May 15, 1951 T. M. DICKINSON 2,553,305

INJECTION COMPENSATION IN HIGH-ENERGY PARTICLE ACCELERATION

Filed May 12, 1949 2 Sheets-Sheet 1

Fig. 1.

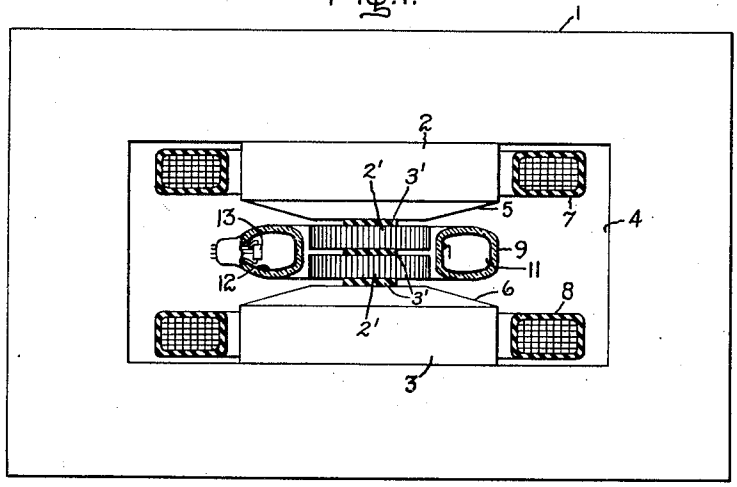


Fig. 3.

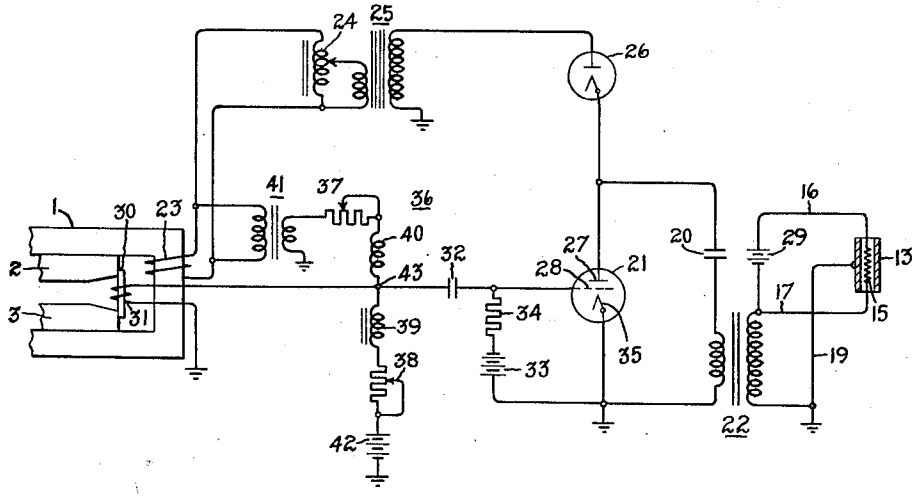
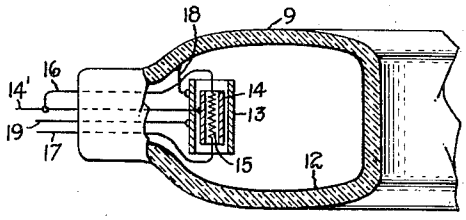


Fig. 2.



Inventor:
Theodore M. Dickinson,
by Richard E. Hosley
His Attorney.

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Fig. 4.

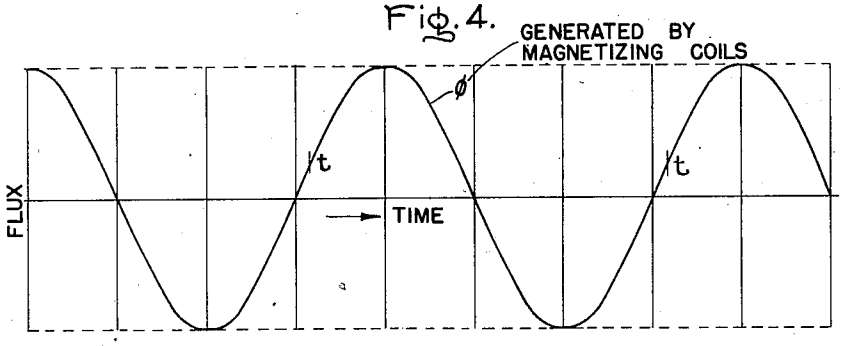


Fig. 5.

