Feb. 6, 1951 K. J. R. WILKINSON ET AL 2,540,853

MAGNETIC INDUCTION ACCELERATOR

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Fig.1.

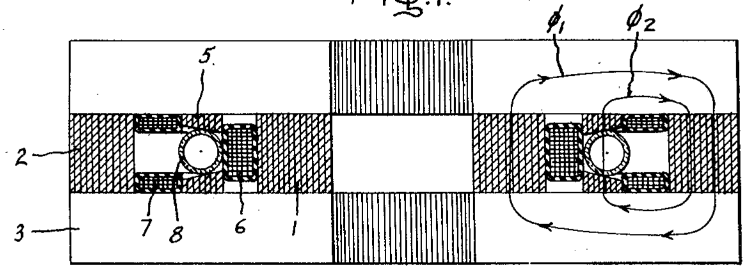

Fig.2.

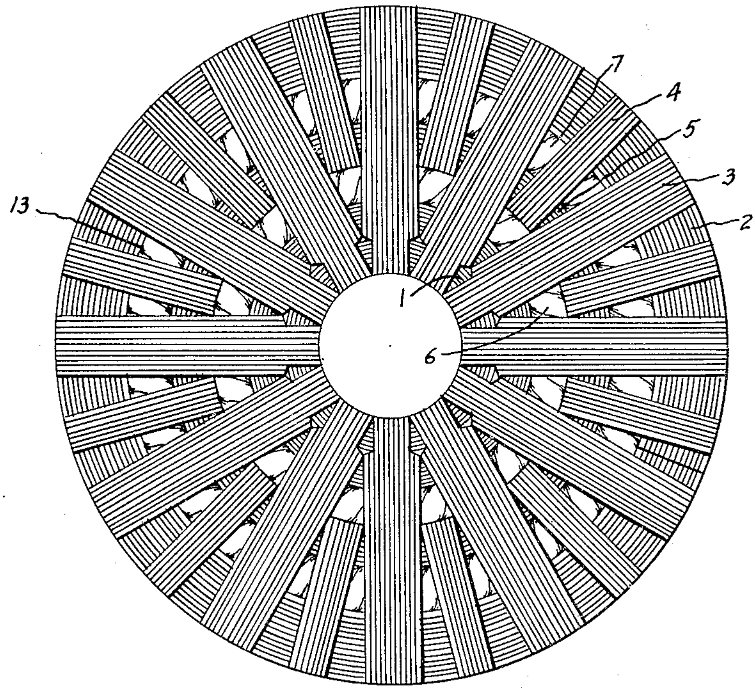

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Fig. 3.

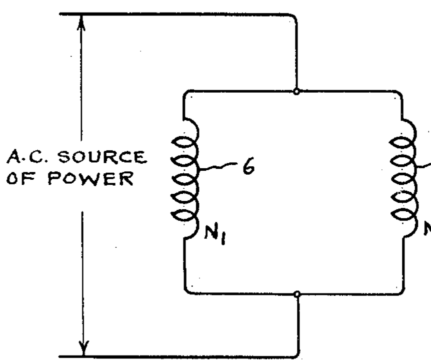


Fig. 4.

