

Nov. 23, 1943.

D. W. KERST

2,335,014

MAGNETIC INDUCTION ACCELERATOR

Filed Jan. 13, 1942

2 Sheets-Sheet 1

Fig. 1.

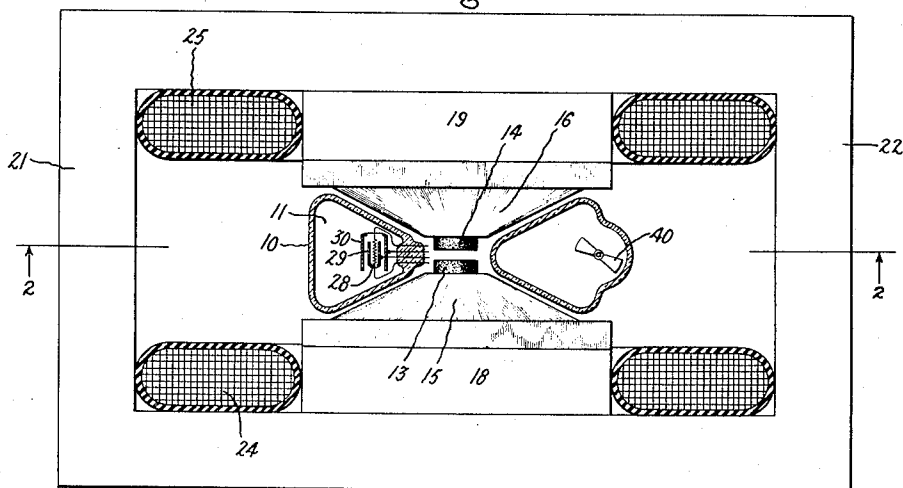


Fig. 2.

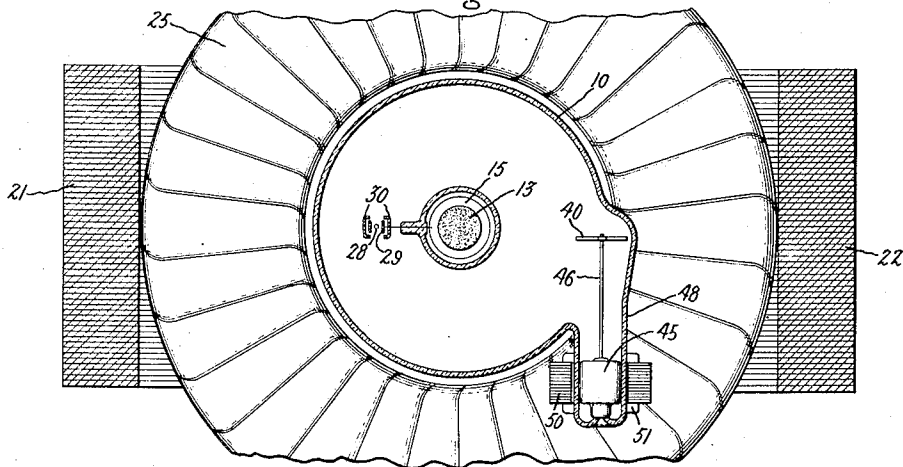
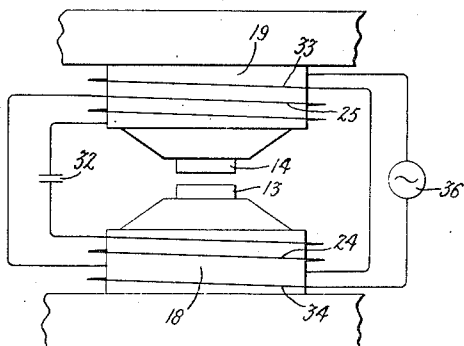


Fig. 1a.



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2 Sheets-Sheet 2

Fig. 3.

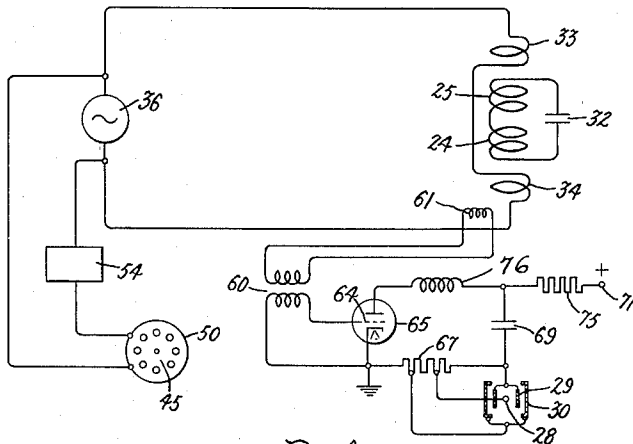


Fig. 4.