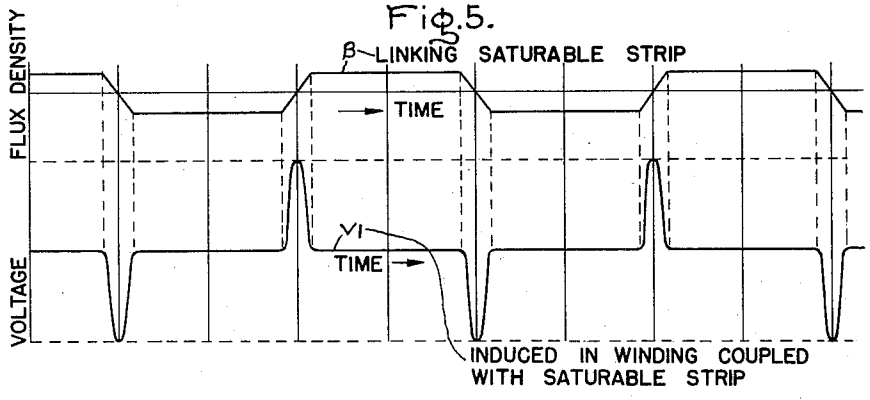


Fig. 6.

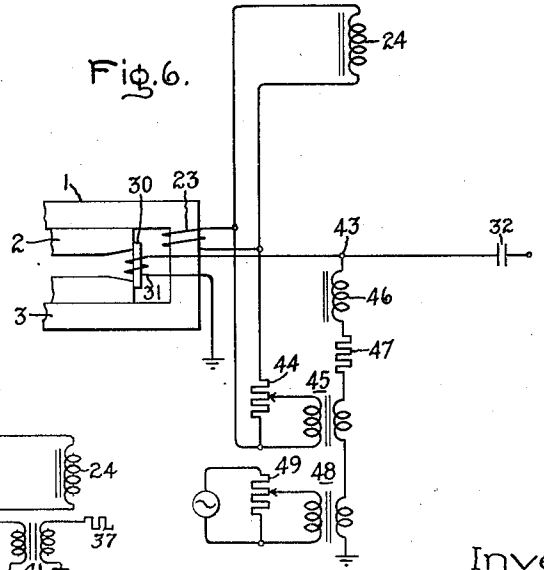
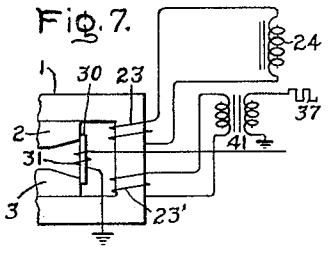


Fig. 7.



Inventor:
Theodore M. Dickinson,
by Richard E. Hosley
His Attorney.

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UNITED STATES PATENT OFFICE

2,553,305

INJECTION COMPENSATION IN HIGH-ENERGY PARTICLE ACCELERATION

Theodore M. Dickinson, Schenectady, N. Y., assignor to General Electric Company, a corporation of New York

Application May 12, 1949, Serial No. 92,768

17 Claims. (Cl. 250—27)

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The present invention relates to apparatus for the acceleration of charged particles by magnetic induction effects. The invention finds useful application in connection with apparatus of the general character described in United States Patent No. 2,297,305, patented September 29, 1942, in the name of Donald W. Kerst and assigned to the General Electric Company, a corporation of New York, as well as apparatus described in copending application, Serial No. 616,634, filed in the name of Willem F. Westendorp on September 15, 1945, copending application Serial No. 639,462, filed in the name of Herbert C. Pollock and Willem F. Westendorp on January 5, 1946 (now matured into Patent No. 2,485,409), and copending application 724,066, filed in the name of John P. Blewett on January 24, 1947 (now matured into Patent No. 2,465,786), all of said copending applications being assigned to the General Electric Company.

Apparatus of the character referred to typically utilize at least in part a cyclically varying magnetic flux for accelerating charged particles in an orbital path. After the particles have been accelerated to desired energy levels, they may be accelerated still further by other means or they may be diverted from the orbit and utilized for the production of useful biological or other effects.

In the operation of magnetic induction apparatus of this type, a primary problem is experienced in the suitable introduction of charged particles into the stable orbit region. If proper particle capture is to be realized, suitable correlation between the injecting means and the cyclically varying flux must be attained.

A principal object of the present invention is to provide improved means for correlating particle injection with the cyclically varying flux.

The cyclically varying flux upon which acceleration of the particles depends, is conveniently provided by the action of a cyclically varying electrical current; and, when it is so produced, acceleration in the desired direction occurs only during alternate half cycles, even though useful operation may be extended by means described in the above-mentioned copending application, Serial No. 616,634. The most advantageous time for particle injection occurs near the time when the flux is beginning to build up in a direction favoring the desired acceleration. To insure maximum particle capture, the kinetic energy of the particles at the instant of injection should match the values of the flux such that continuous acceleration will occur along a stable orbit of desired radius.