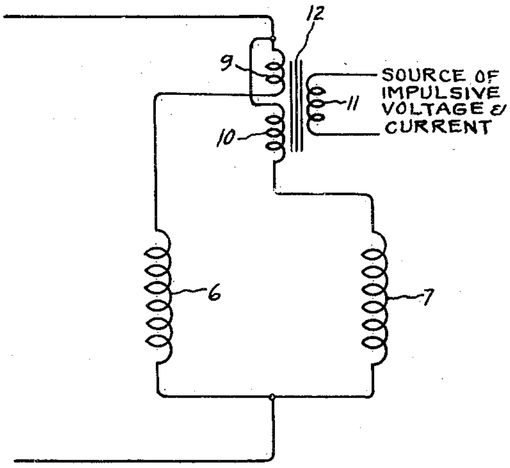
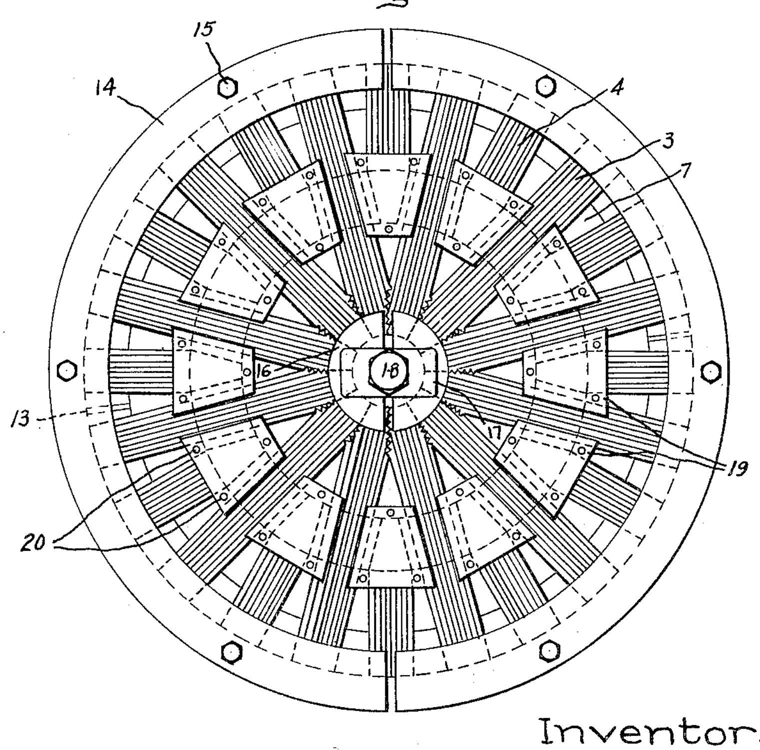


Fig. 5.



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Patented Feb. 6, 1951 2,540,853

UNITED STATES PATENT OFFICE

2,540,853

MAGNETIC INDUCTION ACCELERATOR

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Application August 5, 1947, Serial No. 766,360
In Great Britain October 4, 1945

Section 1, Public Law 690, August 8, 1946
Patent expires October 4, 1965

4 Claims. (Cl. 250—27)

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

It is an object of the invention to prov'de a new and improved accelerator of the aforesaid type.

It is a further and more specific object to provide improved means for diverting orbitally moving electrons after their acceleration has reached the desired degree.

In the drawings, Fig. 1 is a cross-section view of a magnetic field producing device constructed in accordance with the invention; Fig. 2 is a plan view of the device with clamping members omitted; Fig. 3 shows the method of connecting the concentric windings in parallel; Fig. 4 shows the manner in which the auxiliary transformer is connected to the parallel concentric windings in order to provide impulsive change in the flux density for the purpose of orbit expansion or contraction; and Fig. 5 is a plan view of the device showing the manner in which the clamping members are applied.

Equipments for producing electron streams of high velocity by induction acceleration have become well-known. They involve a magnetic field-producing device providing a central flux path in which a time varying flux of high amplitude is present, the flux density being greatest at the center or axis of the field and diminishing towards the periphery, an evacuated discharge tube of circular or annular form being present in the flux path and substantially linked by the flux. An electron stream is produced in the evacuated tube and the high rate of change of flux linking the tube causes the electrons produced to rotate around the axis of the field while the electrons are prevented from permanently leaving their orbits until they have attained their desired velocity by the field existing at or near their orbit.

In order to balance the centrifugal force of the electrons the flux density near the orbit must be accurately controlled with relation both to the flux which links the orbit and to the radius of the orbit.

As a result of the high intensities of magnetic field required in practice and the presence of an air gap at the center of the flux path, a source of considerable kva. may be needed to energize the magnetic field-producing device. However, with the construction employed in our invention, the magnetic field-producing device is capable of providing the required field intensities and flux densities having appropriate related values with

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a considerable reduction in the required electrical kva. input.

