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CYCLOTRON DEVICE INCLUDING DUMMY MAGNETIC COMPONENTS
FOR IMPROVED MAGNETIC FIELD SYMMETRY
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Fig. 1

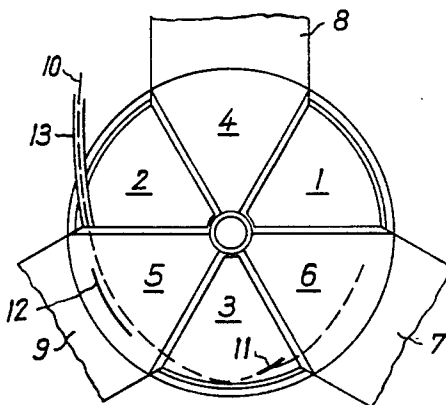
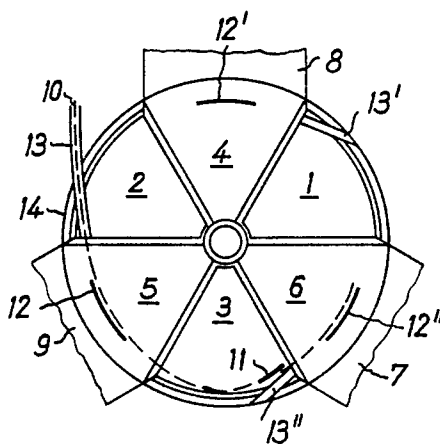


Fig. 2



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CYCLOTRON DEVICE INCLUDING DUMMY MAGNETIC COMPONENTS FOR IMPROVED MAGNETIC FIELD SYMMETRY

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4 Claims. (Cl. 313—62)

ABSTRACT OF THE DISCLOSURE

A device for improving the symmetry of the magnetic field to which particles are subjected during acceleration in a cyclotron, which cyclotron includes a particle extraction system having magnetic components disposed in a peripheral portion of the cyclotron magnetic field region, the device including several sets of dummy components equal in number to one less than the total number of cyclic variations of the composite magnetic field in the cyclotron, the magnetic components of the extraction system being disposed at a given point in a region defining one cycle of variation of the composite magnetic field and each set of dummy components being disposed at a corresponding point in a region defining a respective other cycle of the composite field.

The present invention relates to improvements in a cyclotron, and particularly to improvements in the symmetry of the magnetic field to which particles are subjected during acceleration.

Many types of cyclotrons are constructed to present a closed path for particles to be accelerated, which path traverses a series of weak accelerating magnetic fields interposed between a series of strong bending, or guide, magnetic fields. Thus, a particle travelling in a substantially circular, or helical path around the axis of the cyclotron is subjected to several cycles of magnetic field variation during each complete revolution around the cyclotron. In order to permit optimum control of the cyclotron, it is desirable that all of the cycles of magnetic field variation be identical to one another.

Many types of cyclotrons are equipped with means for extracting the stream of accelerated particles, which means are placed at a point on the outer circumference of the region in which acceleration takes place. The most widely used extraction means generally operate by producing suitable magnetic fields which act to deflect the beam outwardly and through a magnetic shield to some point outside the cyclotron. These extraction means tend to produce distortions in the magnetic fields producing one of the cycles of magnetic field variation around the cyclotron and hence, tend to disturb the azimuthal, or angular, symmetry of the total cyclotron magnetic field configuration.

It is also common in such cyclotrons to provide a magnetic component in one weak field region of the cyclotron which acts to further weaken the field in this region in order to permit the particles to be given a greater linear acceleration. The placing of this component in one of the weak magnetic field regions also acts to disturb the azimuthal symmetry of the magnetic field variations about the cyclotron axis.

It is an object of the present invention to overcome these drawbacks.

It is a more specific object of the present invention to compensate for asymmetrical distortions created in the magnetic field of a cyclotron by the presence of extraction means and magnetic field weakening components.

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It is another object of the present invention to reduce the magnetic field to a minimum in the region where the accelerated particles are extracted.

Another object of the present invention is to increase the separation between the outermost paths followed by particles accelerated in a cyclotron.

The present invention is intended for use with a cyclotron having means for producing a plurality of identical, strong, guide magnetic fields alternating with a plurality of identical, weak, accelerating magnetic fields to form a composite magnetic field which varies cyclically about the cyclotron axis, the cyclotron further including a particle extraction system having magnetic components disposed in a peripheral portion of the cyclotron magnetic field region. The improved results of the present invention are attained by the provision of means constituted by at least one set of dummy magnetic components identical with the extraction system magnetic components, with the magnetic components of the extraction system being disposed at a given point in a region defining one cycle of variation of the composite magnetic field and with each set of dummy components being disposed at a corresponding point in a region defining a respective other cycle of the composite field.

