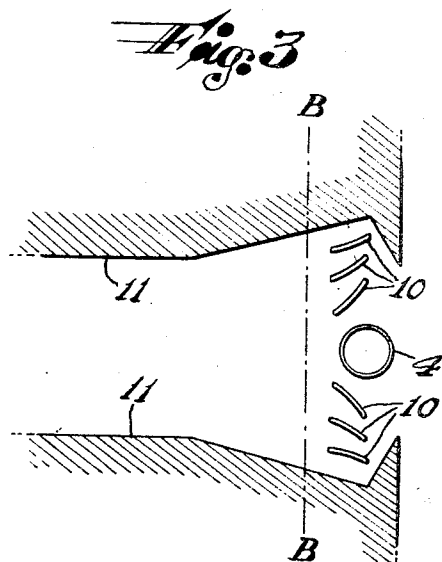
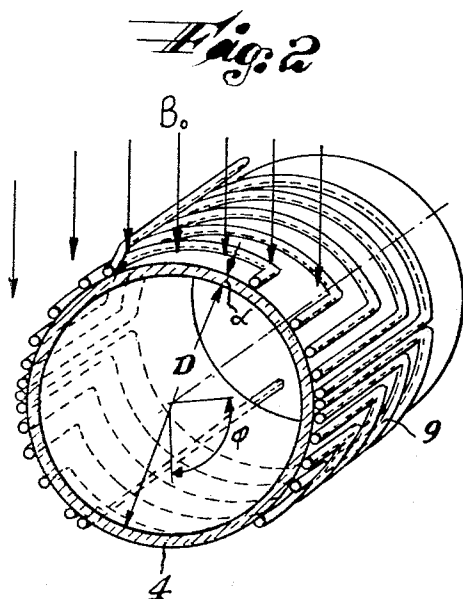
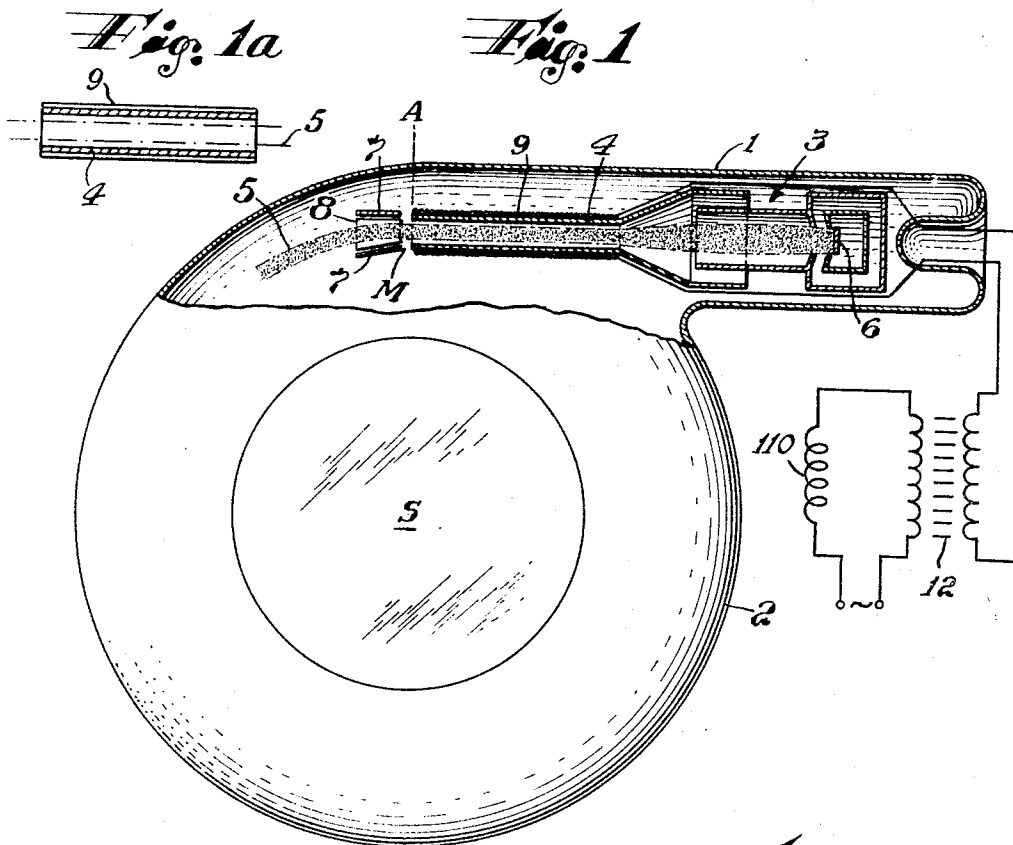


