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A. M. SKELLETT
ELECTRIC DISCHARGE DEVICE FOR
HIGH-FREQUENCY OSCILLATIONS
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FIG. 1

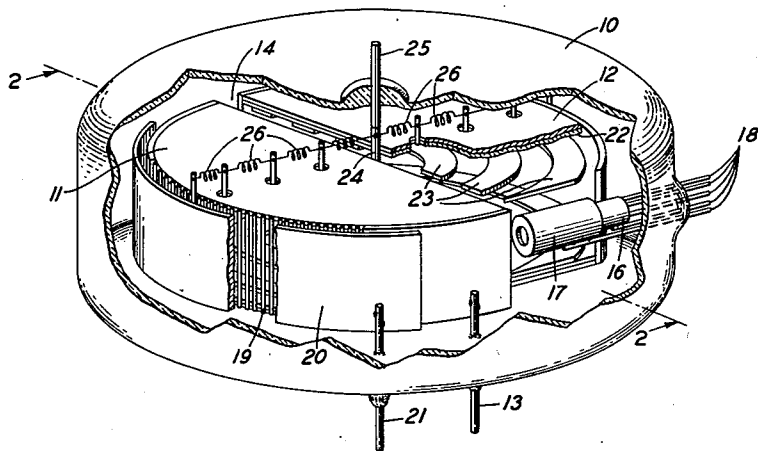


FIG. 2

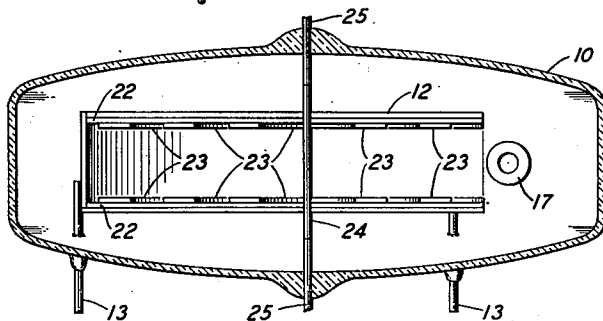
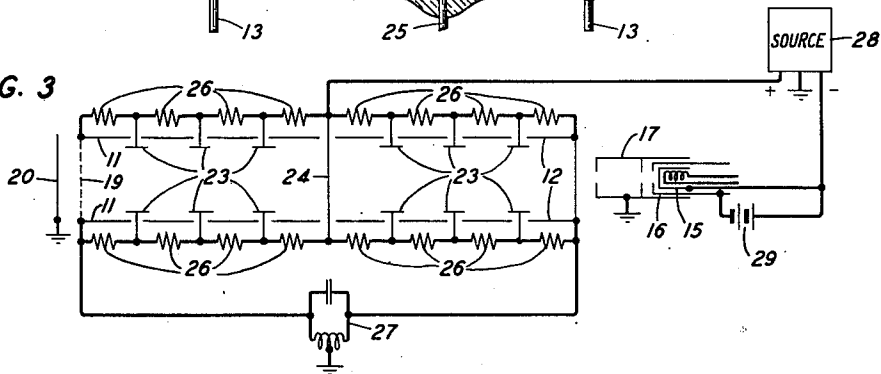


FIG. 3



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ELECTRIC DISCHARGE DEVICE FOR HIGH-FREQUENCY OSCILLATIONS

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9 Claims. (Cl. 315-4)

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This invention relates to electric discharge devices and more particularly to high frequency electronic oscillation generators.

One object of this invention is to obtain repeated generally circular motion about a prescribed axis of electrically charged particles injected into an electrostatic field such that the period of revolution of the particles about the axis is substantially independent of the radius of the particle orbits.

Another object of this invention is to facilitate the efficient conversion of the energy of a direct current stream of electrically charged particles into high frequency energy.

In one illustrative embodiment of this invention, a high frequency electronic oscillation generator comprises a pair of hollow, for example semicylindrical, output electrodes coupled to an oscillating circuit and having juxtaposed edges defining a gap, and an electron gun for projecting an electron stream into the region bounded by the output electrodes and adjacent one end of the gap.

In accordance with one feature of this invention, means are provided for establishing in the region bounded by the output electrodes an electrostatic field having circular symmetry about an axis passing through the gap and having a negative radial gradient such that electrons projected thereinto with approximately a prescribed velocity are directed along generally circular paths of successively decreasing radius, about the axis noted, and the period of revolution of the electrons is substantially the same for all the paths. This period is correlated with the frequency to which the oscillating circuit is tuned so that at each crossing of the gap the electrons contribute energy to the circuit to sustain oscillations.

