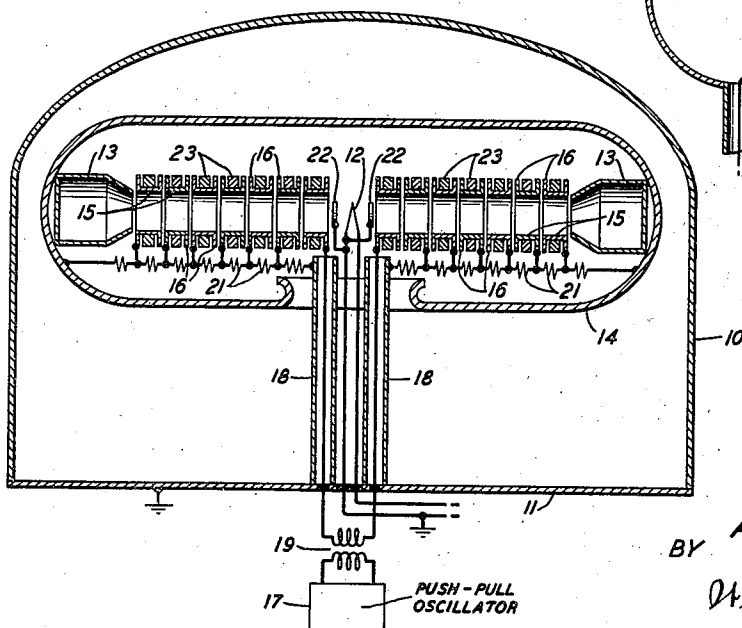


FIG. 2



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ELECTRON DISCHARGE APPARATUS

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This invention relates to electron discharge apparatus and more specifically to electronic devices for converting energy of one form into energy of another form.

One object of this invention is to enable and to facilitate the generation electronically of high potentials, for example potentials in the million-volt range.

Another object of this invention is to generate oscillations of very high frequencies.

A further object of this invention is to simplify the construction of electronic devices adapted for the generation of high potentials or very high frequency oscillations.

Still another object of this invention is to improve the efficiency of electronic energy converting devices.

In accordance with one feature of this invention, an electron stream is caused to traverse repeatedly a region or gap across which an alternating field exists, executing simple harmonic motion to and fro across the gap and in such phase relation to the field that the electrons in the stream either deliver increments of energy to or acquire energy from the field.

In one device illustrative of this invention and adapted for the generation of extremely high potentials, electrons are injected into a region in which the direct current electrostatic field increases negatively as the square of distance from a median plane in the region and a low potential alternating field is produced in the vicinity of the median plane. The electrons execute simple harmonic to and fro motion across the median plane in such phase relation to the alternating field that at each traversal of the median plane the electrons acquire an increment in their kinetic energy. After multiple traversals of the plane and at a region where the electron velocity is substantially zero, and, hence, where the energy of the electrons is substantially entirely potential, the electrons are collected, thus delivering their energy to an electrode to maintain the electrode at a high direct current potential.

In another illustrative embodiment of this invention, a direct current electron stream is projected across a gap in a high frequency circuit element and direct current electrostatic fields increasing negatively as the square of distance from the gap are produced on both sides of the gap. The electrons execute to and fro simple harmonic motion across the gap and in such relation to the alternating field at the gap that at each traversal of the gap the electrons deliver energy to the high frequency circuit element whereby the direct current energy of the electron stream is converted into high frequency energy.

The invention and the above-noted and other features thereof will be understood more clearly and fully from the following detailed description

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with reference to the accompanying drawing, in which:

Fig. 1 is a graph illustrating the direct current electrostatic field distribution in one device constructed in accordance with this invention;

Fig. 2 is an elevational view in section of an electronic device illustrative of one embodiment of this invention suitable for the generation of very high voltages; and

Fig. 3 is a view in section of electron discharge apparatus illustrative of another embodiment of this invention, adapted for the generation of ultra-high frequency oscillations.

If an electrically charged particle, such as an electron or ion, is to traverse a gap or restricted region at which an alternating field exists, repeatedly and in phase with the alternating field, it must execute simple harmonic motion with respect to the gap or region. Such motion can be realized by the establishment of direct current electrostatic fields of particular variation and strength on opposite sides of the gap or region.

