# United States Patent

[11] 3,617,908



[72] Inventor Henry Greber
225 West, 80th Street, Apt. 8-D, New York, N.Y. 10024



[21] Appl. No. 801,276
[22] Filed Feb. 24, 1969
[45] Patented Nov. 2, 1971


[54] **CHARGED PARTICLE ACCELERATOR WITH SINGLE OR MULTIMODE OPERATION**
4 Claims, 9 Drawing Figs.


[52] U.S. Cl. .... 328/233, 313/63, 313/161, 328/234, 328/237
[51] Int. Cl. .... H05h 9/02, H05h 11/00, H05h 13/00
[50] Field of Search .... 313/63, 161; 328/233, 234, 237


[56] References Cited

UNITED STATES PATENTS

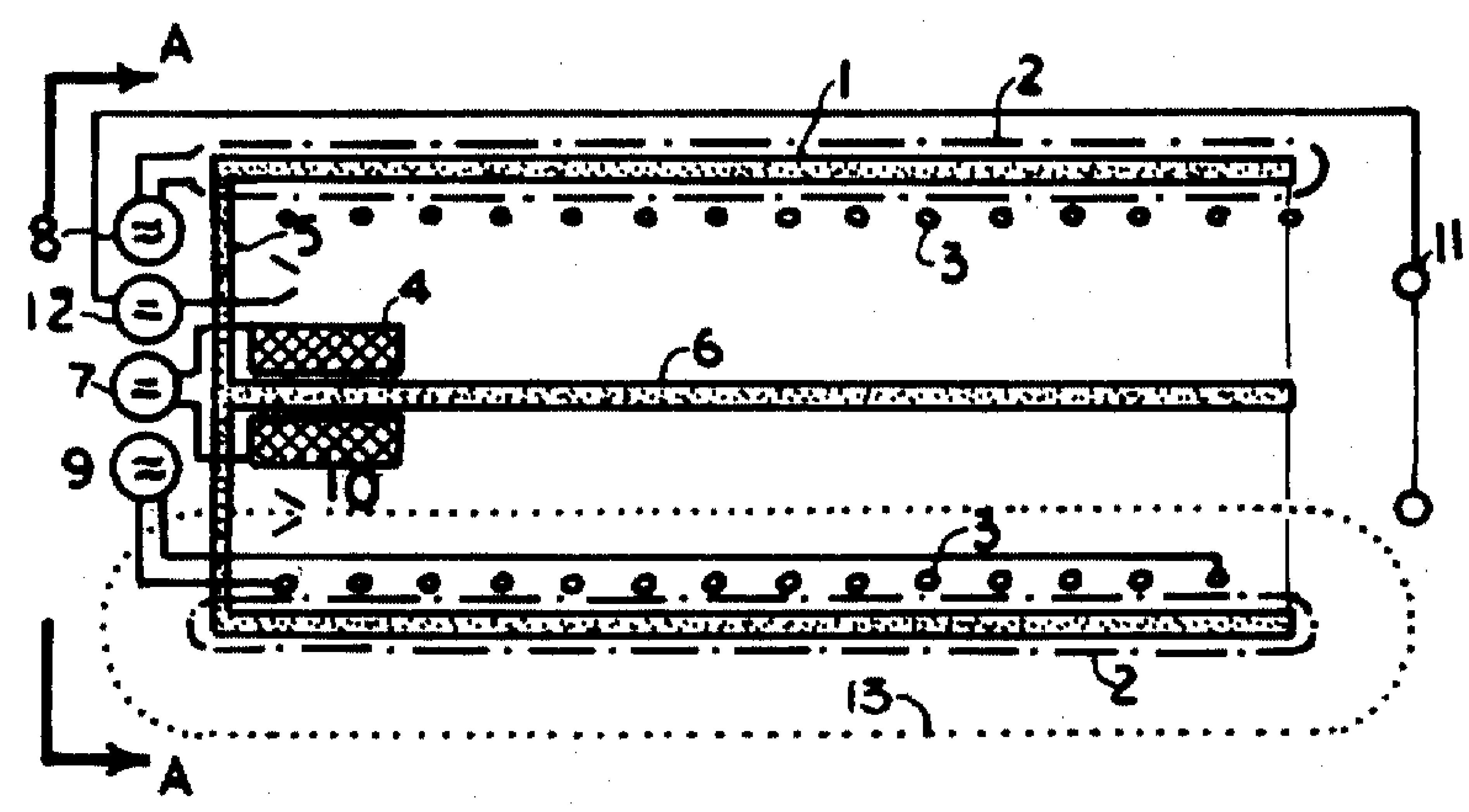

| | | | |
|---|---|---|---|
| 2,473,477 | 6/1949 | Smith | 328/234 UX |
| 3,386,040 | 5/1968 | Maschke | 328/237 X |
| 3,390,303 | 6/1968 | Abramyan et al. | 313/63 X |
| 3,417,273 | 12/1968 | Gates et al. | 313/63 |
| 3,450,931 | 6/1969 | Feinstein et al. | 313/63 X |



*Primary Examiner*—Roy Lake
*Assistant Examiner*—Palmer C. Demeo



**ABSTRACT:** This invention pertains to a particle accelerator which can be made in linear, circular, helical or spiral form. It functions in one, or in a combination of modes of operation as a double betatron, double cyclotron, double traveling wave tube, or double-rotating magnetic flux device. In the double betatron mode, the particles rotate around two magnetic fluxes intertwined like two consecutive links of a chain. In the double cyclotron arrangement, the particles are accelerated at their passage between two consecutive tubes, and also between two halves of the same tube section, split longitudinally. In the traveling wave tube mode, the particles are accelerated through their energy exchange with traveling waves flowing along a coiled coil helical winding. In the arrangement with two sets of windings producing two interlinked rotating magnetic fluxes, the particles act like free electrons in the rotor of an asynchronous motor. In any one, or in any combination of these modes of operation of this particle accelerator, the particles perform a motion along a helical path, along which they cut the lines of the magnetic force of a radial, stationary, (DC excited) magnetic flux, which induces in them an electromotive force in direction of their acceleration. Normally, this particle accelerator is evacuated, but it can also be filled with a semiconductor, semimetal, or electrolyte, with the result of a considerable simplification of the device. This accelerator can be used for single, or for repeated passages of the particles through it.

