Feb. 26, 1946. H. M. STROBEL 2,395,647

GROUP IMPULSED HIGH-FREQUENCY GENERATOR

Filed Aug. 14, 1941

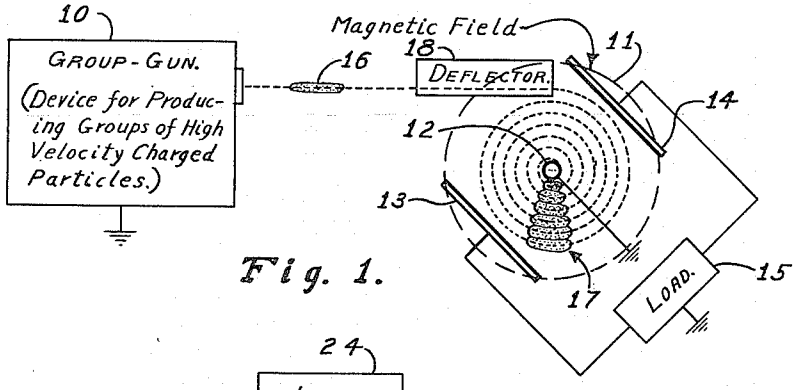



Fig. 1.

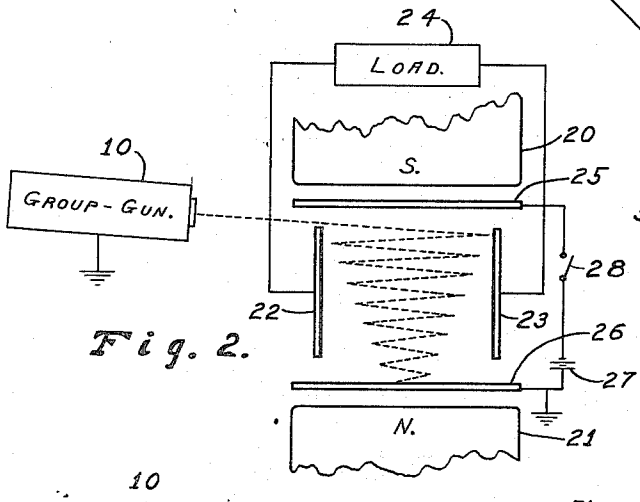



Fig. 2.

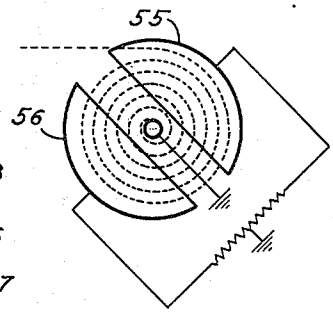



Fig. 4.

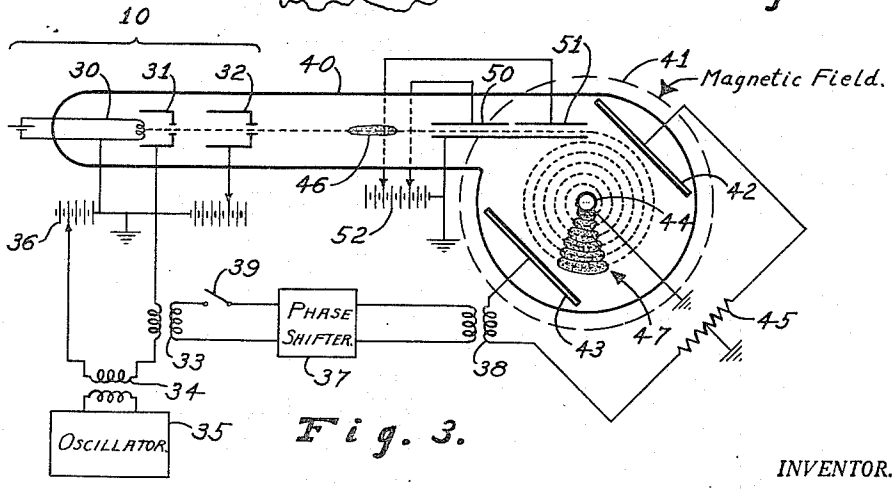



Fig. 3.

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## GROUP IMPULSED HIGH-FREQUENCY GENERATOR

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6 Claims. (Cl. 315—5)

This invention relates to a high-frequency generating system of the type which is impulsed by successive groups of high velocity charged particles moving through space, and in which the same high speed group of charged particles may be caused to energize a collection circuit several times in succession, and in which the spent group of charged particles is collected at a relatively low speed, thus increasing the conversion efficiency of the apparatus.