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 APPARATUS FOR INJECTING CHARGED PARTICLES INTO THE
 MAGNETIC FIELD OF A CYCLIC PARTICLE ACCELERATOR
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INVENTORS.
 Miloš Seidl
 Zdeněk Sedláček
 BY Pavel Šunka
 Richard Lund
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APPARATUS FOR INJECTING CHARGED PARTICLES INTO THE MAGNETIC FIELD OF A CYCLIC PARTICLE ACCELERATOR

Miloš Seidl, Zdeněk Sedláček, and Pavel Šunka, Prague, Czechoslovakia, assignors to Československá akademie věd, Prague, Czechoslovakia

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The present invention relates to cyclic accelerators of electrons and ions, and deals more particularly with a device for injecting charged particles into the magnetic field of an accelerator. The invention will be explained in its application to a betatron, it being of course understood, that the invention is in no way limited to this particular type of apparatus and can be used in connection with any suitable accelerator.

It is a well known fact that the correct operation of a betatron requires the electrons to be introduced into the magnetic field of the accelerator with a certain initial energy and substantially in azimuthal direction. This problem has heretofore been dealt with by two principal methods: The older is Kerst's method (U.S. Patent No. 2,497,891, dated Feb. 21, 1950) according to which a three-electrode gun accommodated directly in the accelerating space is used. The electrons, emitted by the gun with an energy of, for instance, 60 kev., are immediately captured by the guiding magnetic field. In order that an electron gun, positioned in this way, should hinder the circulating electrons to the least extent, its dimensions must be kept at a minimum; this necessity, however, places a limit on the injection voltage. The number of captured electrons increasing with the injection energy, it is preferable to use as high an injection voltage as possible.

The aforementioned drawback is removed by the injecting method according to Gund (German Patent No. 810,286, dated Aug. 9, 1951, and No. 891,433, dated Sept. 28, 1953). According to said method an electro-static deflector is used, by means of which the electrons are injected in azimuthal direction to the guiding magnetic field from an electron gun, which can be accommodated outside the actual accelerating region. This arrangement does not require a compact electron gun, and the injection energy of the electrons may be substantially increased.

The use of an electrostatic deflector entails, however, a number of grave disadvantages:

(1) The focussing of the electron beam emerging from the electron gun is impaired by electron-optical deficiencies of the deflector, which are the greater the larger the angle through which the particles are deflected, but which are present even if the deflector does not bend the beam, but merely overcomes the forces of the magnetic field.

(2) The trajectory of the electrons within the deflector is substantially influenced by the arrangement of the magnetic field of the accelerator, which can differ in products of various origin. If the aperture of the deflector is not sufficiently large, injected particles may be lost on the deflector electrodes.

(3) An electrostatic deflector requires a separate high voltage source.

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(4) The angle under which the charged particles are injected into the guiding magnetic field of the accelerator, is constant during the injection period (lasting several microseconds) only if the voltage across the gun and across the deflector varies with time in the same manner, which is difficult to achieve. A variation in the injection angle with time results in a reduction in the magnitude of the captured charge.

The aforesaid difficulties are avoided according to the invention by the provision of a channel that is shielded from the magnetic field and therefore free from deflecting magnetic forces, said channel serving for the admission of electrons to the magnetic field.

The novel feature of the invention, including various novel details of construction and combination of parts, will now be more particularly described with reference to the accompanying drawings and thereafter pointed out in the claims.