PATENTED NOV 2 1971 3,617,908

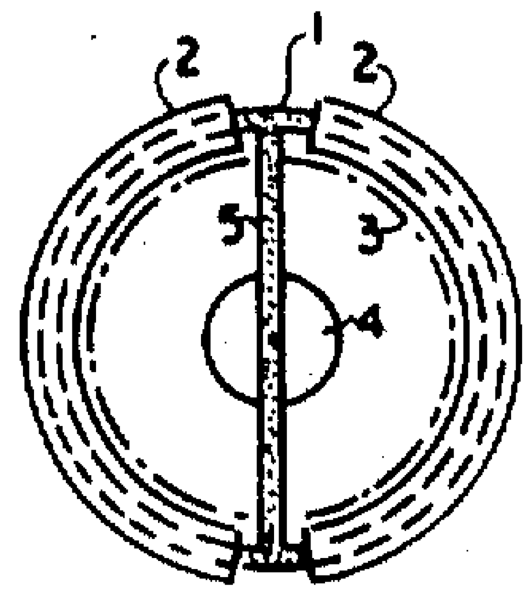


FIG.1

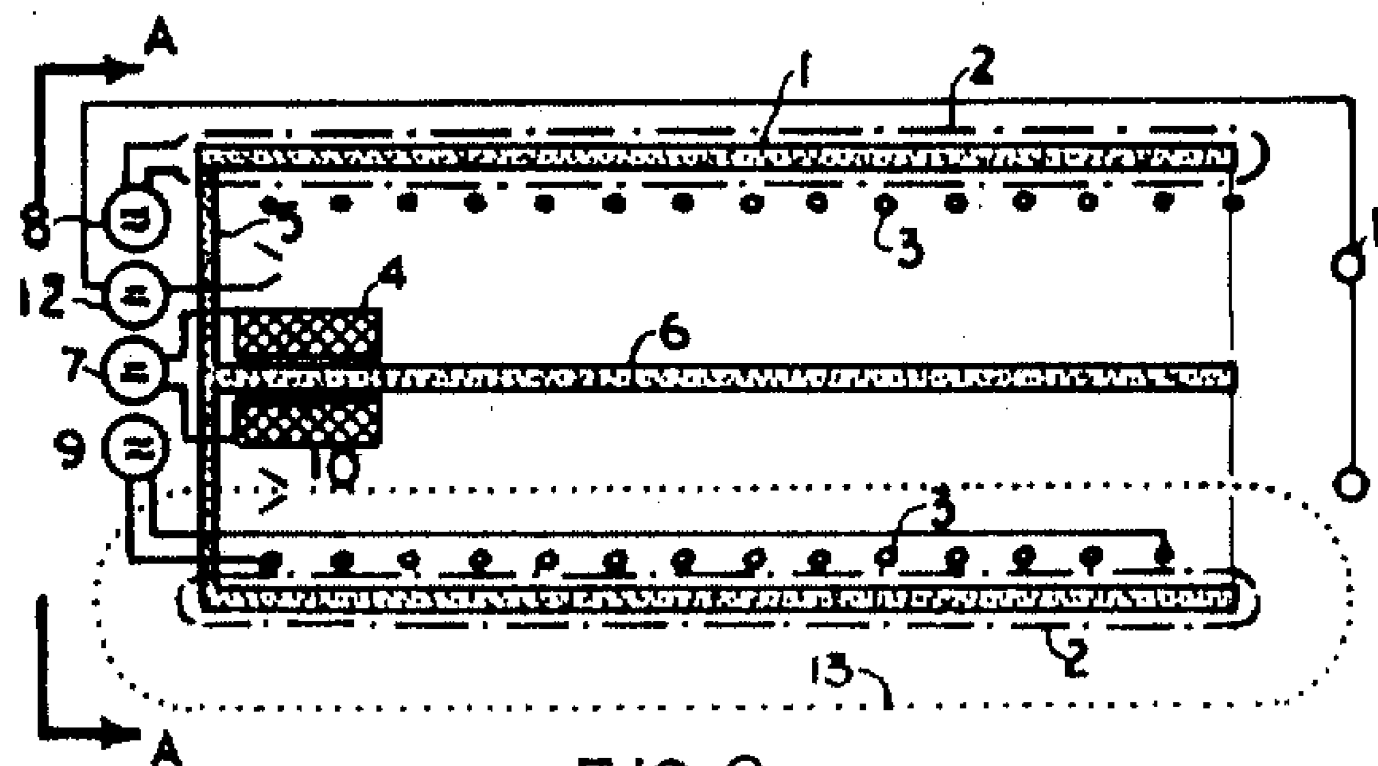


FIG.2

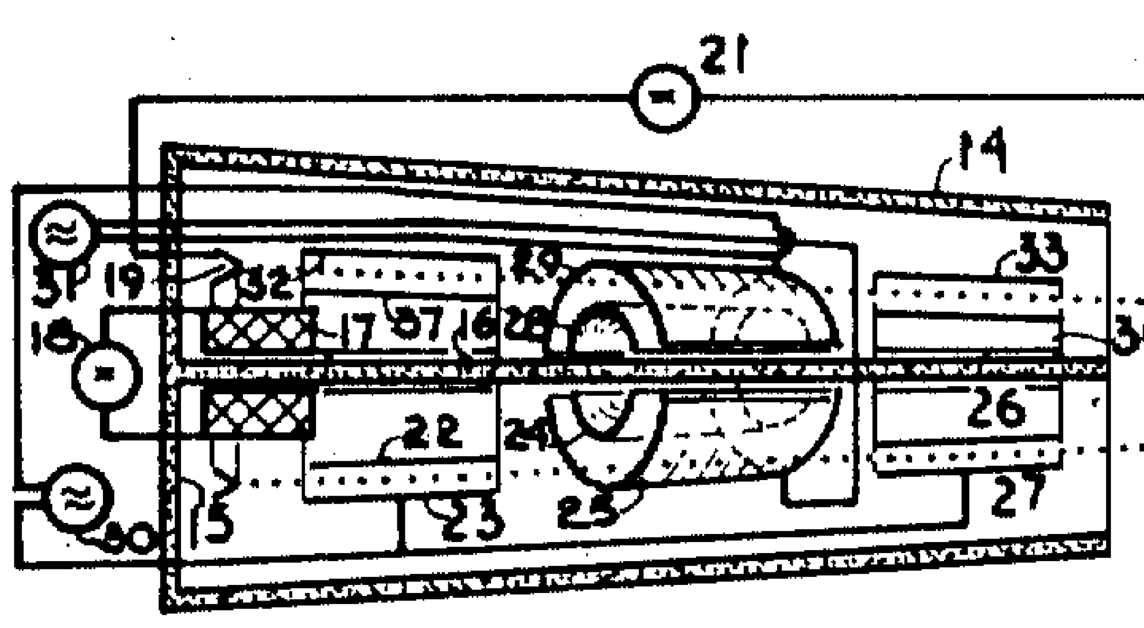


FIG.3

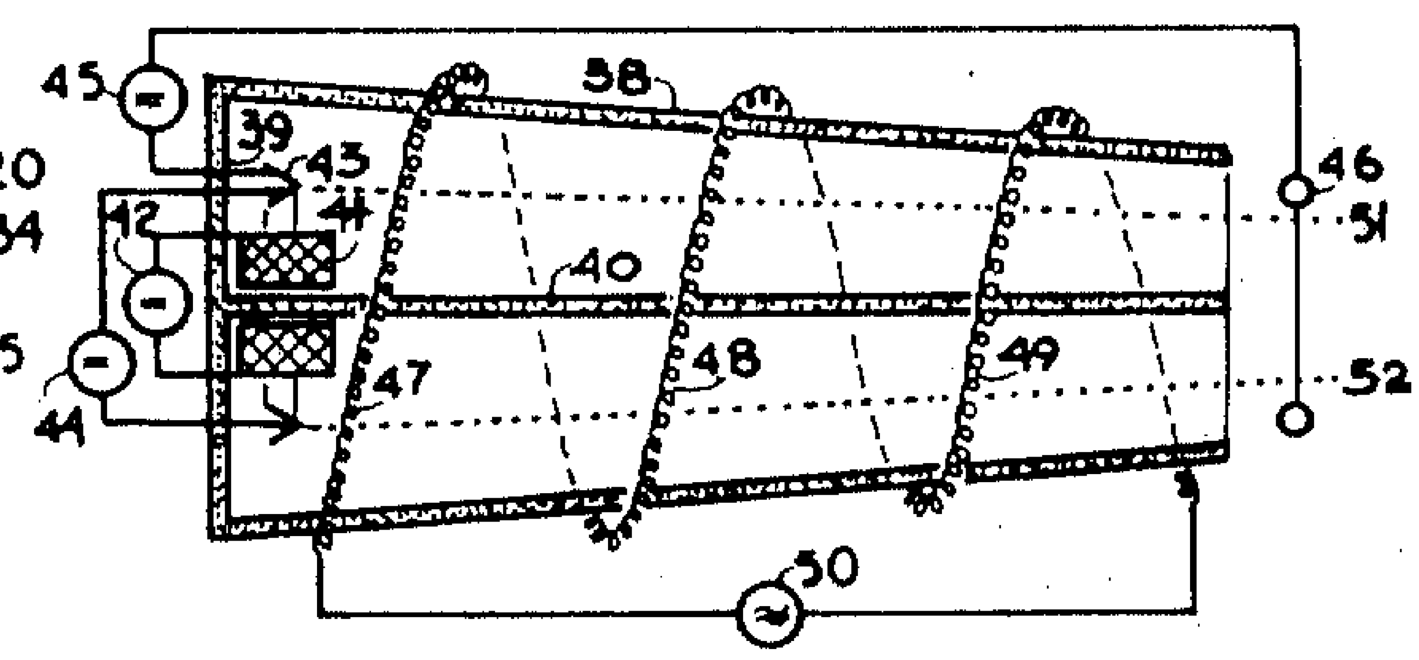


FIG.4

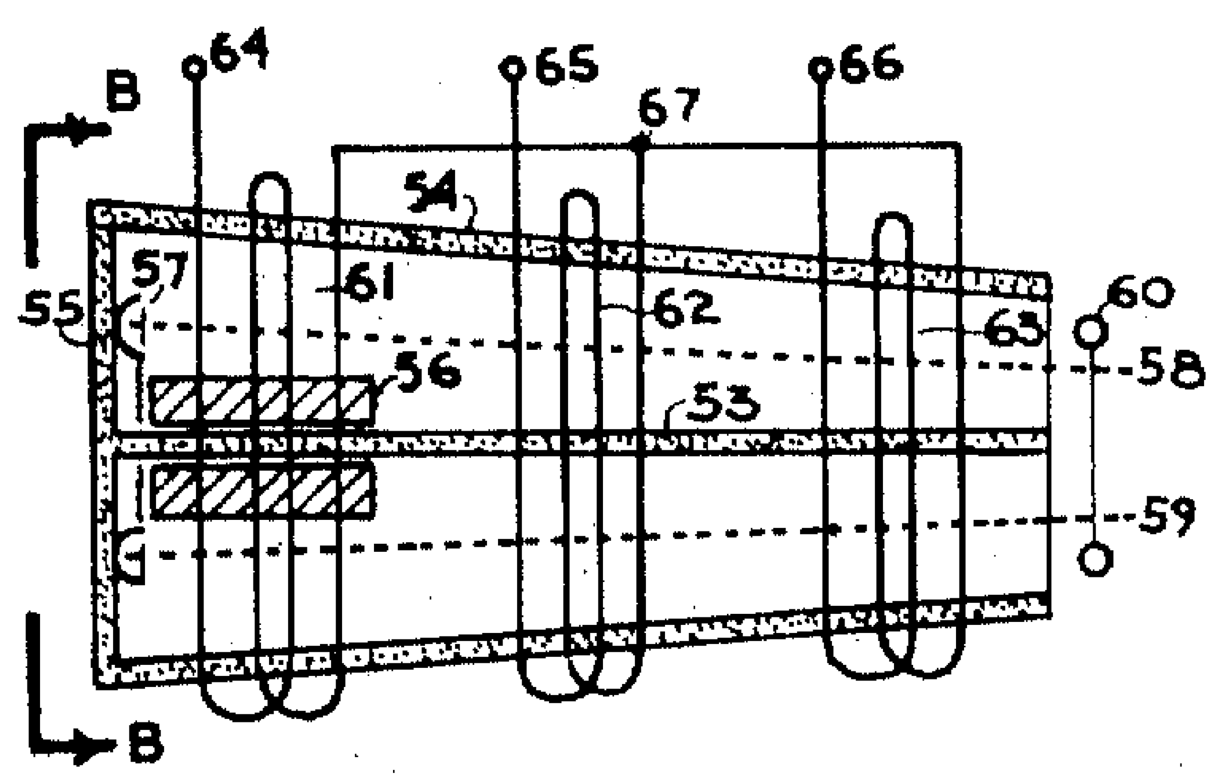


FIG.5

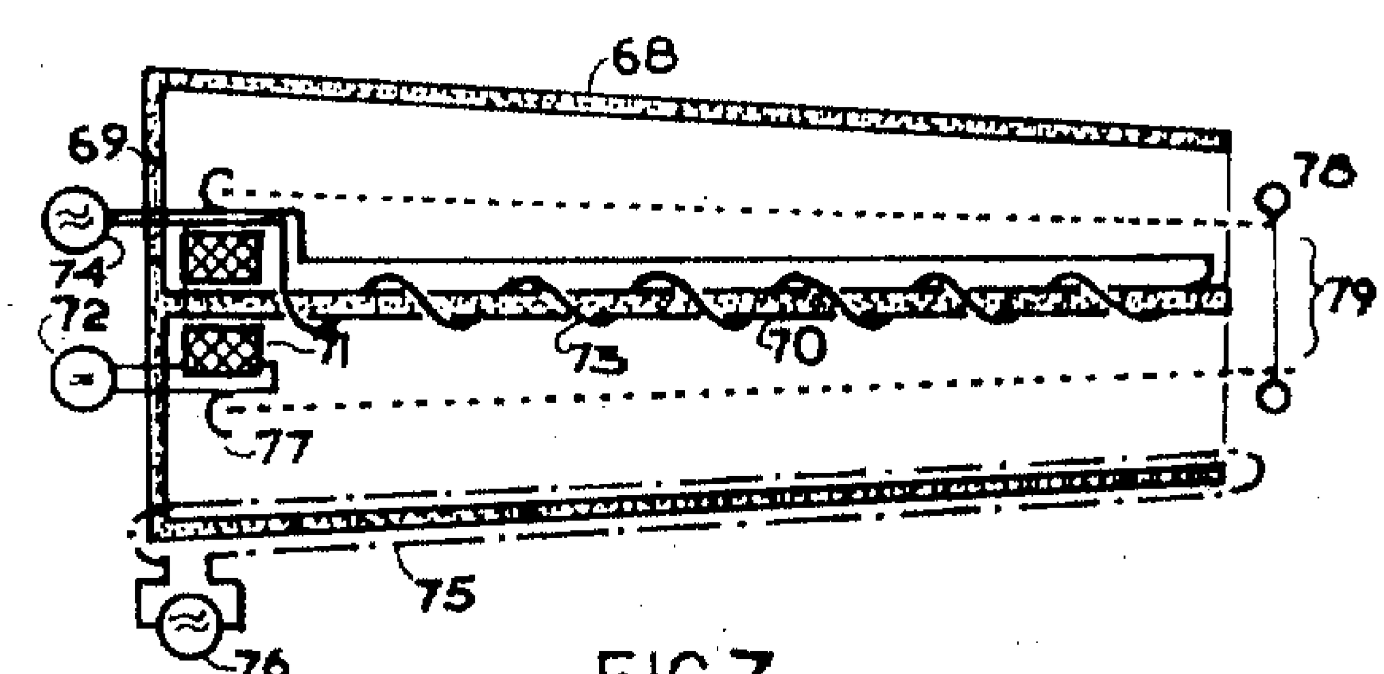


FIG.7

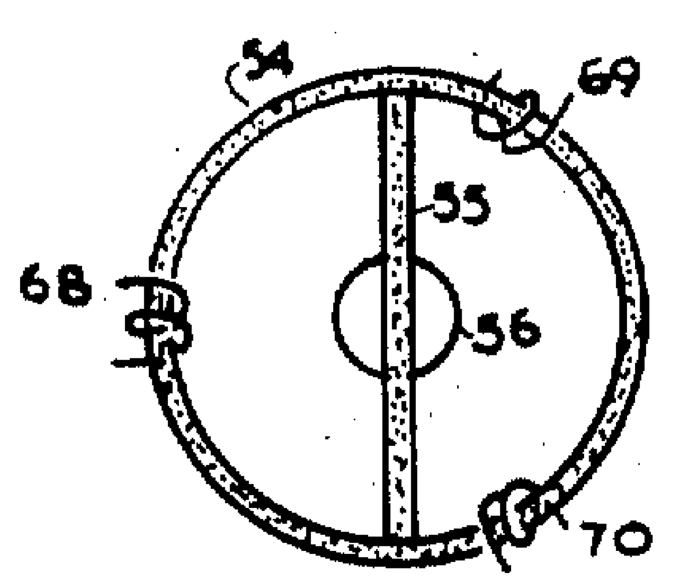


FIG.6

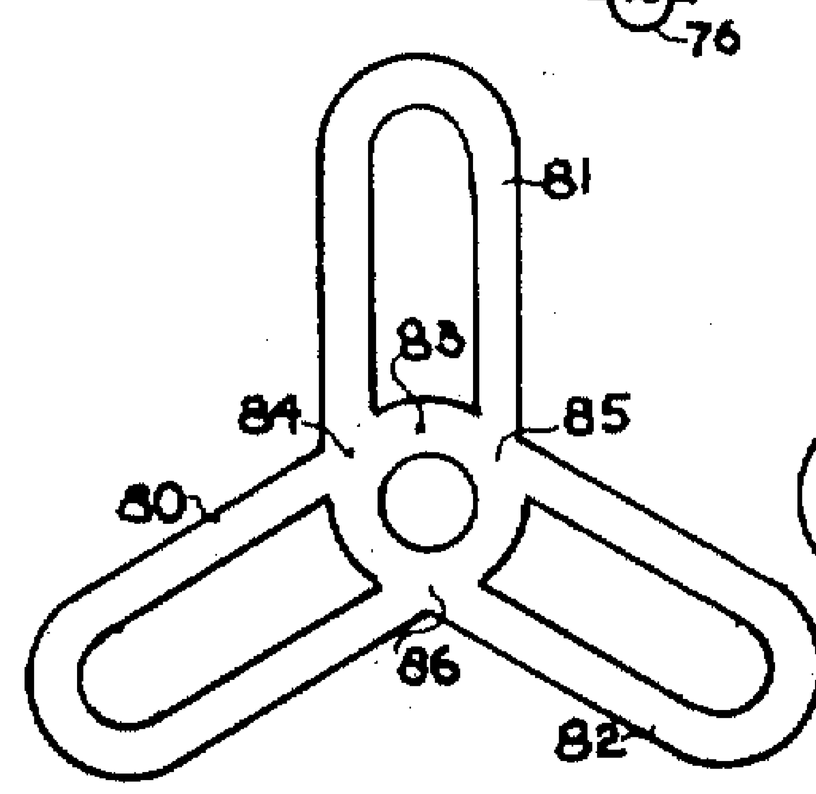


FIG.8

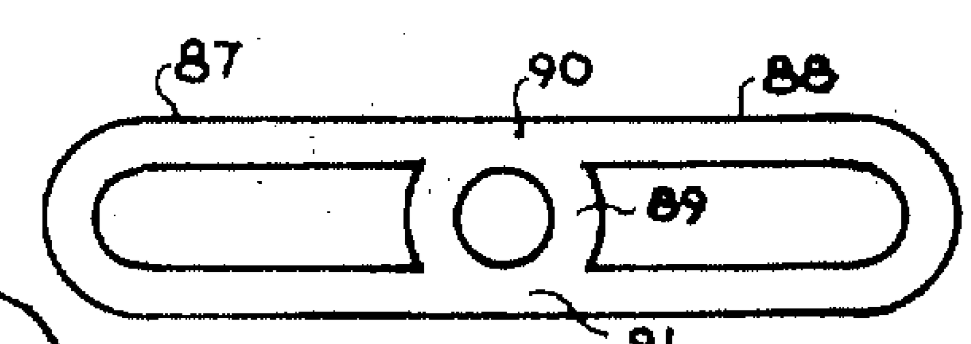


FIG.9

BY

Henry Grebe

INVENTOR.

# CHARGED PARTICLE ACCELERATOR WITH SINGLE OR MULTIMODE OPERATION

The purpose of this invention is to provide an efficient, high-power, particle accelerator capable of accelerating charged particles of any kind. Another objective is to provide a particle accelerator of small size and modest energy requirements, but capable of yielding charged particles of high kinetic energy.

These purposes are achieved by accelerating the particles along the track of the accelerator as well as by rotating them azimuthally in planes perpendicular to that track, so that in effect their paths are helical. While the particles follow such paths, they cut the magnetic lines of force of a stationary radial magnetic flux, excited with DC, which induces in them electromotive forces. This principle is maintained in all modes of operation of this device. It can function as a double betatron, double cyclotron, double traveling wave tube, and as a device with windings producing two interlocked rotating magnetic fluxes, or in any combination of these modes. This particle accelerator can be linear of cyclic. Through deviation of the particles from the outlet back into the inlet of a linear particle accelerator, it can work cyclically. In one design modification or in the other, this particle accelerator operates with only moderately high voltages, so that problems of dielectric breakdowns in containment chambers are avoided. The normally evacuated containment chamber of the accelerator can be filled with a semiconductor, or an electrolyte, or a semimetal.