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It has been proposed heretofore to correlate the particle injection with the flux by the provision of a magnetic path which is adapted to change abruptly and reversibly from a saturated to an unsaturated condition in accordance with the variations of the flux. By linking an appropriate circuit with the magnetic path, sharp pulses of voltage bearing a timed relation with respect to the variations of the flux are obtained and utilized to initiate particle injection. Such an expedient assures injection at the proper time, if after the desired time has been selected, the magnitude of the varying flux does not change. If such changes do occur, the kinetic energy of the particles at injection will not be of proper value and inefficient capture will result. The present invention insures proper injection energies at all times during the operation of the apparatus by the provision of suitable circuit means to cause the injection energy to be proportional to such changes.

The features of the invention desired to be protected herein are pointed out with particularity in the appended claims. The invention itself together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawings in which Fig. 1 is a simplified front elevation of a particle accelerator with which the invention may find useful application; Fig. 2 is a sectionalized view of the particle source portion of the accelerator tube; Fig. 3 is a circuit diagram illustrating the electrical interrelation of the various components embodied in the invention; Figs. 4 and 5 inclusive are graphical representations useful in explaining the invention, and Figs. 6 and 7 are circuit diagrams illustrating alternative electrical interrelations of various components embodied in the invention.

Referring particularly to Figs. 1 and 2, there is shown a magnetic induction accelerator comprising a rectangular magnetic core 1 having pole piece members 2 and 3 located within the opening 4. Pole piece members 2 and 3 are suitably tapered at their opposed faces as indicated at 5 and 6 to provide a desired magnetic field configuration. To provide energization for the magnetic structure comprising the core and pole pieces, serially-connected magnetizing windings 7 and 8, which may be connected to a suitable source of voltage (not shown), are respectively concentrically arranged about pole piece members 2 and 3. Between the opposed pole piece members, there is located a closed rotationally symmetrical glass vessel 9 which defines within its

interior an annular chamber 11. The vessel may be highly evacuated and coated on its interior surface with a conductive layer of silver or other suitable material 12 for the purpose of reducing wall-charging. For the purpose of introducing charged particles into the vessel there is provided within the region of influence of the magnetic field generated by the magnetizing windings a charged particle source comprising an electrode 13 having an opening for the egress of electrons, a focusing member 14 and a thermionic cathode 15 which may be energized by a suitable source of potential (not shown) through leads 16 and 17. Electrode 13 may be connected to layer 12 by a lead 18 and to ground through a lead 19 for a purpose to be more fully described hereinafter in connection with Fig. 3. Connected to shield 14 and to lead 16 is a lead 14' which together with leads 17 and 18 may be insulatingly introduced through the vessel 9 by means of a suitable glass seal. Between the opposed faces of the pole piece members, laminated disks 2' are supported by insulating spacers 3' to provide the proper reluctance within the flux path enclosed by the vessel.

As will be readily understood by those skilled in the art, the magnetizing coils 7 and 8, when energized by a suitable cyclically varying current, establish a similarly cyclically varying magnetic flux within the magnetic structure. When charged particles are introduced into the region of influence of this varying flux by the particle source within the vessel 10, they will be accelerated along an orbital path providing a certain relationship obtains. In general, it may be stated that successful acceleration may be achieved if

$$\phi = 2\pi r^2 H_r$$

where ϕ is the flux included within or linking the stable particle orbit, r is the radius of the aforesaid particle orbit and H_r is the field strength at the orbit. This relation means that the flux ϕ must be twice as great as that which would be produced by a homogeneous field equal to the field H_r extending over the entire area enclosed by the orbital path. This condition may be realized by properly arranging the reluctance of the magnetic circuit with such members as laminated disks 2' and pole piece members 2 and 3.

The charged particles, i. e. electrons, provided by filamentary cathode 15 are affected in two ways when they are injected into the stable orbit region. First, the field established at the orbit tends to cause the electrons to follow an inwardly spiralling path. Secondly, the flux enclosed by the orbit or any particular electron produces an electric field tending to accelerate the electrons. Thus, the electrons may be considered to be accelerated by a portion of the cyclically varying flux which links the orbital path while being guided along the path by the cyclically varying magnetic field established along the orbit.

As has been heretofore explained, acceleration of the electrons takes place only during alternate half-cycles of the varying flux, and therefore the electrons must be injected during each half cycle in which acceleration is desired. This may be accomplished by driving the electrons emitted by cathode 15 from the particle source at a timed instant with respect to the varying flux. As will be observed, if cathode 15 is abruptly caused to assume a negative potential with respect to electrode 13, the electrons within the source will be subjected to a repelling force which will drive them through the opening provided for their egress into the region of influence of the varying flux.

The energy at which the electrons must be injected will be determined by the value of the cyclically varying flux at that instant. In order to assure most efficient electron capture, the energy of the electrons must match the intensity of the guide field at injection to make their radius of curvature approximately equal to that of the stable orbit of the accelerator apparatus. For energies at which injection is customarily accomplished, the energy required for such matching will vary approximately as the square of the field strength for a given radius of curvature. The present invention insures the required matching by providing means for injecting the electrons at an energy level proportional to the magnitude of the cyclically varying flux and at a time corrected to compensate for the square law requirement.