The invention and the above-noted and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing in which:

Fig. 1 is a perspective view of an electron discharge device illustrative of one embodiment of this invention, portions of the enclosing vessel and of certain of the electrodes being broken away to show details of construction;

Fig. 2 is a sectional view along plane 2-2 of Fig. 1; and

Fig. 3 is a circuit diagram illustrating one manner of operation of the device shown in Figs. 1 and 2.

Referring now to the drawing, the electron discharge device illustrated in Figs. 1 and 2 com-

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prises a highly evacuated enclosing vessel 10, for example of vitreous material, in which a pair of semicylindrical output electrodes 11 and 12 are supported by rigid leading-in conductors 13. The output electrodes are mounted in substantially concentric relation and the diametral edges thereof are in juxtaposition and define a gap 14. A portion of the electrode 12 is cut away to receive an electron gun which comprises an indirectly heated cathode 15, a focussing electrode 16 and an accelerating electrode 17, the electrodes of the electron gun being cylindrical and mounted in coaxial relation by rigid leading-in conductors 18 sealed into the enclosing vessel 10. A portion of the other output electrode 11 is removed to receive an arcuate screen 19 opposite which a collector plate or electrode 20 is mounted by a leading-in conductor 21.

As shown more clearly in Fig. 2, each of the output electrodes 11 and 12 has therein a pair of semicircular insulating members 22, for example of mica. Each of the insulating members 22 has thereon a plurality of concentric, substantially semicircular field electrodes 23, the electrodes 23 on opposite sides of the gap 14 also being concentrically arranged so that the several field electrodes constitute two identical groups circularly symmetrical about the axis of the electrode system. Extending along this axis is a linear rod or wire collector electrode 24 which is supported by leading-in conductors 25.

The field electrodes 23 of each group are connected electrically to one another and to the collector electrode 24 and output electrodes 11 and 12 by resistors 26 so that upon connection of the electrodes to a suitable source as described hereinafter there is established within the region bounded by the output electrodes 11 and 12 an electric field having circular symmetry about the collector electrode 24 and having a prescribed radial gradient.

As illustrated in Fig. 3, in the operation of the device as an oscillator, the output electrodes 11 and 12 are connected by a tuned circuit 27 and are operated at direct current ground mean potential. The collector electrode 24 is biased at a positive potential, for example of the order of 1,000 volts above ground, by a direct current source 28. The cathode 15 is biased at a negative potential, for example of the order of 1,000 volts below ground, by the source 28 and is held positive with respect to the focussing electrode 16, as by a battery 29. The collector electrode 20 and accelerating electrode 17 are connected to ground as shown.

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Because of the potentiometer interconnection of the field electrodes 23, output electrodes 11 and 12 and collector electrode 24 by the resistors 26 and the symmetry of the electrodes about the collector electrode 24, it will be seen that there is established in the region bounded by the output electrodes a circularly symmetrical electric field having a negative gradient of form determined by the resistors 26. The electrons projected from the electron gun are injected into this region adjacent the periphery thereof and in the direction substantially tangent to the field. Inasmuch as the output electrodes and the accelerating electrode 17 are both at direct current ground potential, the velocity of the injected electrons, at the point of entry of the electrons into the electric field, will not be changed as they enter the field at this point. When the device is oscillating, inasmuch as the several field electrodes are coupled capacitively to the output electrodes by the mica members 22, the field in the region noted varies as a whole in accordance with the oscillating potentials appearing on the output electrodes.

It is apparent that the trajectories of the electrons in the region bounded by the output electrodes will be dependent upon the radial gradient of the electric field. In accordance with one feature of this invention, the field electrodes 23 are correlated with one another and the output electrodes and collector electrode 24 so that many of the electrons injected into the region aforementioned traverse substantially circular paths of successively decreasing radii and in such manner as to contribute energy to the oscillating circuit and, thus, to sustain oscillations. The principles involved in this correlation will be understood from the following considerations.

The negative radial gradient of the direct current electric field in the region bounded by the output electrodes 11 and 12 may be designated as E or

$$\frac{\delta U}{\delta r}$$

where r is the radius and U is the voltage at any radius r . If an electron is projected into this field initially tangentially thereto and has the proper velocity, it will follow a circular path over which U is constant and, for these conditions, the centrifugal and centripetal forces acting upon the electron are equal. Mathematically expressed

$$\frac{mv^2}{r} = eE$$

so that

$$r = \frac{mv^2}{eE} \quad (1)$$

where

r =radius of the path.
 m =electron mass.
 v =electron velocity.
 e =electron charge.

The electron velocity in terms of the accelerating voltage is given by

$$v = \sqrt{\frac{2Ve}{m}} \quad (2)$$

where V =the accelerating voltage necessary to give the electron the velocity v . By substitution in Equation 1

$$r = \frac{2V}{E} \quad (3)$$

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The time required for an electron to complete one revolution in the field is expressed by

$$T = \frac{1}{f} = \frac{2\pi r}{v} \quad (4)$$

where

T =the time of one revolution
and

f =frequency.