In order that simple harmonic motion may be realized, the force acting upon the particle must vary as the distance from the plane of stability, in the case under consideration the region or gap aforementioned, according to the relation

$$F = -Kx \quad (1)$$

where F is the force, K is a constant, and x is distance from the plane of stability, being zero at this plane. If the particle is an electron and the force is due to an electrostatic field, Equation 1 may be written

$$e \frac{\delta V}{\delta x} = -Cx \quad (2)$$

where e is the electron charge, V is potential and C is a constant.

From Equation 2, it will be seen

$$V = \int -\frac{C}{e} x dx = -\frac{C}{2e} x^2 \quad (3)$$

which may be written

$$V = K^2 x^2 \quad (4)$$

Thus, the field requisite for the realization of simple harmonic motion is one wherein the voltage varies as the square of distance x from the plane of stability and increases negatively in this ratio on both sides of the plane of stability. A graph illustrating a field satisfying these requirements is shown in Fig. 1.

Referring to Fig. 1, an electron traveling across the plane of stability from left to right and having a velocity v at this plane will be retarded by the field and as a result will be brought to rest at some plane a distance a from the plane of stability. Then its direction of travel is reversed and it is accelerated by the field toward the plane of stability and will cross this plane with its

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initial velocity v . The electron then travels to the left, is brought to rest and again returns to the plane of stability.

The transit time, T , from the plane $x=a$ to the plane of stability, $x=0$, referring voltages to the plane $x=a$, can be shown to be

$$T = \frac{\pi}{K} \sqrt{\frac{m}{8e}} \quad (5)$$

where m is the electron mass. Inasmuch as the period of oscillation is equal to $4T$, from (5) it follows that

$$P = \frac{2\pi}{K} \sqrt{\frac{m}{2e}} \quad (6)$$

where P is the period of oscillation, from which it will be seen that the period is independent of the amplitude a . Referring voltages to the plane of stability, the period of oscillation can be shown to be

$$P = 2\pi a \sqrt{\frac{m}{2Ve}} \quad (7)$$

the voltage V at the plane $x=a$ being $K^2 a^2$. From Equation 7 it follows that the frequency

$$f = \frac{9.44 \times 10^6 \sqrt{V}}{a} \quad (8)$$

where a is in centimeters and V is in practical volts. The voltage, then, is given by the relation

$$V = 1.12 \times 10^{-14} a^2 f^2 \quad (9)$$

If the charged particles are ions instead of electrons

$$f = \frac{9.44 \times 10^6 \sqrt{V}}{a \sqrt{M}} \quad (10)$$

and

$$V = 1.12 \times 10^{-14} M a^2 f^2 \quad (11)$$

where M is the ratio of the mass of the ion to that of an electron.

Referring now to Fig. 2, the high voltage generator there illustrated comprises a highly evacuated enclosing vessel having a dished portion 10, for example of metal or vitreous material, and a base 11, for example of metal, sealed hermetically to the dished portion 10. Mounted within the vessel is a source of electrons or ions which for the case of electrons may be a filament 12 as shown, positioned midway between a pair of cup-shaped collector electrodes 13 mounted on a metallic radio frequency shield 14 which also acts as the high voltage terminal. For the case of ions, an ion gun may be employed in place of the filament 12. Disposed between the cathode 12 and the collector electrodes 13 and symmetrically arrayed with respect to the cathode are two groups of coaxial annular electrodes 15.

These electrodes are provided with annular flanges 16, the flanges on adjacent electrodes being in juxtaposition so that each electrode 15 is capacitively coupled to the adjacent electrode or electrodes 15 and during the operation of the device all of the electrodes of each group are at substantially the same alternating current potential. An alternating potential is applied between the two groups of electrodes 15 as by an oscillator 17 coupled to a pair of coaxial lines 18 by a transformer 19, the inner conductor of each coaxial line being connected to a corresponding one of the electrodes 15 nearest the cathode 12 and the outer conductors of each of the coaxial lines being grounded to the metallic base 11 of the enclosing vessel. The electrodes 15 of each group

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and the associated collector electrode 13 are interconnected by a high resistance potential divider 21 in such manner that the resistance between electrodes increases substantially as the square of distance from the plane of the cathode 12.