Reference may now be had to Fig. 3 wherein portions representative of elements of an induction accelerator such as that shown in Figs. 1 and 2 are similarly identified. For driving cathode 15 abruptly to a negative potential with respect to electrode 13, there is shown a pulse-generating circuit comprising an energy-storing device represented by a capacitor 20 in circuit with a grid-controlled gaseous discharge device 21 and a pulse transformer 22. For the purpose of charging capacitor 20, a winding 23 may be placed so as to be inductively linked by the cyclically varying flux of the accelerator; e. g., wound about the magnetic core 1 as shown. In circuit with winding 23 are an adjustable autotransformer 24, a step-up transformer 25 and diode rectifier tube 26, the cathode of which is connected to capacitor 20 and the plate 27 of discharge tube 21. As may be readily understood capacitor 20, after it has been charged by the voltage induced in winding 23 as a result of the cyclical variations of flux, may be discharged through the discharge device 21 and the primary of pulse transformer 22 by the application of a suitable triggering voltage or signal to grid 28. This discharge causes a voltage pulse to be induced in the secondary of pulse transformer 22, such pulse appearing between the filamentary cathode 15 and ground since one end of the secondary of transformer 22 is connected to the cathode 15 and the other to ground. Electrode 13 is also connected to ground through lead 19 and therefore this voltage pulse, which may be in the order of 100 kilovolts, results in the cathode 15 being driven to a negative voltage with respect to electrode 13. As a consequence, electrons provided by heating the cathode with a suitable source of potential, conventionally shown as battery 29, are projected into the region of influence of the cyclically varying flux so that they may be accelerated to the desired energy levels.

For the purpose of timing the application of the hereinbefore mentioned voltage to grid 28 with respect to the cyclically varying flux, there is provided a magnetically saturable core or strip 30 around which is placed a winding 31. As the flux which links the saturable core varies, an abrupt pulse is produced in winding 31 and is transmitted through blocking capacitor 32 to grid 28. To suitably bias discharge device 21 biasing battery 33 is connected in series with grid resistor 34 between the grid 28 and cathode 35.

To obtain a better understanding of the timing of the application of the abrupt pulse to grid

28, reference may be had to Figs. 4 and 5. In Fig. 4 the curve labeled ϕ may be considered as representative of the cyclically varying flux generated by windings 7 and 8 and the points t may be considered as the time at which particle injection is desired in order that advantageous acceleration may be procured. In Fig. 5 the curve label β may be considered as representative of the variations in magnetic flux linking the saturable strip or core 30. It will be observed, due to the ready saturability of the core, that the only changes of magnetic flux in the core occur near regions of reversal of the curve ϕ. The curve v_1 appearing in Fig. 5 indicates the abrupt voltage pulses which will be induced in windings 31 as a result of the changes in magnetic flux within the saturable core 30.

It will be noted that the maxima of the curve v_1 occur approximately at the points of zero flux indicated by the curve ϕ. The relative relation of the maxima of curve v_1 with respect to the curve ϕ may be altered by the suitable application of a biasing flux to the saturable core 30. This biasing flux may be produced by means of a current flowing through the winding 31 (Fig. 3) supplied from a battery 42 and adjusted in value by variable resistor 38. Choke coil 39 having a low impedance to the biasing current but a high impedance to the abrupt pulse of voltage produced in the winding 31 by the varying flux prevents this abrupt pulse from being by-passed to ground through the relatively low impedance of resistor 38 and battery 42 and thus from failing to reach the grid 28 of discharge device 21 through capacitor 32. The biasing current through winding 31 produces a biasing field in saturable core 30 which opposes the field produced across the pole faces 2 and 3 during the accelerating half cycle and thus causes the flux in the saturable strip to pass through zero at a time later than does the guide field. Accordingly, the application of the voltage pulse to grid 28 of discharge device 21 may be arranged such that the particle source will be energized at a particular value of the cyclically varying flux whereby the particles may be injected into the region of influence of the varying flux at a time corresponding to the correct value for continuous acceleration.

It will be readily understood, however, that after the timing of the voltage pulse, represented by curve v_1, has been set by adjustment of the biasing flux in the saturable core 30 for a particular energy level of the source, if the magnitude of the cyclically varying flux changes, the energy level of the injected particles will no longer match the value of the cyclically varying flux at the instant of injection and inefficient capture will result. To correct for this, either the energy level of the injected particles or the time of injection or both must be changed.