From Equations 2 and 4, it follows that

$$V = Kr^2f^2 \quad (5)$$

where

$$K = \frac{2\pi^2 m \times 10^{-7}}{e} = 1.12 \times 10^{-14}$$

for V in practical volts.

From Equation 5 it will be seen that if the period of revolution of an electron in the field is to be independent of the radius r , that is if this period is to be the same for all values of r , the voltage at any point in the field must vary as the square of the radius. The requisite gradient for establishing such a field is determinable from Equations 3 and 5 thus:

$$\frac{\delta U}{\delta r} = -K_1 r f^2$$

where

$$K_1 = 2.24 \times 10^{-14}$$

so that the voltage, U , at any radius, r , in the field is given by

$$U = K_1 f^2 \int_{r=0}^{r=r} r dr = -K f^2 r^2 \quad (6)$$

Since this is identical with Equation 5 except for the negative sign it follows that the voltage V corresponding to the velocity of the electrons is numerically equal to the negative potential U of the point in the field where those electrons are.

This relation between V and U , namely:

$$V = -U$$

is important in determining the velocity of the injected electrons. They are accelerated by a positive voltage V between the cathode 15 and anode 17 that is numerically equal to the negative potential U of the field at the place where they enter. For the case cited above these voltages, obtained from the source 28, are $V = +1,000$ and $U = -1,000$ volts.

Hence, in a device of the construction illustrated in Figs. 1 and 2, the field requisite for attainment of the condition of a constant period of revolution of electrons about the axis in which the collector electrode 24 lies, for all values of radius is realized by constructing the resistances 26 to produce this relation between voltage and radius, for a given frequency, f , that is the frequency to which the oscillatory circuit 27 is tuned, expressed by Equation 6 supra.

The operation of the device shown in the drawing, as an oscillator is as follows: When the output electrode 11 is positive with respect to the electron gun, that is during the positive half cycle of the oscillation, electrons from the gun are projected into the region bounded by the output electrodes with a velocity, in volts, substantially equal to the field voltage U at the point of injection of the electrons into the region. They will be accelerated to a velocity too great to traverse a circular path and thus will flow to and be collected by the collector electrode 20.

However, when the output electrode 11 is negative, that is during the negative half cycle of the

oscillation thereof, the injected electrons are retarded upon entering into the field so that their velocity will be substantially equal to that corresponding to the voltage at their point of entry into the field. Consequently, the electrons will follow a substantially circular path and one half cycle later will arrive at the gap 14 at a point substantially 180 degrees from the point of their initial entrance into the field. At this time, that is one half cycle after the initial entry of the electrons into the region bounded by the output electrodes, the electrode 12 swings negative. Hence, the electrons are subjected to a negative gradient in crossing the gap and are retarded so that they are directed along a substantially semicircular path of somewhat smaller radius than the path traversed during the first half cycle noted. This action is repeated so that the electrons traverse semicircular paths of successively decreasing radii until they are collected by the collector electrode 24.

As is clear from the foregoing, at each crossing of the gap 14 the electrons are subjected to a negative gradient so that, at each such crossing, they deliver a part of their energy to the oscillating circuit. Because of the nature of the radial gradient, described hereinabove, the time between successive crossings of the gap by the electrons is the same for all the semicircular paths traversed and, therefore, by delivering their energy to the output circuit, the electrons sustain oscillation thereof at the frequency to which it is tuned.

Although a specific embodiment of this invention has been shown and described, it will be understood that it is 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. For example, although the invention has been described with reference to a device utilizing electrons as the electrically charged particles, it is obvious that it may be practiced with devices employing ions. In this case, of course, the constant K in Equation 6 would be different, determined by the ion mass, and the requisite gradient would be correspondingly different.

What is claimed is:

1. Electric discharge apparatus comprising a pair of electrodes mounted in juxtaposition and bounding an operating region, a utilization circuit coupled to said electrodes, means for establishing in said region an electrostatic field having circular symmetry about the axis of said region and having a radial gradient such that the potential of said field varies proportionately to the square of radius from said axis, and means opposite said region for injecting a stream of electrically charged particles into said region adjacent the periphery thereof, substantially tangential thereto and with a velocity in electron volts substantially equal to the field voltage adjacent said periphery.