The object of the invention is to improve the high-frequency generating efficiency of that type of generators which are impulsed by successive groups of high velocity charged particles.

It is possible to form high velocity groups of charged particles which may be used to impulse an oscillatory circuit. In such systems, a beam of charged particles is interrupted by a given control frequency to form groups of given space length and velocity; by increasing the velocity of the groups without proportionately increasing their space length, or by decreasing their space length without proportionately decreasing their velocity, it is possible to make the time interval of collection of the resulting modified groups less than their time interval of formation, thus generating in the collection circuit a frequency higher than the given control frequency. One such method is disclosed in applicant's pending application Serial No. 372,562, filed Dec. 31, 1940. A disadvantage of such systems is that the collection circuit is impulsed but once by each high velocity group, so that all of the energy of the high velocity group is not converted into oscillatory energy. Another disadvantage is that the high-frequency collection circuit is not impulsed each cycle, but only once in several cycles.

The present invention relates to an improved method of high-frequency generation wherein high velocity groups of charged particles, such as electrons, are directed into a specially constructed collector region which is designed to convert the high speed energy of the electron groups into oscillatory energy. The collector region includes a magnetic field which is substantially transverse to the direction of motion of the high velocity electrons, and which is of such strength as to curve the electrons into a substantially circular path or closed curve of given radius. High-frequency collector electrodes are positioned outside the circular path of the electrons and in opposite sectors of the circular region formed by the magnetically curved electrons. The high-frequency collector electrodes are connected to an oscillatory circuit or load in the conventional manner. A rod electrode axially positioned with respect to the circular path of the electrons may be used as a ground return circuit for the spent electrons, thus completing the electric current circuit to the electron gun which formed the initial high velocity electrons.

In describing the operation of the device, assume that a high velocity group of electrons is directed into the collector region field. The electrons will be curved into a circular path, whose radius is determined by their speed and by the strength of the transverse magnetic field. Now if the space length of the electron group is less than the circumferential length of the circular path, it follows that the electron group in swinging around the circular path will first be in one semicircular sector, and then in the other, for each revolution around the circular path. With respect to the high-frequency collector electrodes, the revolving group of electrons will in effect be an electronic charge oscillating back and forth between the collector electrodes, and hence by electrostatic induction will induce an oscillating current in the collector oscillating circuit which will have the same oscillation period as the revolving group of electrons. Since the revolving high speed group of electrons transfers some of its kinetic energy to the collector circuit on each revolution, the kinetic energy (or speed) of the group is decreased by each revolution, and since the strength of the magnetic field is constant, the group revolves in a curved path of smaller radius for each revolution, and in effect describes an inward spiral path until the electron group converges upon the central axial electrode. It is important to note that although the electron group moves in a curved path of decreasing radius as its kinetic energy or speed decreases, its angular velocity remains constant; that is, a low speed group makes one complete revolution in its curved path of small radius in the same time or period as a high speed group makes one complete revolution in its curved path of large radius. Because of this fact, the frequency which is generated by the high and low speed electron groups is the same, and is independent of their kinetic energy, so that a high speed electron group can be used to successively energize or impulse an oscillatory circuit until substantially all of its kinetic energy is converted into oscillatory energy. When the electron group is finally collected by the central axial electrode, it is moving at a relatively low speed so that dissipation of energy at the collector electrode is small. It follows that

the conversion efficiency of the device is correspondingly high.

When successive groups of high speed electrons are directed into the collector region, their periods of separation or periodic intervals should be some multiple of the period of revolution of the groups revolving in the magnetic field. Under such conditions, the entering electron groups will be in phase with the electron groups already revolving in the collector region, and will reinforce the revolving charge with new high speed electrons while the spent low speed electrons, having spiraled inward, will be collected by the central axial electrode. It is to be noted that if a steady stream of electrons were directed into the collector region, that no oscillatory energy could be collected therefrom, since there would always be as many electrons entering a given circular sector as there were leaving it, so that the net number of charges in the sector would remain substantially constant. By periodically interrupting the electron beam so that electrons enter the collector region in groups, an unsymmetrical distribution of the revolving charge results, which by its eccentricity is capable of electrostatically inducing high-frequency energy into a high-frequency collection circuit or load.

More particularly, the invention consists in the system and method hereinafter described, illustrated in the accompanying drawing and defined in the claims hereto appended, it being understood that various changes in form, arrangement and details both of circuits and of method within the scope of the claims may be resorted to without departing from the spirit or sacrificing any of the advantages of the invention.