A magnetic field-producing device for the purpose set forth according to the invention provides for a substantial portion of the time-varying flux which must link the electron orbit for the purpose of accelerating the electrons tangentially, to pass substantially or wholly throughout its length through a magnetic core, while the magnetic flux density which is to occupy the non-magnetic evacuated orbit space for the purpose of counteracting the centrifugal force on the electrons is restricted to a space of minimum volume.

The magnetic field-producing device preferably comprises a magnetic core construction having a central core which is excited by two concentric windings in such a manner that, when an A. C. voltage is applied to the windings, flux linking both windings is substantially in time phase with the leakage flux not linking both windings, while the leakage flux not linking both windings is made to traverse the non-magnetic annular volume occupied by the circular electron orbit space, whereas all other flux paths comprise highly permeable magnetic material substantially throughout their lengths. The relative turns in each winding are so chosen in relation to the reluctance of the electron orbit space flux that the flux ϕ_0 linking the equilibrium orbit bears substantially the relation:

$$\Delta\phi_0 = 2\pi R_0{}^2 B_0$$

In this relation, while the electrons are accelerated B_0 is the flux density at, and R_0 is the radius of, the equilibrium orbit.

By this means we fulfill the equilibrium condition necessary for accelerating the electrons by magnetic induction. The further condition that the equilibrium orbit shall be stable is that

$$B = B_0\left(\frac{R_0}{R}\right)^n \text{ where } 0 < n < 1$$

where B is the flux density at radius R in the neighborhood of the orbit radius. This condition is achieved by appropriate shaping of the orbit flux space poles coupled with the disposition of the two windings.

The two concentric windings may be connected in series or parallel. When the windings are connected in parallel, as is to be preferred, the two windings are wound in the same sense and embody differing numbers of turns, the outer winding having fewer turns than the inner winding. If, however, the windings are connected in series, they are wound in opposite sense and the inner winding has a fewer number of turns than the outer winding.

When the process of electron acceleration is complete, or sufficiently advanced, it may be necessary to expand or contract the electron orbit so as to produce collision with a suitable target, and in order to provide for orbit expansion or contraction, the flux linking the equilibrium orbit is made to change impulsively, relative to the flux density of leakage flux not linking both windings at the orbit. For the case where two concentric windings are connected in parallel, expansion or contraction may conveniently be effected by applying an impulsive voltage in each cycle of the applied voltage at the instant at which electron energy is substantially a maximum, by means of an auxiliary transformer having two secondary windings with turns respectively proportional to, and connected in series with, the parallel concentric windings.

In order that the invention, together with further objects and advantages thereof, may be more readily understood and carried into effect we will now describe, with reference to the accompanying drawings, an embodiment of the same.

Referring to Fig. 1, the magnetic field-reproducing device embodying the invention consists of an inner annular core **1**, an outer annular core **2**, and an intermediate annular core **5** in two parts. These several cores are linked by radial laminated members **3** and **4**. The cores **1**, **2** and **5** may be in the form of spirally wound strips of magnetic material, although the inner and outer cores may be of any other suitable laminated construction. Thus it is to be understood that in place of spirally wound cores we might employ standard core limbs both for the inner and outer core paths. The device is energized by an inner winding **6** and an outer winding **7** concentric therewith, the outer winding being, for convenience in affording access to the orbit space, in two sections, as indicated, which may be connected either in series or in parallel. The evacuated tube **8** in which the orbitally moving electrons are contained is introduced into the air gap between the two parts of the core **5**.