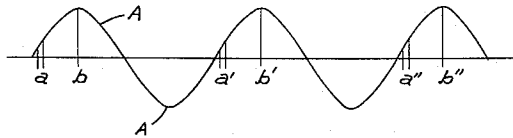


Fig. 5.

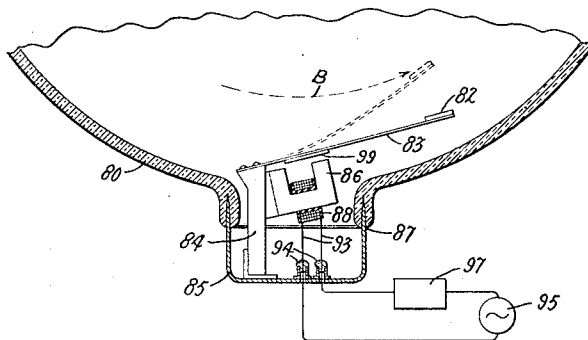
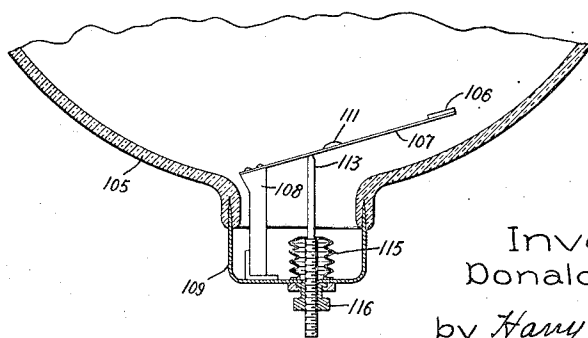


Fig. 6.



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UNITED STATES PATENT OFFICE

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MAGNETIC INDUCTION ACCELERATOR

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10 Claims. (Cl. 250-99)

The present invention relates to apparatus for accelerating charged particles, such as electrons, by means of magnetic induction effects.

One form of apparatus which has been used for this purpose comprises the combination of a closed vessel and a magnetic system for producing a time-varying magnetic field of such space distribution as to confine electrons projected within the vessel to a circular orbit along which they are continuously accelerated by the field. By this means it proves possible to obtain electrons of very high energy (of the order of several million electron volts) by the use of a low voltage energizing source.

In usefully applying an accelerator of the type just described, it is necessary to provide means for effectively utilizing the energy of the electrons (or other charged particles) after they have been accelerated to high velocity; for example, by causing them to impinge on a target so that useful radiations such as X-rays may be obtained. This has been done in one way by abruptly modifying the space distribution of the accelerating field with the end of causing the accelerated particles to deviate from the accelerating orbit and to impinge upon an appropriately positioned target. However, while this procedure has given highly satisfactory results, it requires relatively complicated auxiliary equipment for performing the orbit shifting function.

It is a primary object of the present invention to provide simplified means for utilizing the energy of orbitally moving charged particles produced by a magnetic induction accelerator.

In this connection, an important feature of the invention consists in the provision of a movable target which is normally outside the orbit in which acceleration of charged particles is to occur, but which may be moved into the orbit after the particles have been fully accelerated, thus intercepting the particles when they have attained maximum energy. In a particular embodiment, the desired motion of the target is accomplished by associating it with a driving means which is energized in synchronism with the cyclical variations of the accelerating field so that the movements of the target and the variations of the field may be precisely correlated. In one case, the target is made of rotary character and is driven by an electric motor supplied from the same source as that which supplies the accelerating field, while in another embodiment the target is mounted upon a member which is caused to vibrate synchronously with the variations of the accelerating field and in such a direction as to move the target alternately into and out of the electron orbit.

The aspects of the invention which I desire to protect 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 drawings in which Fig. 1 is a partially sectionalized elevation of an accelerating apparatus suitably embodying the invention; Fig. 1a illustrates means for exciting the magnetic structure of Fig. 1; Fig. 2 is a cross section taken on line 2-2 of Fig. 1; Fig. 3 shows diagrammatically an energizing circuit which may be employed for controlling the operation of the apparatus of Fig. 1; and Figs. 4 and 5 are fragmentary views illustrating modifications of the invention.