The way in which the above delineated concepts are carried out and the design features of the different embodiments of this invention can be seen from this specification and from the accompanying drawing.

In this drawing FIG. 1 is a front view of a double betatron accelerator, whose longitudinal cross section is presented in FIG. 2. In FIG. 3, is shown a longitudinal cross section of a double-cyclotron-type linear particle accelerator. A longitudinal cross section of a double traveling wave tube particle accelerator is drawn in FIG. 4. In FIG. 5, can be seen a longitudinal cross section of a particle accelerator having windings producing two interlinking magnetic fluxes. The front elevation of this particle accelerator is shown in FIG. 6. FIG. 7, represents a longitudinal cross section of a particle accelerator functioning as a dual traveling wave tube. A diagrammatic view of three interlinked cyclic particle accelerators can be seen in FIG. 8. Finally FIG. 9 shows a diagrammatic view of two interlinked cyclic particle accelerators.

In detailed consideration of FIG. 1, it can be seen that the cylindrical tube **1**, of the accelerator carries winding **2**, wound around the wall of the tube. Inside tube **1**, there is another winding **3**, diagrammatically indicated with a dash-dotted circular line. In the middle of the tube is installed the cylindrical winding **4**, producing the stationary radial magnetic flux. This flux passes through the bar-shaped part **5**, of the magnetic circuit connecting diametrically opposite points of tube **1**. The front view shown in FIG. 1, is taken along line "A–A", indicated in FIG. 2.

In the longitudinal cross section of the dual betatron particle accelerator drawn in FIG. 2, can be seen tube **1**, carrying winding **2**, which is indicated diagrammatically with dash-dotted lines. In this FIG. the cross sectional view of cylindrical winding **3**, can be seen, as well as that of cylindrical winding **4**, mounted on the rod-shaped part **6** of the magnetic circuit. The total magnetic circuit consisting of parts **1**, **5**, and **6**, can be made of ferrites, ferrites sintered with ceramics, or of ceramics. In the latter case the magnetic core is equivalent to an air core. Winding **4**, is fed from a source of DC indicated with the numeral **7**. Similarly winding **1**, is fed from a AC source **8**; and AC source **9**, feeds winding **3**. Numeral **10**, denotes a source of charged particles, such as a radioactive isotope, or a slotted cathode cooperating with a circular anode **11**. The potential difference between ring-shaped cathode **10** and anode **11** is maintained from a DC potential source **12**. The time variable magnetic flux induced by winding **2**, in magnetic core **1**, reverses the stream of particles from the outlet of the accelerator at anode **11**, to its inlet at cathode **10**. If the source of charged



particles **10** emanates positively charged particles, circular electrode **11** is, of course, charged negatively. The path of the charged particles is diagrammatically indicated with the dotted line **13**. In actuality, the particle stream around the entire wall of tube **1**.

In the longitudinal view of the dual cyclotron particle accelerator shown in FIG. 3, the magnetic circuit consists of tube **14**, bar-shaped part **15**, and rod-shaped part **16**, in complete analogy with the magnetic circuit shown in FIG. 2. The cylindrical winding **17**, fed from the DC source **18**, produces a magnetic flux which flows out radially from rod **16** toward tube **14**, and returns via bar **15**. Annular cathode **19**, and circular anode **20**, are connected to source **21**, of DC potential. The cyclotron electrodes consist of pairs of concentric conical tube sections: **22**, **23** and **24**, **25**, as well as **26**, **27**. The middle pair of concentric conical tubes is shown in perspective in order to point out that the inner tube section consists actually of two symmetrical parts **24**, **28**. Similarly, the outer tube section is made up of tube parts **25**, **29**. The other concentric conical tube sections are structured in the same way, that is, their inner and outer tubes consist each of two symmetrical parts. It can be seen that whereas outer tube sections **23** and **27** are connected to one terminal of AC source **30**, outer tube **29** is linked to the other terminal of the same source **30**. In addition, each symmetrical part of an outer tube section, such as for example **25**, **29** is connected to a separate AC source **31**. Though such source is shown only for parts **25**, **29** of the outer tube of the middle cyclotron electrode, it is to be understood that also the other parts of outer tubes **23** and **32**, as well as **27**, **33** are provided with such AC sources, which are not shown in order not to overcrowd the drawing. Dotted lines **34** and **35** indicate a conical particle beam passing through the conical double-walled tube section, such as the space between parts **24**, **28**, and **25**, **29**. The numeral **36**, designates the tube segment opposite to that marked **26**. Likewise, the numeral **37**, labels the tube segment opposite to **23**.

The magnetic circuit of the linear accelerator functioning in the traveling wave tube mode, whose longitudinal cross section is shown in FIG. 4, consists of three parts **38**, **39**, **40**. This magnetic circuit is completely analogous to these shown in FIGS. 2 and 3. Cylindrical winding **41**, fed from DC source **42**, produces a stationary magnetic flux, whose lines of force flow out from rod-shaped part **40**, and return through parts **38**, **39**. The source of charged particles is exemplified as a ring-shaped cathode **43**, heated by the DC source **43**. DC source **45** maintains a potential difference between the cathode **43** and the ring-shaped anode **46**. The traveling wave tube winding consists of a coil helically wound on tube **38**. The convolutions **47**, **48**, **49** of this winding are fed from AC source **50**. Dotted lines **51**, **52** indicate the particle beam.