In Fig. 5 we have shown in plan the method which may be adopted for securing together the parts of the magnetic field-producing device illustrated in Figs. 1 and 2. It is necessary to split circumferentially the core members **1**, **2**, **5** to prevent them from forming short-circuit paths, and to adopt a similar precaution with regard to clamping rings employed in the construction. The splits in the ring **2** are indicated at **13** in Fig. 2. In Fig 5 the two halves of the semi-circular cores are held together at their outer periphery by clamping half-rings **14** of L-shape in cross-section which are bolted to similar half-rings at the bottom of the device by bolts **15**. At the center half-rings **16** and a transversely located clamping plate **17** hold the inner periphery of the device, a central bolt **18** extending through the hollow central portion of the core construction. Pairs of plates **19** bear at their edges on the adjacent bridging members and serve to hold the core parts **5** in position, clamping bolts **20** passing through the spaces between **3** and **4** to engage plates, similar to plates **19**, located on the inner faces of the parts **5**. These latter plates are of non-magnetic material, such as bronze.

The principal fluxes ϕ_1 and ϕ_2 are shown in the section of Fig. 1; ϕ_1 being linked to both coil **6** and coil **7**, ϕ_2 being linked only to coil **7**. The voltage per turn of coil **6** is therefore proportional

to ϕ_1 and the voltage per turn of coil **7** is proportional to $\phi_1+\phi_2$. The requirement that ϕ_1 and ϕ_2 shall be in the same direction, is made by ensuring, in the case of a parallel connection of windings **6** and **7**, that the turns comprising the winding **7** shall be less in number than those comprising the parallel winding **6**. For a series connection it would be necessary that the turns comprising the winding **7** should be greater in number than those comprising the winding **6**, but as we have previously mentioned the parallel arrangement is to be preferred because by this means the time phase angle between fluxes ϕ_1 and ϕ_2 can be made smaller.

The conditions to be met in this apparatus are well known and have been hereinbefore specified by the two expressions given above. In a practical example, using a parallel arrangement of windings **6** and **7**, we may cite, for example, that the winding **6** comprises 20 turns each carrying 800 amperes, and the windings **7** together comprise 14 turns each carrying 1200 amperes, while the current to be supplied from a source of A. C. power is the difference between these two currents, namely 400 amps. Again, in this example, the voltage of supply was 2000 and frequency 200 cycles.

The arrangement of the windings as shown in Fig. 3 is to be modified for the purpose of orbit expansion, which demands a relative change in amplitude between ϕ_1 and ϕ_2, by the use of the auxiliary series transformer arrangement shown in Fig. 4. In the preferred form of this transformer an impulsive voltage and current are applied to a primary winding **11** which excites by means of the common core **12** two secondary windings **9** and **10** which are in series with the concentric windings **6** and **7** respectively. Relative turns and polarity of the windings **9** and **10** are so chosen that the resultant excitation by load currents in windings **6** and **7** of the core **12** is sensibly zero. This requirement is met by arranging that the turns **9** and **10** are respectively proportional to the turns of **6** and **7**. When an impulsive voltage and current is applied to winding **11** at the time appropriate for shifting the orbit, the exctitation of core **12** assumes a finite magnitude whose algebraic sign is determined by the polarity of the impulse with respect to the alternating current source of power. Since the impulse causes the magnitude of the excitation of core **12** to become other than zero, it is apparent from Fig. 4 and transformer theory that the pre-existing relative values of the voltages across windings **9** and **10**, and hence windings **6** and **7**, can no longer exist. Thus, the relationship between the amplitudes of ϕ_1 and $\phi_1+\phi_2$ is modified; the relationship between the flux ϕ_0 linking the electron orbit as previously stated and the flux density B_0 at the orbit is similarly altered; and the electron orbit shifts. By appropriate choice of polarity of the impulse, the voltage of winding **10** due to the impulse is additive with the voltage from the A. C. power source; consequently, the voltage of winding **9** is also additive and greater than that of winding **10**. Therefore, the ratio of the rates of change of ϕ_1 and $\phi_1+\phi_2$ is increased; hence, the ratio of the rates of change of ϕ_1 and ϕ_2 is increased and the ratio of the rates of change of ϕ_0 and B_0 will increase, thereby causing the orbit to expand.