Mounted on opposite sides of the cathode 12 are shields 22, which may be metallic discs connected directly to one of the lead-in wires for the cathode. A magnetic field within the electrodes 15 and substantially coaxial therewith may be produced by a series of annular permanent magnets 23 each encompassing a corresponding one of the electrodes. Alternatively, such a field may be produced by magnetic coils appropriately positioned within the enclosing vessel 10, 11.

Because of the capacitive coupling between the electrodes 15 of each group provided by the flanges 16 and inasmuch as, at the frequencies supplied by the oscillator 17, the coupling capacities have very low impedance as compared with the resistances provided by the potential divider 21, each group of electrodes oscillates in potential as a whole with negligible alternating current potential difference between the electrodes of each group and, therefore, there are no appreciable alternating current potentials in the space within the groups except adjacent the ends of each group.

The operation of the device illustrated in Fig. 2, as a voltage generator will be understood from the following considerations. Upon the application by the oscillator 17 of a high frequency potential between the two groups of electrodes 15, the collector electrodes 13 are at ground potential and there is, therefore, no direct current field within the groups of electrodes 15. Electrons emitted by the cathode 12 will be accelerated toward one or the other of the collector electrodes 13 and be collected thereby thus to charge the collector electrodes negatively in potential. Consequently, a direct current field is produced within each group of electrodes, by virtue of the coupling of the electrodes 15 and the collector electrodes 13 by the potential divider 21. Subsequently emitted electrons are thus caused to execute a to and fro movement across the gap between the two electrodes 15 nearest the cathode 12. At each crossing of the gap, the electrons receive energy from the high frequency field and their amplitude of oscillation is increased until they impinge upon one of the collector electrodes 13 to drive it more negative in potential. The distance between each electrode 13 and the cathode 12 corresponds to the parameter a in Equation 9. When the potential of the collector electrodes is less than that given by Equation 9, the oscillating frequency of the electrons is less than that of the oscillator 17 and there is not, therefore, exact resonance between the electrons and the alternating current potential at the gap noted. However, the electrons do acquire some energy each time they cross the gap, and inasmuch as the electrons require few oscillations to reach the collector electrodes while the potential of the latter is below the value noted, the potential of the collector electrodes will be increased until the value given by Equation 9 is reached.

When this condition is reached, the collector electrodes 13 are at a high negative direct current potential and power is thus supplied to the voltage dividers 21 to establish within the groups of electrodes 15 a direct current field of the form given by Equation 4 and illustrated in Fig. 1. The

alternating current potential supplied by the oscillator 17 is greater than the direct current potential with respect to ground of the electrodes 15 nearest the cathode 12. Hence, when the alternating current potential difference between the two groups of electrodes 15 is at its maximum value, there is a positive field on one side of the cathode 12 and a negative field on the other side. Electrons, therefore, are accelerated into the region bounded by the group of electrodes at the positive alternating current potential. One-half cycle later, these electrons will have returned to the region of the cathode, the plane of stability. At this time the alternating current field across the gap is in the opposite direction so that the electrons will be further accelerated and projected into the region bounded by the other group of electrodes. The electrons oscillate to and fro across the gap acquiring increments of kinetic energy at each crossing of the gap and the amplitude of their motion increasing at each excursion. When the electrons have acquired sufficient energy to reach one of the collector electrodes 13, they impinge thereon and deliver their energy thereto. At the maximum amplitude of motion, as noted heretofore, the energy of the electrons is substantially entirely potential, and in impinging upon the collector electrodes the electrons transfer this potential energy thereto, whereby on each half cycle a negative charge is supplied to the collector electrodes to maintain these electrodes at a high negative potential and to replace the power which is lost by conduction through the potential dividers.

The magnetic field produced by the magnets 23 or the coils serves to focus the electrons and prevent their impingement upon the electrodes 15. The discs 22 shield the cathode 12 and prevent impingement thereon of the oscillating electrons.