Referring particularly to Fig. 1, there is shown a closed glass vessel 10 which defines within its interior an annular chamber 11. As will be explained in greater detail at a later point, the vessel 10 provides a space within which electrons may be accelerated to a high voltage, say on the order of several million volts. The vessel is preferably highly evacuated, although the presence of a small amount of gas is permissible under some circumstances. A high resistance coating, such as an extremely thin layer of silver (not shown), may advantageously be applied to the interior surface of the vessel to prevent wall-charging and the like.

The electron-accelerating mechanism comprises a magnetic structure having generally circular pole pieces which are coaxial with the annular vessel 10. These pole pieces include a pair of juxtaposed circular parts 13 and 14 which consist, for example, of laminated iron and which are respectively supported on conically tapered parts 15 and 16. The tapered parts in turn are based upon large cylinders 18 and 19 which connect with closed magnetic cores 21 and 22 so as to provide a complete path for magnetic flux. The elements of the magnetic structure are constituted of ferromagnetic material and should be of laminated or otherwise subdivided construction so as to minimize eddy currents. The magnetic structure is excited by means of a pair of coils 24, 25 which are mounted on the cylinders 18 and 19 and which are energized in such a manner as to produce a time-varying flux in the magnetic circuit.

The energizing means may appropriately be of the character shown in Fig. 1a which illustrates diagrammatically a portion of the structure of Fig. 1. The coils 24 and 25 are connected in series with each other and with a bank of condensers 32 which are of such capacity as to resonate with the inductance of the coils at a frequency corresponding to the desired frequency of operation of the apparatus. (This may be, for example, on the order of 600 cycles per second, although frequencies differing widely from this value are usable.) To supply the losses of the resonant circuit thus formed, the coils 24 and 25 may be coupled to coils 33 and 34 which

are directly energized from an A.-C. power source 36. A relatively small amount of power supplied by the source 36 will serve to maintain the resonant system in excited condition.

Within the closed vessel 10 and also within the region of influence of the magnetic field produced by the pole pieces 15 and 16 there is provided a thermionic cathode 28 which, in conjunction with other electrode structures, 29 and 30, serves to inject into the magnetic field successive streams of electrons. These electrons are affected by the magnetic field in two ways. In the first place, since the field is in a direction transverse to the plane of the electron motion, it tends to force the electrons to follow a generally circular orbit. Secondly, the time-varying flux enclosed by the orbit of any particular electron necessarily produces an accelerating action on the electrons. In this latter respect, the apparatus as a whole consists essentially of a transformer with a secondary comprising a circular path along which the various electrons are accelerated. Although, in general, the voltage per turn in such a transformer is low, the electrons can achieve very high velocities (e. g., several million volts) because of the tremendous number of turns which they may execute in their closed path during a single quarter cycle of the field variation.

It has been shown that by a proper design of the magnetic structure the field existing at the electron orbit may be caused to produce a centripetal force in balance with the centrifugal tendencies of the accelerated electrons. In general, this result requires that the following relationship be satisfied:

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

where ϕ is the flux included within the electron orbit, r is the radius of the electron orbit, and H_r is the field strength at the orbit. This equation obviously means that the flux ϕ must be twice as strong 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 electron path.

The condition just specified may be realized by making the reluctance of the magnetic path greater by an appropriate amount at the electron orbit than its average reluctance within the orbit. In order to maintain fixed proportionality between the enclosed flux and the guide field (i. e., the field H_r) at all times during the accelerating period, one may include in the magnetic path an air gap or its equivalent. It is readily practicable to control the dimensions of such a gap from point to point over the pole area in such a fashion as to effect the balanced relationship of guide field and enclosed flux which is desired for the purpose specified above. The configuration illustrated in Fig. 1 indicates one way in which this may be done.

It is expedient to introduce electrons into the electron orbit in intermittent fashion by appropriate energization of the electrodes 28, 29 and 30. In general, best results are obtained by energizing these electrodes for a brief interval of time at instants when the accelerating magnetic field is near its zero value. This procedure appears to result in maximum acceptance of electrons by the field producing system and in a maximum yield of high velocity electrons at the end of each accelerating period.