The linear accelerator, whose longitudinal cross section is shown in FIG. 5, has a magnetic core consisting of three parts **53**, **54** and **55**, similar to those described in the preceding FIGS. The cylindrical winding **56**, fed from a DC source, which is not shown to avoid unnecessary repetition, produces a radial stationary magnetic flux. A ring-shaped channel **57** emanates, for example, positively charged particles from a radioactive isotope. These particles in the tubular beam indicated with the dotted lines **58**, **59**, are attracted to the negatively charged ring-shaped electrode **60**. The source of the potential charging this electrode is not drawn, since it is immaterial to this invention. What is material is the polyphase, in this case, three-phase windings, **61**, **62**, **63**, connected with one of their ends to the terminals **64**, **65**, **66**, of the three-phase source, not shown, and with the other ends to the neutral point **67**. These windings produce a rotating magnetic flux circling around the wall of the tubular core of this accelerator. The front view of this device, taken along line "B—B" is shown in FIG. 6.

In FIG. 6, it can be seen that the tubular part **54**, of the magnetic circuit of this accelerator is provided with three windings **68**, **69**, **70**, constituting a three-phase system producing a rotating magnetic flux. The three-phase potential source feeding these windings, which may be the same as that feeding windings **61**, **62**, **63**, of the preceding FIG., is not shown for simplicity. Cylindrical winding **56**, and part **55** of the magnetic circuit, both shown already in the foregoing, are drawn again in this FIG.

The longitudinal cross section of a linear particle accelerator functioning as a dual betatron is shown in FIG. 7. Parts of the magnetic circuit of this accelerator are designated with the numerals **68**, **69**, **70**. Cylindrical coil **71**, fed from DC source **72**, produces the stationary radial flux. The cylindrical part **70** of the magnetic circuit carries winding **73**, fed from AC source **74**. This is one of the betatron windings forcing the particles to rotate around the longitudinal axis of this accelerator. The other betatron winding **75**, is wound around the wall of tube **68**, and is fed from AC source **76**. Ring-shaped channel **77**, contains a source of positive particles, for example, emitted from a radioactive isotope. These particles are attracted toward a negative ring-shaped electrode **78**. The source of potential feeding this electrode is not shown, for simplicity. Dotted lines **79**, indicate the tubular stream of positively charged particles.

Two linear accelerators according to this invention can be used in tandem. As already mentioned, any of the described accelerators can be used for cyclic operation, by reverting the particles coming out from its outlet back to its inlet. This, however, does not preclude the design of this particle accelerator in circular or elliptical form, and ganging up several such accelerators into one system. An example of such a system is diagrammed in FIG. 8. There, can be seen three elliptical particle accelerators **80**, **81**, **82**, combined in one system. Particles accelerated in one elliptical accelerator may be different than those in the other elliptical accelerators. They are brought to collision in the inner torus **83**, particularly at its points **84**, **85**, **86**. It is important to notice that ring **83** can be used as a retaining storage ring in which particles rotate without being accelerated.

In FIG. 9, two elliptical accelerators **87**, **88**, are combined into one system. The particles accelerated in this system collide in the inner torus **89**, particularly at its points **90**, and **91**. Also torus **90** can be used for retaining particles in storage.

Either the entire particle accelerator, except its potential sources, is mounted in a vacuum chamber, or such chamber is installed within the tubular magnetic core of the device. In the latter case, the vacuum chamber is made of glass or ceramics, lightly silvered to prevent the accumulation of static charges due to stray charged particles. This film must be interrupted at intervals in order not to let a current flow in it. The betatron, traveling wave tube or rotating-magnetic-flux-producing windings can be connected in series or in parallel with condensers, for the purpose of creating a resonance condition in them, and thereby large currents and consequently, large magnetic fluxes.

A typical accelerator according to this invention is relatively short, contains only two electrodes, a negative at its entrance, and a positive at its exit for negative particles, or electrodes of opposite polarities for positive particles, and is used either for single, or for repeated passages of the particle bunches through it. The essential mode of operation of this particle accelerator is that of a dual betatron. It is provided with two betatron windings. One creating a longitudinal, the other producing an azimuthal magnetic flux. In addition to these two windings, the accelerator may be equipped with other windings whose functions will be described shortly. In its betatron mode of operation, the longitudinal magnetic flux of the accelerator causes the contained in it particles to rotate around its longitudinal axis. By doing so, they cut the lines of the stationary, DC induced magnetic force, consequently, a magnetomotive force is induced in them. This magnetomotive force increases the electrostatic attraction between the particles and the electrode at the exit from the accelerator. This electrode is loaded with a charge of opposite sign to that of the particles. The azimuthal magnetic flux accelerates the particles along the axis of the accelerator. The same flux turns the particles around from the exit to the entrance of the accelerator for repeated passage through it. As known, the operation of the betatron is based on the same principle as that of an ordinary transformer. The alternating primary current produces a time-varying magnetic flux, which induces an electromotive force in the charged particles. This accelerator has two such magnetic fluxes interlocked like two consecutive links of a chain. Both fluxes induce electromotive forces in the particles, which are injected in pulses into the accelerator, or bunched in it. The total run of the particle through the accelerator lasts one-quarter of a cycle, so that it hits the target with maximal velocity. At a frequency of $10^8$ Hz. and a tube length of 100 cm; the particle velocity would be $100/4=10^{18}=c/12$, where $c$ is, as usually, the velocity of light. This is its average velocity. Its maximal velocity is larger by a factor of $2^{1/2}$, and still larger by the same factor taken another time due to the geometrical addition of the equally large azimuthal velocity, and would, therefore reach one-sixth of the velocity of light. The energy gained by the particle around one of the betatron fluxes corresponds to the voltage of an imaginary one turn coil wound around the same flux. This voltage equals the time rate of change of this flux:

$$eV=ed\Phi/dt=amv^2/2$$

where, $e$ is the elementary charge of the particle, $\Phi$ is the magnetic flux, $eV$ is the energy gain of the particle in electronvolts, $m$ is the mass of the particle, and $v$ is its velocity, whereas $a$ is a coversion factor $1eV=1.6\times10^{11 2}$ergs. The radius of rotation $r$, of the particle in an azimuthal plane is given by

$r=mv/Be$ (or given a maximal $r$, $v_{max}$ can be computed)

where $B$, is the intensity of the azimuthal magnetic flux. The period of rotation $T$, of the particle in the azimuthal plane is $T=\pi m/Bev$ is independent from $r$.