2. Electric discharge apparatus comprising a pair of hollow electrodes mounted in juxtaposition to define a gap therebetween, a tuned circuit connected between said electrodes, means for producing within the region bounded by said electrodes an electric field having circular symmetry about the transverse axis of said gap and varying radially proportionately both to the distance from said axis and to the resonant frequency of said circuit, and means opposite said gap for injecting into said region adjacent one end of said gap electrically charged particles hav-

ing a velocity corresponding substantially to the voltage of said field at the point of injection of said stream thereinto.

3. Electric discharge apparatus comprising a pair of electrodes mounted in juxtaposition and defining an elongated gap, means opposite said gap for projecting electrically charged particles across said gap at a region removed from the center thereof, and means for causing said particles to revolve about the transverse axis of said gap at a prescribed frequency and along curved paths substantially concentric with said axis and of successively decreasing radius, said last means comprising electrodes adjacent said pair of electrodes and an energizing source therefor for producing an electrostatic field having circular symmetry about said axis and a negative radial gradient.

4. Electric discharge apparatus comprising means for producing a circularly symmetrical electric field having a radial gradient such that the voltage at any point therein is in accordance with the relation

$$U = 1.12 \times 10^{-14} f^2 r^2$$

where U is the voltage, r is any radius and f is a prescribed frequency, means opposite the space in which said field obtains for injecting electrons into said field tangentially thereto and with a velocity corresponding to the field voltage at the point of injection of said electrons, a pair of electrodes mounted on opposite sides of a plane transverse to said field, and a circuit connected between said electrodes and tuned to said frequency.

5. An electronic oscillation generator comprising a pair of hollow electrodes mounted in juxtaposed spaced relation and bounding an operating region, a tuned circuit connected between said electrodes, means for producing in said region an electrostatic field circularly symmetrical about an axis passing between said electrodes and decreasing radially proportionately to

$$1.12 \times 10^{-14} f^2 r^2$$

f being the resonant frequency of said circuit and r any radius, and means opposite said region for injecting electrons into said region, normal to said axis and remote therefrom and with a velocity corresponding substantially to the field voltage at the point of their injection into said field.

6. An electronic oscillation generator in accordance with claim 5 wherein said field producing means comprises two groups of substantially semicircular field electrodes at opposite sides of said region and substantially concentric with said axis and resistance means interconnecting the field electrodes of each group.

7. Electron discharge apparatus comprising a linear collector electrode, a pair of semicylindrical electrodes on opposite sides of said collector electrode and substantially coaxial therewith, a tuned circuit connected between said pair of electrodes, means for establishing in the region between said pair of electrodes an electrostatic field having circular symmetry about said collector electrode and having a radial gradient proportional to

$$-2.24 \times 10^{-14} r f^2$$

r being radius and f being the frequency to which said circuit is tuned, and means opposite said region for projecting electrons into said field in the direction normal to said collector electrode

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and at a point removed from said collector electrode and with a velocity corresponding to the field voltage at said point.

8. Electron discharge apparatus comprising a linear collector electrode, a pair of semicylindrical electrodes on opposite sides of said collector electrode and substantially coaxial therewith, a tuned circuit connected between said pair of electrodes, means for establishing in the region between said pair of electrodes an electrostatic field having circular symmetry about said collector electrode and having a radial gradient proportional to

$$-2.24 \times 10^{-14} r f^2$$

r being radius and f being the frequency to which said circuit is tuned, said field establishing means comprising two groups of semicircular field electrodes adjacent the ends of said pair of electrodes and substantially concentric with said collector electrode and resistances interconnecting the field electrodes of each group with one another and said collector and pair of electrodes, and means opposite said region for projecting electrons into said field in the direction normal to said collector electrode and at a point removed from said collector electrode and with a velocity corresponding to the field voltage at said point.

9. Electron discharge apparatus comprising a pair of substantially semicylindrical electrodes having closed metallic ends and mounted in juxtaposed spaced substantially concentric relation and bounding a substantially cylindrical space, a collector electrode extending along the axis of said space, one of said pair of electrodes having an aperture in the cylindrical wall thereof, a second collector electrode opposite said aperture, an electron gun adjacent one side of the other of said pair of electrodes and directed toward said opening, insulating members on the inner surfaces of the ends of said pair of elec-

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trodes, two similar groups of substantially semicircular field electrodes mounted on said insulating members and substantially concentric with respect to said first collector electrode, a utilization circuit connected between said pair of electrodes, means for producing in said space an electrostatic field having circular symmetry about said first collector electrode and a negative radial gradient such that the field voltage at any point in said space is proportional to

$$-1.12 \times 10^{-14} f^2 r^2$$

where f is a prescribed frequency and r is distance of the point from said first collector electrode, said last means comprising said field electrodes and resistances interconnecting the field electrodes of each group with one another and said first collector and pair of electrodes, and means connected to said gun and said pair of electrodes for maintaining said gun and said pair of electrodes at substantially the same direct current potential.

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