A clearer understanding of the operation of the invention and its improvement over known methods can be obtained by reference to the following figures and the descriptions relating thereto.

Figure 1 shows the essential elements of the high-frequency generating system and gives a top view of the substantially spiral path of the groups of charged particles.

Figure 2 shows a side view of how pole pieces may be used to create the magnetic field, and gives a side view of an extended spiral path of the groups of charged particles.

Figure 3 shows a circuit diagram of the high-frequency generating system.

Figure 4 shows a modification in the type of high-frequency collector electrodes that may be used.

Figure 1 shows the essential elements of the high-frequency generating system, wherein it is assumed that the region through which the charged particles move is evacuated according to standard practice. Block 10 represents the group-gun, and includes means for producing high velocity groups of charged particles. The dashed line circle 11 indicates the region wherein a magnetic field is applied vertical to the drawing. The magnetic field 11 can be formed by any of the conventional means well known to the art, as by means of a permanent magnet or an electromagnet. The number 12 indicates a central axial electrode member, which is grounded to form an electric current return path to the group-gun 10. The high-frequency collecting electrodes are indicated by 13 and 14, and the load impedance connected thereto by 15. The group 16 represents a high velocity group of charged particles, say electrons, while 17 indicates the built up groups of revolving electrons in the magnetic field of the collector region. The path that the electron groups from the group-gun 10 follow is indicated by the dotted line, and it will be noted that within the magnetic field 11 of the collector region the path is curved substantially into a spiral. The block 18 indicates a deflector, which may include means for counteracting the effect of the magnetic field 11 upon the charged particles while they are being directed into the collector region, thereby controlling the point at which the spiral begins. The deflector 18 can also include means for giving the groups of charged particles a vertical velocity component parallel to the lines of the magnetic field 11, so that the groups follow the path of an extended spiral, instead of a flat spiral.

Operation of the device may be understood by reference to Figure 1. The group-gun 10 includes means for producing high velocity groups of charged particles or electrons, such means being well known to the art. A conventional means could include an electron gun with a grid control, the grid being energized by an oscillator so as to interrupt the electron beam, thus breaking it up into groups. Electron group 16 indicates a high velocity group formed by the group-gun 10 and being directed along the dotted line path toward the collector region. When the electron group enters the magnetic field 11 it is curved into a substantially circular path whose radius of curvature is determined by the kinetic energy of the group and the strength of the magnetic field 11. With each revolution the electron group electrostatically induces energy, by virtue of its movement between electrodes 13—14, into the high-frequency collector circuit 13, 14, and 15, and loses some of its kinetic energy thereby. With each loss of a portion of its kinetic energy, the electron group follows a curved path of smaller radius. By properly timing the period of the successive groups directed by the group-gun 10 into the collector region, a revolving group 17 of electrons can be built up. In the drawing, the revolving group 17 is revolving clockwise, and by the time it has revolved another 180 degrees the electron group 16 will be entering the collector region in phase with it, and therefore will merge with the group 17. As the electrons of the group 17 lose their kinetic energy, they will spiral inward until they reach the central axial collector electrode 12. Since they are collected at the electrode 12 at relatively low speeds, the dissipation of energy at the electrode 12 is small, and a high conversion efficiency results.

Still referring to Figure 1, it is to be noted that the revolving group 17 of electrons constitutes an electrostatic charge which in effect oscillates back and forth between the high-frequency collector plates 13 and 14. In thus revolving between the collector plates 13 and 14, an alternating voltage is induced in the oscillatory collector circuits 13, 14, and 15. With every revolution of the revolving charges, however, some of their kinetic energy is converted into high-frequency energy, so that each working electron of the group 17 suffers a decrease in its kinetic energy. This decrease in kinetic energy or speed for each revolution causes the electrons to be curved in paths of smaller and smaller radius to form the substantially spiral path shown in the drawing. It is to be observed that the revolving group 17 is formed of electron groups which have decreasing kinetic energies as they approach the central electrode 12, but all of which have the same angular velocity, making one complete revolution in the same interval of time. As the

electron group 17 revolves in the magnetic field 11, the electrons also move radially inward and are finally collected by the electrode 12 at the center, while new high speed electrons are added to the group 17 at its outer rim.