For operation with high frequencies, for example in the megacycle range, it is advantageous that the distance between the cathode 12 and each of the collector electrodes 13 be substantially a quarter wave-length of the applied frequency, or an odd multiple thereof, to provide resonance of the electrode structure and so to build up the maximum voltage across the gap and thus assure substantially maximum transfer of energy between the alternating field and the electrons. For such distance-wave-length relation, it will be seen from Equation 8 that the voltage generated

$$V = 7 \times 10^{-16} c^2 n^2 \quad (12)$$

where c is the velocity of light and n is an odd integer corresponding to the number of quarter wave-lengths in the cathode to collector electrode distance. For example, if $n=3$, i. e., if $a=3/4$ wave-length, $V=5,700,000$ volts.

The invention is not limited, however, to the distance-wave-length relation noted. For example, the capacitances coupling the electrodes 15 may be adjusted so that the device resonates at any desired frequency.

As noted heretofore, the shield 14 serves as the high potential terminal. The load may be mounted within the vessel 10 or an evacuated coaxial line may be employed to establish connection from the high potential terminal.

The invention may be utilized also to convert direct current energy into high frequency energy and thus to generate oscillations. An illustrative device for this purpose is illustrated in Fig. 3 and comprises two groups of electrodes 15, similar

to those included in the device shown in Fig. 1 and described heretofore, symmetrically arranged in coaxial relation on opposite sides of the gap 25 in a cavity resonator 26, the middle two electrodes 15 being connected directly to the resonator. As in the device illustrated in Fig. 1, the electrodes 15 of each group are coupled capacitively, as by the flanges 16, and are connected by potential dividers 21 in such manner that the direct current field within the regions bounded by the electrodes 15 increases negatively as the square of distance from the gap 25, the direct current energy from this field being supplied by a source, such as a battery 27.

The collector electrodes 28 may be discs as shown, one of these electrodes being provided with a central aperture opposite which a cathode 12, for example filamentary in form, is mounted. The several electrodes are appropriately mounted within an evacuated, vitreous enclosing vessel 29, the cavity resonator 26 having wall portions hermetically sealed to and extending through the wall of the vessel. Magnetic coils 30, encompassing the vessel 29, provide an axial field for concentrating the electrons.

Electrons emanating from the cathode 12 are accelerated toward and projected across the gap 25. On crossing the gap, the electrons in phase with the oscillating field extant across the gap enter a retarding field and give up a portion of their energy to the field thus supplying the resonator and losing some of their velocity. Because of their reduced energy and velocity, the electrons travel a reduced distance into the retarding field, are reversed in direction, return to the gap and, meeting there a retarding field, again give up another increment of their energy. The electrons continue executing simple harmonic to and fro motion across the gap 25, with successively decreasing amplitude of oscillation, delivering energy to the high frequency field of the resonator at each traversal of the gap until all their energy is expended.

Those electrons which reach the gap out of phase with the alternating field extant across the gap, cross the gap when the field is accelerating as to them and absorb some energy from the oscillating field. However, because of their increased energy, the amplitude of motion of these electrons is increased and they reach and are collected by the collector electrode 28 to the right in Fig. 3, so that they cannot continue to absorb energy. The total energy lost by absorption by the out-of-phase electrons is very small in comparison with that delivered by the in-phase electrons so that oscillations are maintained and high operating efficiency is realized.

Energy may be taken from the resonator by way of a coupling loop 31 connected to a coaxial type line 32.

Although specific embodiments of the invention have been shown and described, it will be understood that they are but illustrative and that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. Electron discharge apparatus comprising a pair of electrodes mounted in spaced relation and electrically connected to each other, means for producing in the space between said electrodes direct current fields with voltage increasing negatively in both directions from the median plane between said electrodes substantially as the square of distance from said plane, said means including

two groups of electrodes on opposite sides of said plane and resistance means connecting the electrodes of each of said groups, means capacitively coupling the electrodes of each of said groups to one another, a high frequency circuit connected between said groups, and means for introducing electrons into the space between said pair of electrodes.

2. Electron discharge apparatus comprising two groups of cylindrical, coaxial electrodes mounted on opposite sides of a median plane, means capacitively coupling the electrodes of each group to one another, a high frequency circuit connected between said two groups of electrodes, collector electrode means adjacent the electrode of each of said groups furthest from said plane, means for introducing electrons into the space bounded by said groups of electrodes, and means for producing within each group of electrodes a direct current field with voltage increasing negatively from said plane substantially as the square of distance from said plane, said last-mentioned means including resistance means interconnecting the electrodes of each of said groups.