A principal problem in the operation of apparatus of the type under consideration consists in

the provision of suitable means for utilizing or realizing the energy of the accelerated electrons after they have attained the desired high velocity. However, this is accomplished in a relatively simple manner in accordance with the present invention by providing movable target means for intercepting the electrons at an appropriate point in the accelerating cycle. In the arrangement of Fig. 1, such means comprise a rotating element 40 which is constituted of a pair of similar circular metal segments (suitably of tungsten) supported from a common axis. Accordingly, as the target rotates, it becomes alternately pervious and impervious as viewed at any point near its periphery.

Since the electrons are introduced into the accelerating orbit and accelerated in intermittent bursts, as previously explained, fully accelerated electrons exist in the chamber only at spaced intervals of time. It is apparent, therefore, that if the imperforate portion of the target 40 is interposed in the accelerating orbit at appropriate instants, it may be made to intercept the accelerated electrons, with consequent generation of X-rays and other useful radiations. This result can be obtained in one way by driving the target 40 in synchronism with the cyclical variations of the accelerating field. This may be done, for example, by connecting the target to an electrically driven rotor 45 through a shaft 46 in the manner illustrated in Fig. 2. The rotor 45, which is assumed to constitute one element of a synchronous induction motor, is located within a cylindrical arm 48 extending outwardly at a tangent with respect to the annular vessel 10. The stator 50 of the motor is outside the arm 48, the stator winding being represented at 51.

A suitable arrangement for driving the synchronous rotor 45 is illustrated in Fig. 3, in which the elements 28 to 36 correspond to the similarly numbered elements of Figs. 1 and 1a. The alternating current supply source 36, which energizes the accelerating field producing system, also serves as a supply source for the stator 50 by which the rotor 45 is driven. Accordingly, the rotor is necessarily operated in synchronism with the variations of the accelerating field. In order to assure the entry of the imperforate target part into the electron orbit only at that point in the accelerating cycle at which the electrons have attained maximum velocity, there is provided in circuit with the stator 50 a phase shifting device 54 by means of which the angular position of the rotor 45 at any given instant may be closely regulated.

Synchronization of the electron injecting means with the other elements of the system is accomplished by controlling the excitation of the injecting electrodes 28 to 30 also in accordance with the variations of the accelerating field. This may be done, for example, by means of a peaking transformer 60 which is excited by the variations of the accelerating flux through a coupling coil 61. The voltage pulses derived from the transformer 60 are impressed upon the grid 64 of a discontinuously conductive discharge device 65 which may be a gaseous thyatron or the like. This latter device includes in its plate circuit a potentiometer 67 across the various terminals of which the electrodes 28 to 30 are connected. A condenser 69 which is in series with the potentiometer 67 is arranged to be charged from a unidirectional current source (i. e., by connection to terminal 71) when the device 65 is non-conductive. Upon triggering of the device by the action

of the transformer 60, the condenser discharges through the device, and potentials are impressed upon the various electrodes 20 to 30, the electrode 30 being rendered sufficiently positive to insure injection into the vessel 10 (Fig. 1) of a burst of electrons at a velocity of the order of several thousand volts. The injection of electrons is quickly terminated, however, by loss of charge from the condenser 60, continuance of the discharge by current derived directly from the current charging source 71 being prevented by means of a current-limiting resistor 75. An inductance 76 connected in series with the condenser assists in reversing the potential on the anode of the discharge device 65 in order to restore the device to non-conductive condition and to prepare it for further operation at the beginning of the next cycle.

The complete cycle of operation may be understood by reference to the graphical representation of Fig. 4 in which the curve A represents the variations of the accelerating magnetic field. Electrons are assumed to be injected into the accelerating orbit at the intervals a , a' and a'' . Acceleration of these electrons proceeds until the instants b , b' and b'' , at each of which instants the accelerated electrons are assumed to be intercepted by passage of an imperforate portion of the rotating target into the accelerating orbit. In order to assure the functioning of the system in this manner, it is necessary that the target remain outside of the accelerating orbit only over the intervals ab , $a'b'$, $a''b''$, etc. This means that as a practical matter the area of the perforate portion of the target needs to be only a small fraction of the area of its imperforate portion.