Figure 2 shows a side view of the essential elements of a modified form of high-frequency generator according to this invention. It is assumed that the region in which the charged particles move is evacuated according to standard practice. The block 10 indicates a group-gun for directing high speed charged particles into the magnetic collector region. The magnetic field for the collector region is maintained by a permanent magnet or electromagnet whose N-pole 21 and S-pole 20 are shown in the drawing. Conventional means for controlling the strength of this field may be provided. Collector electrodes or plates arranged in opposite sectors of the circular region wherein the charges revolve are indicated at 22 and 23. A load impedance 24 is connected to the oscillatory collector circuit. The plates 25 and 26 may be energized from a source 27 by closing switch 28 to provide an electrostatic field which is parallel to the magnetic lines of force. The dotted lines indicate the path followed by the moving charged particles, and it will noted that the side view shows an extended spiral, similar to a spiral curve drawn on a conical surface.

The operation of the device in Figure 2 is essentially the same as that of Figure 1. When the electron groups are directed into the magnetic field of the collector region, if they enter the magnetic field along a line contained in a plane which is perpendicular to the lines of the magnetic field, the path within the field will be substantially a flat spiral; if they enter the field along a line which makes a small angle with this perpendicular plane, the groups will have a constant component of velocity parallel to the magnetic lines of force, and the spiral path will be extended substantially as shown in Figure 2. The above method extends the spiral by controlling the angle at which the electron groups are directed into the magnetic field. It is also possible to extend what would otherwise be a flat spiral by providing a small electrostatic field parallel to the magnetic flux lines, such as could be set up between the plates 25 and 26 by applying a voltage through the closing of switch 28. If the spiral is extended by the use of an electrostatic field, the component of velocity parallel to the magnetic field will increase towards the apex of the extended spiral, due to the accumulative velocity effect of the accelerating electrostatic field. In Figure 2, the bottom plate 26 serves as the ground return for the collected charged particles. By thus extending the spiral path of the electrons, the space charge density in the collector region is reduced and the revolving electron groups follow a path substantially as described above. When the electron groups follow a flat spiral path, the revolving group resulting constitutes a space charge of high density whose electrostatic fields tend to disperse the electrons in all directions. These dispersed electrons fall out of step with the revolving group and as a result decrease the amount of high-frequency energy which can be extracted from the electrons.

Figure 3 shows a circuit diagram of a high-frequency generator according to this invention. The group-gun 10 includes the cathode 30, grid 31, and accelerating anode 32. The grid 31 can be biased by a grid battery 36, so that only the positive peaks of an applied alternating current voltage permit groups or pulses of electrons to pass from the cathode 30 to the anode 32. An energizing control voltage may be applied to the grid 31 by the oscillator 35 through the coupling transformer 34, thus operating the device as a power amplifier; or the energizing voltage may be fed back from the collector circuit 42, 43, 45 through the coupling transformer 38, phase shifter 37, switch 39 and coupling transformer 33, thus operating the device as an oscillator. The vessel 40 permits the evacuation of air from the region in which the groups of charged particles move. The dashed line 41 indicates the region in which a magnetic field is applied which is here assumed vertical to the drawing. 42 and 43 represent high-frequency collector electrodes, and 45 shows a load impedance connected thereto. The group-gun 10 is shown directing the electron group 46 toward the collector region, while the built up revolving electron group in the collector region is shown at 47. The dotted line indicates the path of the electron groups. A ground return circuit is provided by the axial electrode 44. The deflector circuit, 50, 51, and 52, indicates means for electrostatically counteracting the undesired deflective action of portions of the magnetic field 41. By properly adjusting the voltages applied to deflector plates 50 and 51 it is possible to keep the entering electron groups in a substantially straight or predetermined path until they reach that point in the collector region field where the spiral begins.

Figure 4 shows an alternative method of constructing the high-frequency collector plates 55 and 56. The plates are made in the form of hollow circular segments, and the electron groups follow the path indicated by the dotted line, substantially as explained for the preceding figures. Each time an electron group passes from one segmental electrode into the other, it induces a voltage in the high-frequency collection circuit, thereby transforming some of its kinetic energy into oscillatory energy.