As has been hereinbefore stated, the energy level at which the particles should be injected for proper capture is proportional to the square of the intensity of the guide field at the instant of injection and in turn, therefore, is proportional to the square of the magnitude of the cyclically varying flux wave. If the energy level of the injected particles is caused to change as the square of this magnitude, the time of injection for proper capture will remain the same. If the energy level of the injected particles is caused to vary linearly with the magnitude of the cyclically varying flux, then it will be required to change the time of injection to maintain proper capture. In practice, over the small range of fluctuations of the cyclically varying current used to excite the magnet, the time for successful injection of particles of a given energy level varies nearly as a linear function of the magnitude of the guide field. Thus, it will be readily understood, for an energy level of the particles which varies in a linear manner with the magnitude of the guide field, if the time of injection is caused to vary in a linear manner with the magnitude of the guide field, a proper match of energy level and guide field can be maintained.

With reference again to Fig. 3 and to the previous description in connection therewith, it will be observed that the value of charge on capacitor 20 is directly proportional to the magnitude of the varying flux since the charging voltage for capacitor 20 is supplied by winding 23. This means that the injection energy level will vary linearly with the magnitude of the cyclically varying flux and secure one desired proportionality, because the magnitude of the pulses supplied by capacitor 20 to the source will be directly proportional to the magnitude of the varying flux.

In order to secure a second direct proportionality between the injection of particles and the varying flux, there is provided a means for altering the timed relation of the voltage pulse applied to grid 28. As shown, this means comprises a biasing supply for saturable core 30 which is indicated generally by the numeral 36 and includes a variable resistor 37, a choke coil 40 connected to the grid circuit of tube 21 at 43, and an energizing step-down transformer 41, the primary of which is connected across winding 23. Biasing supply 36 provides an additional biasing current through winding 31 which, combined with the biasing current from the hereinbefore described current from battery 42, produces a biasing flux in saturable core 30 and determines the time at which particle injection occurs. By proper adjustment of variable resistors 37 and 38, a condition may be obtained whereby injection of particles occurs at the correct time for matching a particular guide field strength. When random fluctuations occur in the magnitude of the current through exciting coils 7 and 8, resulting in random fluctuations of the magnitude of the cyclically varying flux, corresponding variations appear in the induced voltage in winding 23 and cause similar variations in that portion of the biasing current through coil 31 derived from biasing supply 36. This automatically alters the timed relation of the voltage pulse applied to grid 28 in direct proportion to magnitude of the cyclically varying flux.

It will now be evident that the requirements for successful injection are provided even though random variations in the cyclically varying flux may occur. If the magnitude of the varying flux changes, then both the injection energy level and the time of injection will vary in direct proportion thereto and the particles will be injected at the desired combination of energy level and time.

An alternative arrangement for timing the application of the voltage pulse to the grid of discharge device 28 is shown in Fig. 6 wherein portions corresponding to portions of Fig. 3 are similarly identified. Voltage induced in winding 23 by the cyclically varying flux is applied through potentiometer 44 and transformer 45, the secondary of which is connected in series with a choke 46, a fixed resistor 47, and the secondary of a transformer 48. The primary of transformer 48 is connected through potenti-

ometer 49 to a cyclically varying source of current having a constant peak magnitude and the same frequency as that of the cyclically varying flux. By adjustment of potentiometers 44 and 49 the proper voltages are obtained in the secondary windings of transformers 45 and 48 such that their additive effect is similar to that described in connection with Fig. 3. The resistor 47 is made large with respect to the impedance of the remainder of the circuit in order that the cyclically varying biasing current will be substantially in phase with the induced voltage of winding 23, thereby causing the maximum value of bias to occur near zero guide field when the biasing effect is required.

Although only one winding 23 has been shown as an energizing means for charging capacitor 20 and for supplying biasing current, it is obvious that separate windings may be employed for each function in similar fashion, as is illustrated in Fig. 7 which is identical with a portion of Fig. 3 except that separate winding 23' is employed to supply biasing current. In addition, although the biasing current supplied by winding 23 has been shown as cyclically varying, it may be rectified by placing a suitable rectifier in circuit with the secondary of transformer 41; however, it is preferred to employ varying current because the phase angle may be arranged such that the peak will occur at the time of injection, thereby requiring a smaller root mean square value of current. As a further expedient, an amplifier or pulse shaper may be interposed between winding 31 and grid 28 to steepen the wave front of the pulse as it is applied to grid 28 whereby the regularity of the firing of discharge device 21 may be improved. Also, it will be observed that capacitor 20 may be replaced by a lumped constant line which will perform a similar function in storing energy for discharge by discharge device 21. It will likewise be understood that the hereinbefore mentioned flux which links the orbital path to produce acceleration may be generated separately from the magnetic field established along the orbit. In such event, the advantageous application of this invention may be secured in accordance with the principles herein advanced since the magnetic induction acceleration relationship between the accelerating flux and the guide field must be maintained and injection conditions may be related thereto in a similar manner.