In the drawings:

FIG. 1 is a diagrammatic representation showing the vacuum chamber and injection device of a betatron,

FIG. 1a shows the injector of FIG. 1 and the windings connected thereto,

FIG. 2 shows the injector tube of the apparatus of FIG. 1 in a perspective view and partly in transverse section, and

FIG. 3 shows a modified compensating arrangement for the betatron of FIG. 1 in a diagrammatic view.

Referring to FIG. 1, there is seen an electron gun 3 mounted in a tangential tubular extension of a vacuum chamber 2. The vacuum chamber is placed in the usual way in the magnetic field of a betatron. The electron gun is positioned outside the poles of the betatron magnet, and can therefore easily be designed for the required resistance against high voltage and for correct focussing of the beam. The gun produces a cylindrical electron beam with an energy of for instance 100 kev., which is focussed so as to make the beam divergence in the plane A at the end of an injector tube 4 equal to zero. The injector tube 4 is coaxially aligned with the electron gun 3. It is connected to the semi-conductive coating of the vacuum chamber 2 and grounded thereby. The gun, as well as the injector tube, are made of a ferromagnetic material of high permeability, which shields the electron beam 5 from the external guiding magnetic field. In the cylindrical injector tube, which has a diameter D and a wall thickness d (FIG. 2) and is made of a material of a permeability μ , the magnetic field is

$$1 + \frac{d}{D} \frac{(\mu - 1)^2}{\mu}$$

times smaller than the magnetic field outside the injector tube. The electron beam 5 passes from the cathode 6 in the gun 3 to the plane A through a negligibly small magnetic field, independent of the external guiding field. Having passed the plane A, the electron beam enters the guiding magnetic field of the betatron tangentially to an orbital circle having a centre S and passing through the intersection M of the injector axis with the plane A. Small corrections of the injector angle may be required to correct errors in the mounting of the vacuum chamber in the magnet, and can be effected by a system of deflection plates similar to those used in a cathode ray tube.

FIG. 1 shows deflection plates 7 for deflecting the beam in a horizontal plane and plates 8 for deflection in a

vertical plane. The diameter D of the cylindrical injector tube 4 is preferably just slightly larger than the diameter of the electron beam and, with a correctly focussed beam, it may amount to 5-10 mm.

The device of the invention provides a channel in the magnetic field of the betatron which is substantially free from the disadvantages of an electrostatic deflector, but it causes a deformation of the external magnetic field.

If the magnetic field of the betatron is not entirely homogeneous and constant the injector tube is subjected to forces which may exceed the mechanical strength of the injector or of the electron gun.

The last-mentioned difficulties are avoided by an additional feature of the present invention. As the injection of electrons into the betatron takes but a very short fraction of the accelerating cycle (about 1.5×10^{-4} of the cycle), we make the injector tube from a magnetically soft material whose hysteresis loop is of substantially rectangular shape. We select the wall thickness of the injector tube in such a manner that at the moment when the injection is terminated, the magnetic induction in the injector wall is equal to the saturation limit B_s of the injector material. When injection is terminated, the injector tube material immediately becomes magnetically saturated and, after a certain time, its permeability drops to nearly 1, whereby the injector does not cause a deformation of the external magnetic field, and the force action on the injector drops almost to zero. If the magnetic induction of the guiding field equals B_0 , then the wall thickness of the injector tube must be

$$d = D \frac{B_0}{B_s}$$

When the wall thickness is chosen according to the preceding formula, and the permeability of the material amounts to 10^4 , the magnetic field within the injector does not exceed 1% of the external guiding field, so that the path of electrons within the injector is, to all practical purposes, not influenced by the external field. When stronger shielding from the external magnetic field is required, a multiple magnetic shield may be used, by means of which a shielding factor of 1000 and more may be achieved.

Before the material of the injector tube 4 is fully saturated, the deformation of the external magnetic field can be compensated by a current flowing in the direction of the injector tube axis with a linear current density i which satisfied the equation:

$$i = I_0 \sin \varphi$$

The angle φ is shown in FIG. 2. It is in a radial plane with respect to the common axis of the tube 4 and the beam 5, and has its apex in the axis. A sinusoidal current density distribution can be effected, for example, by means of a winding 9 shown in FIGS. 1 and 2.