In the drawing the revolving groups inside the collector region which together make up the revolving group 17 in Figure 1 and the revolving group 47 in Figure 3 are not all of the same length as measured along the path of the spiral. That is, the higher speed groups are shown longer than the lower speed groups. The result is to give a wedge shaped revolving group or circular sector substantially as shown, each group of which has the same angular velocity, but the length of each group being substantially proportional to its speed. As first introduced into the collector region magnetic field, each group has a high speed and a given space length. However, on each revolution it imparts part of its energy to the collector oscillatory circuit, and thereby decreases its own kinetic energy or speed. Since for each revolution the front electrons of the group are the first to start doing work on the high-frequency fields of the collector circuit, they are the first to be slowed down, and hence the rear electrons tend to overtake them, resulting in a shortening of the space length of the group for each working revolution. As a result, the space length of the group decreases substantially in proportion to its decrease in speed. The above represents the idealized case, but in actual practice it must be remembered that space

charge effects may introduce distortion as regards the shape of the revolving groups.

I claim:

1. In a high-frequency generating system utilizing high velocity charged particles in an evacuated vessel and including a collector region, the method of high-frequency generation which includes forming a group of high speed charged particles, directing said group of charged particles into said collector region, creating a magnetic field of predetermined strength across said collector region substantially transverse to the directed path of said group, counteracting the deflective action of that portion of the magnetic field external to the collector region upon the entering group of charged particles, whereby said group of charged particles revolves within said collector region, collecting oscillatory energy from said revolving group of charged particles, and returning the spent charges to the group forming device.

2. In high-frequency generating system utilizing high velocity charged particles in an evacuated vessel and including a collector region, means for forming a group of high speed charged particles, means for directing said group of charged particles into said collector region, means for creating a magnetic field of predetermined strength across said collector region substantially transverse to the directed path of said group, so as to deflect said group of charged particles into a path describing a substantially closed curve, means for counteracting the deflective action of that portion of the magnetic field external to the collector region upon the entering group of charged particles, whereby said group of charged particles revolves within said collector region, means for collecting oscillatory energy from said revolving group of charged particles, and means for returning the spent charges to the group forming device.

3. In a high-frequency generating system utilizing high velocity charged particles in an evacuated vessel and including a collector region, means for forming a group of high speed charged particles, means for introducing said group of charged particles into said collector region, means for creating a magnetic field of predetermined strength across said collector region substantially transverse to the directed path of said group, means for controlling the speed of said charged particles so as to cause said group of charged particles to revolve in a substantially closed curve within said collector region, means for creating an electrostatic field in said collector region substantially parallel to the magnetic field, means for collecting oscillatory energy from said revolving group of charged particles, and means for returning the spent charges to the group forming device.

4. In a high-frequency generating system utilizing high velocity charged particles in an evacuated vessel and including a collector region, means for creating a magnetic field through said collector region, means for forming a group of high speed charged particles, means for introducing said group of charged particles into said collector region along a line oblique to said magnetic field so as to deflect said group into a path describing an extended spiral curve within said collector region, means for collecting oscillatory energy from the moving group of charged particles within said collector region, and means for returning the spent charges to the group forming device.

5. In a high-frequency generating system utilizing high velocity charged particles in an evacuated vessel and including an electric gun for creating a stream of high speed charged particles, said electric gun having a grid structure for controlling the magnitude of said stream of charged particles, an oscillator for energizing said grid with a given control frequency, a collector region in the path of said stream of charged particles, a magnetic field passing through said collector region oblique to the directed path of said entering stream of charged particles, said magnetic field being predetermined in magnitude so as to deflect said charged particles therein into a substantially extended spiral path, an oscillatory circuit including two high-frequency collector electrodes, said electrodes being disposed within said collector region in such a manner as to permit the revolving charged particles therein to oscillate between them, and a current collector electrode centrally disposed within said collector region and electrically connected to the cathode of said electric gun.

6. In a high-frequency generating system utilizing high velocity charged particles in an evacuated vessel and including an electric gun for creating a stream of high speed charged particles, said electric gun having a grid structure for controlling the magnitude of said stream of charged particles when energized, an oscillatory energizing source for energizing said grid structure, a collector region in the path of said stream of charged particles, a magnetic field passing through said collector region and substantially transverse to the path of said stream of charged particles, said magnetic field being predetermined in magnitude so as to deflect said charged particles therein into a substantially closed curve path, a deflector element providing a controlled electrostatic field across a portion of the path of the charged particles and so disposed as to counteract the magnetic deflective action which the charged particles are subjected to while passing through the outer region of the magnetic field of the collector region, an oscillatory circuit including at least two high-frequency collector electrodes, said electrodes being disposed within said collector region in such a manner as to permit the revolving charged particles therein to oscillate between them, a transmission line including a phase shifting device for diverting a portion of the generated high-frequency energy back to serve as an energizing source for said grid structure, and a current collector electrode centrally disposed within said collector region and electrically connected to the cathode of said electric gun.

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