3. The method of converting high frequency energy into high potential direct current energy which comprises causing electrons to execute simple harmonic to and fro motion across a reference plane, increasing the kinetic energy of the electrons at each crossing thereby of said reference plane, and collecting said electrons after repeated traversals of said plane, at a region where the instantaneous electron velocity is substantially zero.

4. An electronic potential generator comprising a cathode, means for causing electrons emanating from said cathode to execute to and fro motion across a reference plane which includes said cathode, said means including means for producing in regions extending from immediately adjacent and on opposite sides of said cathode direct current fields whose gradient is increasing negatively substantially in proportion to the distance from said cathode and means for producing adjacent said cathode an alternating electric field in the direction of said direct current fields, and collector electrode means spaced from said cathode.

5. An electronic potential generator comprising a cathode, two groups of electrodes on opposite sides of said cathode, collector electrode means adjacent the electrode of at least one of said groups furthest removed from said cathode, means capacitively coupling the electrodes of each of said groups to one another, means for impressing a high frequency potential between said two groups of electrodes, and resistance means interconnecting the electrodes of each of said groups such that the direct current field gradient on each side of said cathode increases negatively substantially as the distance from said cathode.

6. An electronic potential generator comprising a cathode, two groups of cylindrical coaxial electrodes mounted on opposite sides of said cathode, collector electrode means mounted beyond at least one of said groups of electrodes, means capacitively coupling the electrodes of each of said groups to one another, high frequency potential supply means connected between the electrodes of said groups nearest said cathode, and resistance means interconnecting the electrodes of each group such that the direct current field on each side of said cathode increases negatively

substantially as the square of distance from said cathode.

7. An electronic potential generator comprising a cathode, two groups of coaxial cylindrical electrodes mounted in symmetrical relation on opposite sides of said cathode, said electrodes having juxtaposed flanges defining condensers capacitively coupling the adjacent electrodes of each group, collector electrode means beyond said groups of electrodes, means for impressing a high frequency potential between said groups of electrodes, and resistance means interconnecting the electrodes of each of said groups such that the direct current electric field gradient on opposite sides of said cathode increases negatively substantially as the distance from said cathode.

8. An electronic potential generator comprising two groups of electrodes mounted in alignment, the inner two electrodes of said two groups defining a gap, means capacitively coupling the electrodes of each of said groups, means for impressing an alternating potential between said groups of electrodes, each of said groups bounding a region of a length substantially equal to an odd number of quarter wave-lengths of the frequency of said alternating potential, a cathode in said gap, collector electrode means at the outer ends of said regions, and resistance means interconnecting the electrodes of each of said groups and said collector electrode means for establishing in each of said regions a direct current field with voltage increasing negatively from said cathode substantially as the square of distance from said cathode.

9. An electronic oscillation generator comprising a high frequency circuit having a gap therein, two groups of electrodes mounted on opposite sides of said gap, means capacitively coupling the electrodes of each of said groups to one another, means biasing said electrodes to produce on opposite sides of said gap symmetrical direct current electric fields with voltage increasing negatively substantially as the square of distance from said gap, and means adjacent one of said groups for projecting electrons toward said gap.

10. An electronic oscillation generator comprising a high frequency circuit having closely spaced portions defining a gap, two groups of coaxial cylindrical electrodes on opposite sides of said gap, means capacitively coupling the electrodes of each group to one another, means biasing the electrodes of each group to produce on opposite sides of said gap direct current fields with voltage increasing negatively substantially as the square of distance from said gap, and means adjacent one of said groups for projecting electrons toward said gap.

11. An electronic oscillation generator comprising a cavity resonator having a gap therein, two groups of coaxial cylindrical electrodes on opposite sides of said gap, the electrode of each of said groups nearest said gap being connected to said resonator, said electrodes having flanges defining condensers coupling adjacent electrodes in each of said groups, means including resistances interconnecting the electrodes of each group for producing within the space bounded by each group a direct current field the potential of which is increasing negatively from said gap substantially proportional to the square of distance from said gap, and a cathode adjacent the electrode of one of said groups furthest from said gap.

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