It will be understood that the impulsive voltage can be provided by any suitable impulsing circuit which is synchronized and properly phased with respect to the variations of main flux. Examples of such circuits are given in United States Patent No. 2,394,072 issued February 5, 1946, to W. F. Westendorp and assigned to the General Electric Company.

From the aforegoing description it is obvious that various advantages may accrue when our invention is employed. One important advantage readily apparent is that the electron orbit may be expanded or contracted to cause the electrons to impinge upon a target without resorting to windings situated upon a portion of the magnetic circuit structure of the accelerator. Thus, by the use of our invention the impulsive disturbance of the flux relationship required to shift the orbit may be obtained from windings in the form of a transformer placed exteriorly of the accelerator, thereby permitting the more effective utilization of the air gap in which the evacuated tube is positioned.

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

1. Apparatus for accelerating charged particles along a re-entrant path comprising a magnetic assembly having a structure which provides a magnetic circuit for flux linking said path and which further provides a magnetic circuit for flux traversing the locus of said path, a pair of coils for energizing said magnetic assembly respectively located inside and outside of the locus of said path, a source of time-varying excitation, circuits respectively connected between said source and said coils for concurrently exciting the coils to establish a desired balance of said magnetic fluxes, and a source of impulsive voltage for changing simultaneously the energization of said coils so that the balance of said fluxes is disturbed and the path of said particles abruptly shifted.

2. Apparatus for accelerating charged particles along a re-entrant path comprising a magnetic assembly having a structure which provides a magnetic circuit for flux linking said path and which further provides a magnetic circuit for flux traversing the locus of said path, a pair of coils for energizing said magnetic assembly respectively located inside and outside of the locus of said path, a source of time varying excitation, circuits respectively connected between said source and said coils for concurrently exciting the coils to establish a balanced relationship of said magnetic fluxes such that the flux traversing the locus of said path is sufficient to confine said charged particles to said path while the flux linking said path causes said charged particles to accelerate, and a source of impulsive voltage for changing simultaneously the energization of said coils to disturb the balanced relationship of said magnetic fluxes and thus abruptly to shift the path of said particles.

3. Apparatus for accelerating charged particles along a re-entrant path comprising a magnetic assembly having a structure which provides a magnetic circuit for flux linking said path and which further provides a magnetic circuit for flux traversing the locus of said path, a pair of concentric windings for energizing said assembly respectively located inside and outside the locus of said path, a source of time-varying excitation, circuits respectively connected between said source and said coils for concurrently exciting the coils to establish a balanced relationship of said magnetic fluxes such that the flux ϕ_0 linking the path, the radius R_0 of the path, and the flux density B_0 at the path bear approximately the relation

$$\Delta\phi_0=2\pi R_0^2 B_0$$

and a source of impulsive voltage for disturbing said balanced relationship to shift the path of said particles comprising a transformer having two secondary windings, each of which secondary windings is serially connected with one of said concentric windings.

4. In an apparatus for accelerating charged particles along a re-entrant path, the combination which includes a magnetic assembly having concentric inner and outer cores defining a magnetic flux circuit for flux which links said path and an annular core intermediate said inner and outer cores defining with said outer core a magnetic flux circuit for flux which traverses the locus of said path, inner and outer concentric windings for energizing said assembly disposed respectively within the space between said inner and said intermediate cores and the space between said intermediate and said outer cores, said windings having a relative turns ratio with respect to the reluctance of said latter magnetic flux circuit so as substantially to fulfil the relation

$$\Delta\phi_0=2\pi R_0^2 B_0$$

where ϕ_0 is the flux linking, B_0 the flux density at, and R_0 the radius of, the re-entrant path, a source of time-varying excitation, circuits respectively connected between said source and said windings to supply excitation to said windings, and a source of impulsive voltage for changing simultaneously the energization of said windings thereby disturbing said relation and abruptly shifting said path.

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CHRISTOPHER J. MILNER.

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