It is clear that the system described in the foregoing is characterized by a high degree of simplicity, both with reference to the mechanical structures involved and the electrical control means required. For this reason, the system has the advantage of low cost and ease of maintenance.

Intermittent interception of the accelerated electrons may be accomplished in another way by an arrangement such as that represented in Fig. 5. In the latter figure, there is shown a fragmentary portion of a circular vessel 80 of the same general character as the vessel 10 of Fig. 1. The dotted line B is assumed to represent the accelerating orbit of electrons intermittently injected into the vessel and accelerated by means of a cyclically varying magnetic field in conformity with the procedure previously described. In this case, however, the target, which is indicated at 82, is supported at the end of a vibratory member 83 which may consist of a flexible metal ribbon or reed secured at its opposite end to a rigid standard 84. The standard is mounted on a cup-shaped metal member 85 which is sealed into the wall of the vessel 80 as indicated at 87.

In proximity to the vibratory member 83 there is provided a U-shaped magnet 86 which is supported from the standard 84 and which has an energizing coil 88 wound upon its central portion. Current-supply connections for the coil 88 are provided in the form of conductors 93 which are sealed through the member 85 by means of eyelet seals 94. Externally these conductors are connected to the terminals of an alternating current supply 95 which is assumed to be also the exciting source for the magnetic structure by which the principal accelerating field of the device 80 is

produced. In circuit between the supply source 95 and the coil 88 there is provided a phase shifting device 97 by means of which the phase of the voltage applied to the coil may be adjusted in a desired manner.

With the arrangement specified the cyclically varying magnetic field produced by the magnet structure 86 acts on an armature 99 which is secured to the reed 83 in such fashion as to excite the reed to vibratory motion. Assuming the reed to be possessed of an appropriate degree of flexibility, the amplitude of its vibration may readily be made such as to carry the target 82 into a position in which it intercepts the electron orbit B. Moreover, by properly phasing the excitation of the coil 88 (i. e., by means of the phase shifting device 97), the instant of electron interception may be made to coincide with the attainment by the electrons of their maximum velocity.

Still another embodiment of the invention is illustrated in Fig. 6 which shows a fragmentary portion of an accelerating vessel 105 containing electron-intercepting means of a form related to but differing from that of Fig. 5. Within the vessel, a movable target 106 (for example, of tungsten) is supported at the extremity of a vibratory reed 107. The reed in turn is supported through a standard 108 from a metal cup 109 which is sealed into the wall of the vessel.

For the purpose of imparting vibratory motion to the reed 107 reliance is in this case placed upon the action of the magnetic accelerating field rather than upon the provision of separate exciting means. This result is obtained by providing in connection with the reed a body of ferromagnetic material 111 (e. g., iron) which is located within the fringes of the accelerating magnetic field. With this arrangement, as the field increases in value, it tends to attract the magnetic element 111 toward the interpolar region. The intermittent impulses thus impressed upon the reed 107 set it into vibration and cause the target 106 to be intermittently brought into coincidence with the electron orbit in the manner specified for the target 82 of Fig. 5.

In order to control the vibrations of the reed 107 and in particular to adjust the phase of these vibrations with respect to the variations of the accelerating field, there is provided a rod 113 having its extremity bearing against the lower surface of the reed. The force which is exerted upon the reed by the rod is adjustable by means of a screw-threaded nut 116 cooperating with a correspondingly threaded, outwardly projecting portion of the rod. The rod is connected at an intermediate region to a flexible metal bellows 115 which is hermetically joined to the cup 107 and which permits the rod to be moved without destroying the vacuum within the vessel 105. The pressure exerted by the rod on the vibratory reed 107 may be used to "tune" the reed to facilitate its vibration at the desired frequency and also to control the amplitude and phase of its motion.

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

1. A magnetic induction accelerator including a source of charged particles, means for cyclically producing a time-varying magnetic field of such space distribution as to confine particles from said source to a desired closed orbit while continuously accelerating them along the orbit, a target movable in and out of said orbit, and means for cyclically interposing the target in the said orbit at times spaced to cause interception

of the charged particles after they have been accelerated to high velocity.

2. A magnetic induction accelerator including a vessel within which charged particles may follow a closed orbital path, means for providing charged particles within said vessel, means adjacent to the vessel for cyclically producing a time-varying magnetic field of such space distribution as to confine charged particles within the vessel to a desired orbit while continuously accelerating them along the said orbit, a target for intercepting the charged particles, and means for cyclically interposing the target in the said orbit at times when such target will intercept highly accelerated charged particles.