While the invention has been described by reference to particular embodiments, it will be understood that numerous modifications may be made by those skilled in the art without actually departing from the invention. I therefore aim in the appended claims to cover all such equivalent variations as come within the true spirit and scope of the foregoing disclosure.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In apparatus for the acceleration of charged particles in an orbital path by the production of a cyclically varying flux which links the path to accelerate the particles and establishes a magnetic field to constrain the particles to the path, the combination which comprises a source of charged particles adjacent the path and effective when energized to inject charged particles into the path, means for energizing said source with energy pulses proportional to the magnitude of the varying flux in response to a triggering voltage, a winding having a magnetically saturable core linked by the varying flux to generate a periodic voltage for triggering said means in timed relation to the varying flux, and a winding linked by the varying flux to generate a current proportional to the magnitude of the flux and connected to said first named winding to produce a magnetic bias in said core for altering the time at which the periodic triggering voltage is generated.

2. In apparatus for the acceleration of charged particles in an orbital path by the production of a cyclically varying flux which links the path to accelerate the particles and establishes a magnetic field to constrain the particles to the path, the combination which comprises a source of charged particles adjacent the path and effective when energized to inject charged particles into the path, means for energizing said source with energy pulses of varying magnitude in response to a triggering voltage including a first winding linked by the varying flux to supply energy for the pulses in proportion to the magnitude of the flux, a second winding having a magnetically saturable core linked by the varying flux to generate a periodic voltage for triggering said means in timed relation to the varying flux, and a bias supply circuit energized by said first winding and connected to said second winding to produce a magnetic bias in said core for altering the time at which the periodic triggering voltage is generated.

3. In apparatus for the acceleration of charged particles in an orbital path by the production of a cyclically varying flux which links the path to accelerate the particles and establishes a magnetic field to constrain the particles to the path, the combination which comprises a source of charged particles adjacent the path and effective when energized to inject charged particles into the path, means for energizing said source with energy pulses of varying magnitude in response to a triggering voltage including a first winding linked by the varying flux to supply energy for the pulses in proportion to the magnitude of the flux, a second winding having a magnetically saturable core linked by the varying flux to generate a periodic voltage for triggering said means in timed relation to the varying flux, and a bias supply circuit energized by a third winding linked by the varying flux to produce a current in said circuit proportional to the magnitude of the varying flux and connected to said second winding to produce a magnetic bias in said core for altering the time at which the periodic triggering voltage is generated.

4. In apparatus for the acceleration of charged particles in an orbital path by the production of a cyclically varying flux which links the path to accelerate the particles and establishes a magnetic field to constrain the particles to the path, the combination which comprises a source of charged particles adjacent the path and effective when energized to inject charged particles into the path, means for energizing said source with energy pulses of varying magnitude in response to a triggering signal including a first winding linked by the varying flux to supply energy for the pulses in proportion to the magnitude of the flux, a second winding having a magnetically saturable core linked by the varying flux to generate a periodic voltage for triggering said means in timed relation to the varying flux, and a bias supply circuit energized by said first winding and serially connected to said second winding to supply a biasing current for altering the time at which the periodic triggering voltage is generated.

5. In apparatus for the acceleration of charged particles in an orbital path by the production of a cyclically varying flux which links the path to accelerate the particles and establishes a magnetic field to constrain the particles to the path, the combination which comprises a source of charged particles adjacent the path and effective when energized to inject charged particles into the path, means for energizing said source with energy pulses of varying magnitude in response to a triggering signal including a first winding linked by the varying flux to supply energy for the pulses in proportion to the magnitude of the flux, a second winding having a magnetically saturable core linked by the varying flux to generate a periodic voltage for triggering said means in timed relation to the varying flux, and a bias supply circuit energized by a third winding linked by the varying flux to produce a current in said circuit proportional to the magnitude of the varying flux and serially connected to said second winding to supply a biasing current for altering the time at which the periodic voltage is generated.

6. In apparatus for the acceleration of charged particles in an orbital path by the production of a cyclically varying flux which links the path to accelerate the particles and establishes a magnetic field to constrain the particles to the path; the combination which comprises a source of charged particles adjacent the path and effective when energized to inject charged particles into the path; means for energizing said source including an energy-storing device, a winding linked by the flux and in circuit with a rectifier for charging said energy-storing device to a voltage proportional to the magnitude of the flux, and a grid-controlled gaseous discharge device in circuit with said energy-storing device for discharging said energy-storing device when rendered conductive by a triggering signal to produce energy pulses for said source; means for rendering said discharge device conductive including a winding having a magnetically saturable core linked by the flux to produce a periodic voltage in said last named winding for triggering said discharge device in timed relation to the cyclical variations of the flux; and means for altering the timed relation of rendering said discharge device conductive including a bias supply circuit energized by said first named winding and connected in circuit with said second named winding to produce a magnetic bias in said core.