Two interlinked magnetic fluxes, as the ones just described, can be produced not only by means of two betatron-type windings, but also with other kinds of windings, which can be used as a substitute, or as a supplement of the betatron winding. So, for example the two magnetic fluxes can be produced with two windings similar to the ones used in electrical rotating machines, and creating rotating magnetic fluxes. Polyphase, usually three-phase current, is used for this purpose. However, two-phase current may be practical when only single-phase high-frequency current is available, and the auxiliary, by 90 degrees shifted phase current can be produced by application of capacitors or inductances. Furthermore, two interlocked magnetic fluxes can be produced by two traveling-wave-tube-type windings, wound one around the wall of the magnetic core tube, and the other wound along that wall. Conveniently, the two windings can be replaced by one, taking on the form of a coiled helix would on the magnetic core tube, as shown in FIG. 4. Obviously, all these different types of windings are equivalents, which can be used either separately or together.

As the velocity of the particles approaches the speed of light the task of the particle accelerator becomes easier. Since with its velocity also the mass of the particle is increased; to small increments of velocity in this range correspond large increases of energy of the particle. Besides, a beam of high velocity particles does not spread, and does not need to be focused by means of an axial magnetic flux. Such flux is capable of preventing the spreading of two oppositely directed beams containing oppositely charged particles.

The evacuated tubular space, in which the charged particles are accelerated in the basic form of this invention, can be replaced with a semiconductor, electrolyte, or semimetal. In these media, the particles can be accelerated to such high velocities that they are ejected from these bodies. The great advantage of using a semiconductor instead of an evacuated enclosure is that many difficult vacuum techniques are thereby avoided, and also a striking simplicity is achievable by this substitution. With semiconductors there are practically no limits to the smallest and largest size to which a particle accelerator can be built.

As already stated, pairs of accelerators, be it linear or cyclic, with evacuated, or semiconductor, or electrolyte, or semimetal acceleration chambers can be combined into systems, such as exemplified in FIGS. 8 and 9.

For large energies the practicality of the particle accelerator for speeding up electrons is limited by their radiation losses. These, however, become negligible for heavier particles, since the radiation loss is proportional to the inverse of the fourth power of the mass of the particle. This fact makes it convenient to accelerate protons, deutrons and tritions, and use these particles to produce nuclear fusion. A strong proton flux produced in a system of these particle accelerators can serve for the creation of controlled nuclear fission, without invoking the phenomenon of chain reaction. Therefore, such fission could be carried out on the smallest scale desired. Other applications of this particle accelerator are: for atomic research, for medical research, diagnosis and therapy, for the production of radioactive isotopes, hard X-rays and gamma-rays, for destructionless testing of materials, for sterilization, including sterilization of food and for many other related purposes.

This invention lends itself to many modifications, variations and changes through addition, omission or substitution or many of its components, and through its adaptation to its many possible applications, all such changes being in the sense of this invention as defined by the following claims.

What is claimed is:

1. A particle accelerator comprising, (a) a tubular envelope with a circular core within it and a magnetic core link connecting said tubular envelope with said circular core, said magnetic core forming a magnetic circuit, in which a static magnetic flux is induced by means of a coil fed from a DC source, with the lines of magnetic force of said magnetic flux being essentially perpendicular to said circular core, (b) two betatron-type windings, from which one encircles the wall of said tubular envelope, and the other forms a cylindrical coil concentric with and within said tubular envelope, (c) two sets of three-phase windings, each set of windings layed out so as to produce a rotating magnetic flux, the two magnetic fluxes being interlocked in a manner similar to two consecutive links of a chain, with one magnetic flux rotating around the wall of said tubular enclosure, and the other magnetic flux rotating in an azimuthal plane perpendicular to the longitudinal axis of said particle accelerator, (d) a traveling-wave-type winding consisting of a coil helically would at the wall of said tubular enclosure, each of said types of windings in combination, creates rotating magnetic fluxes accelerating particles along the longitudinal axis of said particle accelerator, and in azimuthal planes perpendicular to said axis, and by doing so cut the lines of the magnetic flux of said DC-excited static flux, so that an electromotive force is induced in them, which increases their attraction to one of the electrodes, one of which is mounted at the entrance, the other at the exit from said particle accelerator, the two electrodes being connected each to the opposite pole of a DC source, with the electrode of the polarity opposite to the polarity of the charge carried by the accelerated particles being placed at the exit from said particle accelerator.

2. A particle accelerator as described in claim 1, with the space, in which the particles are accelerated, filled with one of the materials of the semiconductors and semimetals group of materials.

3. A particle accelerator as described in claim 1, with the space in which said particles are accelerated, occupied by an insulating tube with double walls, with the space between these walls filled with a dissociated electrolyte.

4. A particle accelerator as described in claim 1, containing cyclotron electrodes, each consisting of pairs of concentric tube sections, each tube being split into two halves insulated from each other, with a source of AC producing a potential difference between two consecutive pairs of concentric tubes at the moment when a particle passes between these pairs, said potential difference accelerating said particle in the direction toward the outlet of said accelerator, with another source of AC producing a potential difference between each pair of half tube sections which accelerate the particles in azimuthal planes perpendicular to the longitudinal axis of said particle accelerator.

* * * * *