3. A magnetic induction accelerator including a source of electrons, means for cyclically producing a time-varying magnetic field of such space distribution as to confine electrons from said source to an annular orbit while continuously accelerating them along the orbit, a target which is movable between a position in which it is wholly outside the said orbit and a position in which it is interposed in the said orbit, and means for cyclically moving the target between its said two positions synchronously with the cyclical variations of the accelerating field, thereby to cause the target to intercept electrons at times when they have been accelerated to maximum velocity.

4. A magnetic induction accelerator including a source of charged particles, means for cyclically producing a time-varying magnetic field of such space distribution as to confine particles from said source to an annular orbit while continuously accelerating them along the orbit, said means including an alternating current supply of fixed frequency, a target which is movable between a position in which it is wholly outside the said orbit and a position in which it is interposed in the said orbit, and means energized from said alternating current supply for cyclically moving the target between its said two positions synchronously with the cyclical variations of the accelerating field, thereby to cause the target to intercept charged particles at times when they have been accelerated to maximum velocity.

5. A magnetic induction accelerator including a source of charged particles, means for cyclically producing a time-varying magnetic field of such space distribution as to confine particles from said source to a desired closed orbit while continuously accelerating them along the orbit, a rotary target having a first rotational position in which it is wholly outside the said orbit and a second rotational position in which it is interposed in the orbit, and means for rotating the target in synchronism with the cyclical variations of the said accelerating field, thereby to cause the target to be interposed in the particle accelerating orbit at times calculated to assure interception of charged particles after they have attained a high velocity.

6. A magnetic induction accelerator including a source of charged particles, means for cyclically producing a time-varying magnetic field of such space distribution as to confine particles from said source to a desired closed orbit while continuously accelerating them along the orbit, a rotary target having a perforate portion and an imperforate portion, and means for supporting the target in proximity to the said accelerating orbit and for rotating the target in synchronism with the variations of the accelerating field, 75

thereby to cause the perforate and imperforate portions of the target to be alternately interposed in the accelerating orbit in such fashion that charged particles are intercepted by the imperforate portion of the target after the particles have been accelerated to high velocity.

7. A magnetic induction accelerator including a source of charged particles, means for cyclically producing a time-varying magnetic field of such space distribution as to confine particles from said source to a desired closed orbit while continuously accelerating them along the orbit, a target which is movable between a position in which it is wholly outside the said orbit and a position in which it is interposed in the said orbit, a vibratory member by which the target is supported and by which its motion between the said positions is controlled, and means for inducing vibrations of the said member in synchronism with the cyclical variations of the accelerating field, thereby to cause the target to intercept charged particles when they have attained a high velocity.

8. A magnetic induction accelerator including a source of charged particles, means for cyclically producing a time-varying magnetic field of such space distribution as to confine particles from said source to a desired closed orbit while continuously accelerating them along the orbit, said means including an alternating current supply of fixed frequency, a target which is movable between a position in which it is wholly outside the said orbit and a position in which it is interposed in the orbit, a vibratory member on which the target is supported and by which its motion between the said two positions is controlled, and means energized from said alternating current supply for inducing vibrations of the said member in synchronism with the cyclical variations of the accelerating field, thereby to cause the target to intercept charged particles only when they have attained a high velocity.

9. A magnetic induction accelerator including a source of charged particles, means for cyclically producing a time-varying magnetic field of such space distribution as to confine particles from said source to a desired closed orbit while continuously accelerating them along the orbit, a target, and a vibratory member supporting the target and operable when excited to vibration to move the target from a position wholly outside the said orbit to a position in which it intercepts the orbit, said vibratory member having a magnetic component which is subjected to the influence of the accelerating field in such a sense as to induce vibratory motion of the member in synchronism with the variations of the field, thereby to cause interception of charged particles by the said target only after the particles have attained a high velocity.

10. A magnetic induction accelerator including an evacuated container, a thermionic cathode, means for releasing successive trains of electrons in said chamber, a time-varying magnetic field whereby said electrons are caused to repeatedly traverse an annular orbit in said container, while being continuously accelerated during traverse, a target which is movable from a position outside of said orbit to a position in said orbit interposed to said electron traverse and means for alternately moving said target from one of said positions to the other.

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