7. In apparatus for the acceleration of charged particles in an orbital path by the production of a cyclically varying flux which links the path to accelerate the particles and establishes a magnetic field to constrain the particles to the path; the combination which comprises a source of charged particles adjacent the path and effective when energized to inject charged particles into the path; means for energizing said source including an energy-storing device, a winding linked by the flux and in circuit with a rectifier for charging said energy-storing device to a voltage proportional to the magnitude of the flux, and a grid-controlled gaseous discharge device in circuit with said energy-storing device for discharging said energy-storing device when rendered conductive by a triggering signal to produce energy pulses for said source; means for rendering said discharge device conductive including a winding having a magnetically saturable core linked by the flux to produce a periodic voltage in said last named winding for triggering said discharge

device in timed relation to the cyclical variations of the flux; and means for altering the timed relation of rendering said discharge device conductive including a winding linked by the flux to generate a current proportional to the magnitude of the flux and connected in circuit with said second named winding to produce a magnetic bias in said core.

8. In apparatus for the acceleration of charged particles in an orbital path by the production of a cyclically varying flux which links the path to accelerate the particles and establishes a magnetic field to constrain the particles to the path, the combination which comprises a source of charged particles adjacent the path and effective when energized to inject charged particles into the path, means for energizing said source with energy pulses proportional to the magnitude of the varying flux in response to a triggering voltage, a winding having a magnetically saturable core linked by the varying flux to generate a periodic voltage for triggering said means in timed relation to the varying flux, and current-supplying means connected to said winding for magnetically biasing said core to alter the time at which the periodic triggering voltage is generated including a source of direct current and a winding linked by the varying flux.

9. In apparatus for the acceleration of charged particles in an orbital path by the production of a cyclically varying flux which links the path to accelerate the particles and establishes a magnetic field to constrain the particles to the path, the combination which comprises a source of charged particles adjacent the path and effective when energized to inject charged particles into the path, means for energizing said source with energy pulses of varying magnitude in response to a triggering voltage including a first winding linked by the varying flux to supply energy for the pulses in proportion to the magnitude of the flux, a second winding having a magnetically saturable core linked by the varying flux to generate a periodic voltage for triggering said means in timed relation to the varying flux, and current-supplying means connected to said second winding for magnetically biasing said core to alter the time at which the periodic triggering voltage is generated including a source of direct current and a current-conducting circuit energized by said first winding.

10. In apparatus for the acceleration of charged articles in an orbital path by the production of a cyclically varying flux which links the path to accelerate the particles and establishes a magnetic field to constrain the particles to the path, the combination which comprises a source of charged particles adjacent the path and effective when energized to inject charged particles into the path, means for energizing said source with energy pulses of varying magnitude in response to a triggering voltage including a first winding linked by the varying flux to supply energy for the pulses in proportion to the magnitude of the flux, a second winding having a magnetically saturable core linked by the varying flux to generate a periodic voltage for triggering said means in timed relation to the varying flux, and current-supplying means connected to said second winding for magnetically biasing said core to alter the time at which the periodic triggering voltage is generated including a source of direct current and a winding linked by the varying flux.

11. In apparatus for the acceleration of charged

particles in an orbital path by the production of a cyclically varying flux which links the path to accelerate the particles and establishes a magnetic field to constrain the particles to the path; the combination which comprises a source of charged particles adjacent the path and effective when energized to inject charged particles into the path; means for energizing said source including an energy-storing device, a winding linked by the varying flux and in circuit with a rectifier for charging said energy-storing device to a voltage proportional to the magnitude of the varying flux, and a grid-controlled gaseous discharge device in circuit with said energy-storing device for discharging said energy-storing device when rendered conductive by a triggering signal to produce energy pulses for said source; means for rendering said discharge device conductive including a winding having a magnetically saturable core linked by the varying flux to produce a periodic voltage in said last named winding for triggering said discharge device in timed relation to the cyclical variations of the flux; and current-supplying means connected to said second named winding for magnetically biasing said core to alter the time at which said discharge device is rendered conductive including a source of direct current and a current-conducting circuit energized by said first named winding.

12. In apparatus for the acceleration of charged particles in an orbital path by the production of a cyclically varying flux which links the path to accelerate the particles and establishes a magnetic field to constrain the particles to the path; the combination which comprises a source of charged particles adjacent the path and effective when energized to inject charged particles into the path; means for energizing said source including an energy-storing device, a winding linked by the varying flux and in circuit with a rectifier for charging said energy-storing device to a voltage proportional to the magnitude of the varying flux, and a grid-controlled gaseous discharge device in circuit with said energy-storing device for discharging said energy-storing device when rendered conductive by a triggering signal to produce energy pulses for said source; means for rendering said discharge device conductive including a winding having a magnetically saturable core linked by the varying flux to produce a periodic voltage in said last named winding for triggering said discharge device in timed relation to the cyclical variations of the flux and current-supplying means connected to said second named winding for magnetically biasing said core to alter the timed relation of rendering said discharge device conductive including a source of direct current and a winding linked by the varying flux.