In accordance with a particular feature of the present invention, there are also provided a plurality of magnetic correction plates equal in number to the number of cyclic variations of the magnetic field and spaced symmetrically in the cyclotron magnetic field region about the cyclotron axis.

In accordance with a further feature of the present invention, the cyclotron is formed of a pair of opposed magnetic pole plates having their edges formed, in the region of the extraction system, to correspond with the path followed by the particle stream travelling through the extraction system.

Additional objects and advantages of the present invention will become apparent upon consideration of the following description when taken in conjunction with the accompanying drawings in which:

FIGURE 1 is a schematic top view of a cyclotron according to the prior art.

FIGURE 2 is a view similar to that of FIGURE 1 showing a preferred embodiment of the present invention.

Identical elements are given the same reference numeral in the two figures. For purposes of clarity, all of the usual cyclotron components which are not involved in the present invention, such as the magnetic yoke, the ion source, etc., have been omitted from the drawing.

Referring first specifically to FIGURE 1, the prior art cyclotron is shown to have six magnetic field sectors, with strong magnetic field sectors alternating with weak ones. Thus, sectors 1, 2 and 3 constitute regions of strong magnetic fields, while the sectors 4, 5 and 6 are regions of weak magnetic fields where acceleration takes place. The elements 7, 8 and 9 represent acceleration electrodes.

For extracting the beam 10 produced by the cyclotron, there is first provided a relatively short septum, or deflection condenser, 11 disposed in the strong magnetic field region of sector 3 and arranged to deflect the beam 10 outwardly by a small amount. The beam then travels to the extraction system which includes a magnetic correction plate 12 disposed in the weak magnetic field region of sector 5 and arranged to effectuate a further deflection of the beam 10. The extraction system also includes a magnetic guide shield, or channel, 13 which is disposed with its inlet end at a transition point between the weak magnetic field region of sector 5 and the strong magnetic field region of sector 2 for guiding the beam 10 to a region outside of the cyclotron.

The device shown in FIGURE 1 has the drawbacks noted above. These drawbacks are substantially avoided

by the modifications contained in the device shown in FIGURE 2. In order to eliminate the disturbing effects created by the presence of the components 12 and 13 of the system of FIGURE 1, the device of FIGURE 2 is modified, according to the present invention, to contain additional magnetic components, which function as dummy extraction elements at each azimuthal point of symmetry of the cyclotron, thus, magnetic "dummy" correction plates 12' and 12'' are provided in the weak magnetic field regions of sectors 4 and 6, respectively, while magnetic "dummy" guide channels 13' and 13'' are disposed in the strong magnetic field regions of sectors 1 and 3, respectively.

Since the dummy extraction elements are identical with the operative extraction elements 12 and 13 both as to structure and associated magnetic field pattern, it is necessary to ensure that the stream of accelerated particles 10 will only exit through guide channel 13. This result is obtained by the provision of a single septum 11 which ensures that the stream will be deflected outward to a radial point at which it will enter the extraction system prior to arriving at the correction plate 12 and guide channel 13.

If desired, the shape of the edge 14 of the pole plates can be varied to conform to the path followed by the beam 10 in the region of the extraction channel.

This variation in the shape of the edge 14 supplements the corrective effects of the "dummy" elements by reducing the amplitude of the magnetic field in the region where the beam 10 is extracted from the cyclotron. It has been found that if the edge 14, which is normally circular and concentric with the axis of the cyclotron, is fashioned so that a portion thereof adjacent the input end of guide channel 13 is displaced radially inwardly by several centimeters so as to be parallel to the path of beam 10 in this region, a lowering of the magnetic field in this region to about $\frac{2}{3}$ of the nominal value will result.

If a magnetic attenuation strip is provided (not shown) it is also desirable that the magnitude of the magnetic field in the region of the attenuation strip also be reduced. This is true because the maintenance of a low magnetic field in the region of the attenuation strip has the effect of increasing the influence of the strip since its effectiveness is inversely proportional to the amount by which the field strength in this region is below the magnetic saturation of the iron pole plates. For example, the influence of the attenuation strip at a field strength of 7 kG. (kilogauss) is twice as large as at 10 kG. Therefore, in accordance with another feature of the present invention, magnetic attenuation strips may be arranged, in a manner similar to that for the correction fins 12, 12' and 12'', about the cyclotron in a symmetrical manner with respect to the circumferentially varying magnetic field.