The current feeding the compensation winding can be derived from the current which energizes the winding 110 of the guiding magnet 11 by means of a saturable transformer. The transformer core 12 is preferably made from the same material as the injector tube 4, and the winding of the transformer 12 is designed so as to make the saturation in the transformer core equal to the induction B_s of the injector tube material at the magnet when injection is terminated. This ensures a variation of the compensating current in precise synchronization with variations in the intensity of the magnetic field. The primary winding of the transformer 12 is connected in series to the magnet winding 110 which ensures the correct maximum value of the compensating current independent of fluctuations to which the power supply of the betatron magnet 11 may be subjected.

The deformation of the guiding magnetic field caused by the injector tube 4 may be compensated, alternatively,

as shown in FIG. 3 by a set of strips 10 made of a magnetically soft ferromagnetic material and placed above and below the injector tube 4 between the poles of the betatron magnet 11.

By a suitable arrangement of the strips 10 it is possible to obtain in a plane B spaced from the strips by a distance equal to the gap between the strips, substantially the same distribution of magnetic potential as in a field not disturbed by the injector tube. The greater the number of strips, the more accurately the deformation of the field can be compensated. In practice, however, two or three strips are sufficient.

The forces acting on the injector tube are very small because the material of the injector becomes saturated soon after the injection. For instance, in a betatron of 15 mev., the force will exceed not 10 to 20 grams per centimeter of injector tube length. If the injector is properly designed, such a force is unable to influence its operation or to overcome its mechanical strength.

What we claim is:

1. In a cyclic particle accelerator, in combination:

(a) electromagnetic means for generating a magnetic guiding field,

(1) said field defining an arcuate orbital path for electrically charged particles;

(b) a source of a beam of electrically charged accelerated particles,

(1) said source being outside said field, and

(2) said beam having an axis substantially tangential to said path;

(c) a tubular injector member of magnetically soft ferromagnetic material elongated in the direction of said axis,

(1) a longitudinal portion of said member being in said field,

(2) said member enveloping a portion of said beam extending from a region adjacent said source to a portion of said field adjacent said path,

(3) said source being adapted to generate said beam in an injection pulse of limited duration, and said injector member being dimensioned to reach magnetic saturation in said field in a time not substantially exceeding said period,

(4) said portion of said injector member being adapted to deform said field during the duration of said pulse; and

(d) compensating means for compensating the deforming effect of said injector member on said field.

2. In an accelerator as set forth in claim 1, said compensating means including means for passing an electric current axially over said injector member, the density of said current being sinusoidally distributed about said axis, and means for varying the magnitude of said current in synchronization with variations of the intensity of said field.

3. In an accelerator as set forth in claim 2, said electromagnetic means including an energizable accelerator magnet having a winding, said current passing means including a saturable transformer, and a compensating conductor means on said injector member, said transformer having a primary winding in series circuit with the winding of said accelerator magnet, a secondary winding in circuit with said conductor means, and a core of magnetically soft ferromagnetic material dimensioned to reach magnetic saturation in a time not substantially exceeding said period when said magnet is being energized.

4. In an accelerator as set forth in claim 1, said electromagnetic means including a magnet having two poles, said portion of said injector member being interposed between said poles, and said compensating means including a plurality of strips of ferromagnetic material interposed between said injector member and said poles, said

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strips being dimensioned to reach magnetic saturation in said field in a time not substantially exceeded said period.

5. In an accelerator as set forth in claim 1, a chamber adapted to be evacuated, said chamber having an arcuate wall and a tubular extension projecting substantially tangentially outward of said chamber from said wall, said electromagnetic means generating said field in said chamber and defining said path in said chamber, said source being mounted in said extension, and said injector member extending from said tubular extension into said chamber, said longitudinal portion of the injector member being in said chamber.

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HERMAN KARL SAALBACH, *Primary Examiner.*

DAVID J. GALVIN, *Examiner.*

S. CHATMON, JR., *Assistant Examiner.*