13. In apparatus for the acceleration of charged particles in an orbital path by the production of a cyclically varying flux which links the path to accelerate the particles and establishes a magnetic field to constrain the particles to the path, the combination which comprises a source of charged particles adjacent the path and effective when energized to inject charged particles into the path, means for energizing said source with energy pulses proportional to the magnitude of the varying flux in response to a triggering voltage, a winding having a magnetically saturable core linked by the varying flux to generate a periodic voltage for triggering said means in timed relation to the varying flux, and current-supplying means connected to said winding for magnetically biasing said core to alter the time at which the periodic triggering voltage is generated including a source of cyclically varying current having a constant peak magnitude and a frequency equal to the frequency of the cyclically varying flux and a winding linked by the varying flux.

14. In apparatus for the acceleration of charged particles in an orbital path by the production of a cyclically varying flux which links the path to accelerate the particles and establishes a magnetic field to constrain the particles to the path, the combination which comprises a source of charged particles adjacent the path and effective when energized to inject charged particles into the path, means for energizing said source with energy pulses of varying magnitude in response to a triggering voltage including a first winding linked by the varying flux to supply energy for the pulses in proportion to the magnitude of the varying flux, a second winding having a magnetically saturable core linked by the varying flux to generate a periodic voltage for triggering said means in timed relation to the varying flux, and current-supplying means connected to said second winding for magnetically biasing said core to alter the time at which the periodic triggering voltage is generated including a source of cyclically varying current having a constant peak magnitude and a frequency equal to the frequency of the cyclically varying flux and a current-conducting circuit energized by said first winding.

15. In apparatus for the acceleration of charged particles in an orbital path by the production of a cyclically varying flux which links the path to accelerate the particles and establishes a magnetic field to constrain the particles to the path, the combination which comprises a source of charged particles adjacent the path and effective when energized to inject charged particles into the path, means for energizing said source with energy pulses of varying magnitude in response to a triggering voltage including a first winding linked by the varying flux to supply energy for the pulses in proportion to the magnitude of the flux, a second winding having a magnetically saturable core linked by the varying flux to generate a periodic voltage for triggering said means in timed relation to the varying flux, and current-supplying means connected to said second winding for magnetically biasing said core to alter the time at which the periodic triggering voltage is generated including a source of cyclically varying current having a constant peak magnitude and a frequency equal to the frequency of the cyclically varying flux and a winding linked by the varying flux.

16. In apparatus for the acceleration of charged particles in an orbital path by the production of a cyclically varying flux which links the path to accelerate the particles and establishes a magnetic field to constrain the particles to the path; the combination which comprises a source of charged particles adjacent the path and effective when energized to inject charged particles into the path; means for energizing said source including an energy-storing device, a winding linked by the varying flux and in circuit with a rectifier for charging said energy-storing device to a voltage proportional to the magnitude of the varying flux, and a grid-controlled gaseous discharge device in circuit with said energy-storing device for discharging said energy-storing device when rendered conductive by a triggering

signal to produce energy pulses for said source; means for rendering said discharge device conductive including a winding having a magnetically saturable core linked by the varying flux to produce a periodic voltage in said last named winding for triggering said discharge device in timed relation to the cyclical variations of the flux; and current-supplying means connected to said second named winding for magnetically biasing said core to alter the time at which said discharge device is rendered conductive including a source of cyclically varying current having a constant peak magnitude and a frequency equal to the frequency of the cyclically varying flux and a current-conducting circuit energized by said first named winding.

17. In apparatus for the acceleration of charged particles in an orbital path by the production of a cyclically varying flux which links the path to accelerate the particles and establishes a magnetic field to constrain the particles to the path; the combination which comprises a source of charged particles adjacent the path and effective when energized to inject charged particles into the path; means for energizing said source including an energy-storing device, a winding linked by the varying flux and in circuit with a rectifier for charging said energy-storing device to a voltage proportional to the magnitude of the varying flux, and a grid-controlled gaseous discharge device in circuit with said energy-storing device for discharging said energy-storing device when rendered conductive by a triggering signal to produce energy pulses for said source; means for rendering said discharge device conductive including a winding having a magnetically saturable core linked by the varying flux to produce a periodic voltage in said last named winding for triggering said discharge device in timed relation to the cyclical variations of the flux; and current-supplying means connected to said second named winding for magnetically biasing said core to alter the timed relation of rendering said discharge device conductive including a source of cyclically varying current having a constant peak magnitude and a frequency equal to the frequency of the cyclically varying flux and a winding linked by the varying flux.

THEODORE M. DICKINSON.

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