In accordance with another feature of the present invention, the magnetic components 12 and 13 and the corresponding dummy components are dimensioned so that their height is approximately $\frac{1}{3}$ to $\frac{1}{4}$ the height of the air gap between the magnetic pole plates of the cyclotron.

In accordance with a further feature of the present invention, the effects of the magnetic field disturbances created by the various extraction and field attenuation components is further reduced by increasing the distance between the last two turns of the path followed by particles during acceleration. This procedure has the effect of creating a greater physical separation between the extraction and attenuation components and most of the helical path followed by the particles. In the case of the synchrocyclotron, and other cyclotrons producing particle speeds which do not approach the speed of light, such a widening can be accomplished by simply placing a wedge in the magnetic field. However, as a practical matter, this measure is only applicable in special cases for cyclotrons producing particle speeds which approach the speed of light. In this latter case, the same result may be obtained by the provision of a septum disposed in the path followed by

the particles during their last revolution in the cyclotron.

Concerning the correction of magnetic field distortions according to the present invention, it should be noted at this point that the provision of carefully dimensioned magnetic correction plates of the type described above in connection with FIGURE 2 can, by itself, compensate almost completely for the undesired distortions produced by the presence of magnetic extraction elements in the case where the energy of the cyclotron magnetic field is maintained constant. However, when it is desired to utilize a cyclotron in which the magnetic field energy can be varied, the use of magnetic correction plates alone does not prove sufficient. It is in this case that the use of symmetrically disposed dummy extraction components for compensating the distortions created by the actual extraction components becomes desirable.

It has been found that, in circular accelerators, the following types of disturbances in the particle stream configurations exist: (1) disturbances of the azimuthal, or angular symmetry; (2) disturbances of the average value of the magnetic field over a path defining one revolution of the particle; and (3) disturbances of the axial stability of the stream due to variations in the radial gradients of the axial magnetic field. The disturbances defined in (2) and (3) can be substantially eliminated either by proper design of the polar geometry or by suitable regulation of the various correction currents. The disturbance defined in (1), particularly in the case where it is desired to vary the magnetic field strength, can be substantially eliminated by the provision of the dummy extraction and correction components described in connection with FIGURE 2 above.

It may thus be seen that the provision of the dummy components of the present invention leads to a substantial improvement in the symmetry of the magnetic field to which an accelerated particle stream is subjected and hence to a substantial improvement in the degree to which this stream can be controlled.

It will be understood that the above description of the present invention is susceptible to various modifications, changes, and adaptations, and the same are intended to be comprehended within the meaning and range of equivalents of the appended claims.

What is claimed is:

1. In combination with a cyclotron having means for producing a plurality of identical, strong, guide magnetic fields alternating with a plurality of identical, weak, accelerating magnetic fields to form a composite magnetic field which varies cyclically about the cyclotron axis, and a particle extraction system having magnetic components disposed in a peripheral portion of the cyclotron magnetic field region, means comprising at least one set of dummy magnetic components identical with the extraction system magnetic components, with the magnetic components of the extraction system being disposed at a given point in a region defining one cycle of variation of the composite magnetic field and with each said set being disposed at a corresponding point in a region defining a respective other cycle of the composite field, said at least one set of dummy components being constituted by a number of such sets equal to one less than the total number of cyclic variations of the composite magnetic fields.

2. An arrangement as defined in claim 1 wherein said number of sets of magnetic components and the magnetic components of the extraction system are all spaced at regular intervals around the peripheral portion of the cyclotron field region.

3. An arrangement as defined in claim 1 further comprising a septum disposed in the cyclotron magnetic field region for increasing the separation between the paths defining the final two revolutions of particles accelerated by the cyclotron.

4. In combination with a cyclotron having means for producing a plurality of identical, strong, guide magnetic fields alternating with a plurality of identical, weak, ac-

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celerating magnetic fields to form a composite magnetic field which varies cyclically about the cyclotron axis, and a particle extraction system having magnetic components disposed in a peripheral portion of the cyclotron magnetic field region, means comprising at least one set of dummy 5 magnetic components identical with the extraction system magnetic components, with the magnetic components of the extraction sysem being disposed at a given point in a region defining one cycle of variation of the composite magnetic field and with each said set being disposed at a 10 corresponding point in a region defining a respective other cycle of the composite field, said means further comprising a plurality of magnetic correction plates equal in number to the number of cyclic variations of the magnetic

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field and spaced symmetrically in the cyclotron magnetic field region about the cyclotron axis.

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