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Delphin et al.

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[54] **MAGNETIC FOCUSING DEVICE FOR AN ISOCHRONOUS CYCLOTRON**

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[73] Assignee: **Thomson-CSF,** Paris, France

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[52] **U.S. Cl.** **335/210,** 313/62, 328/234

[51] **Int. Cl.** **H01t 7/00**

[58] **Field of Search** 335/210, 297; 328/234; 313/62

[56] **References Cited**

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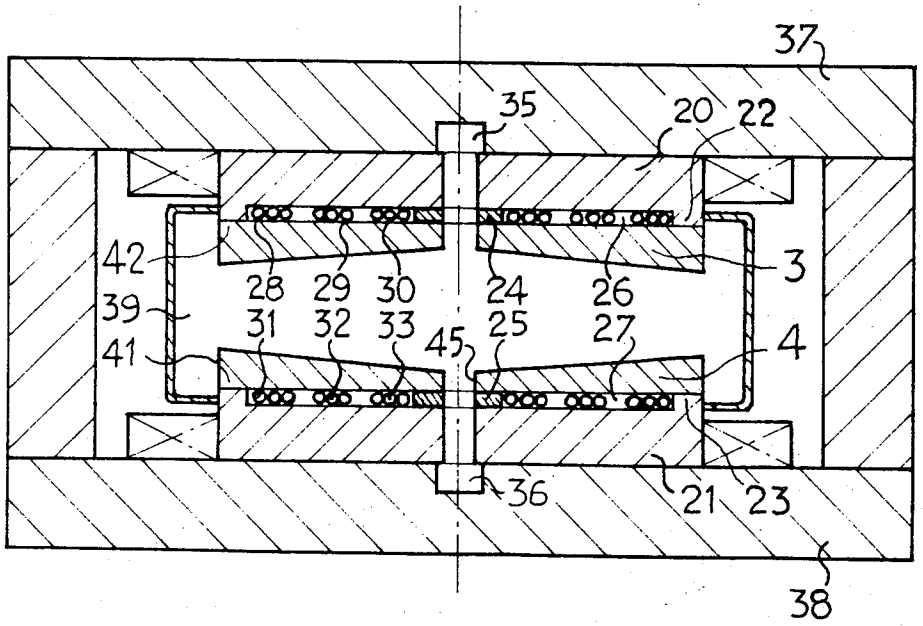
Primary Examiner—George Harris

Attorney, Agent, or Firm—Cushman, Darby & Cushman

[57] **ABSTRACT**

This device makes it possible to secure a major improvement in the efficiency of particle accelerators of the isochronous cyclotron type. It comprises a soft magnetic yoke, two circular soft-iron plates protuding from said yoke, first and second sets of soft magnetic sectors facing each other and building up the main air-gap of the device, these sectors being respectively carried by two plates, two annular spacings being respectively provided between the sectors and their carrying plate, and correcting magnetic means being positioned within said annular spacings.

9 Claims, 5 Drawing Figures



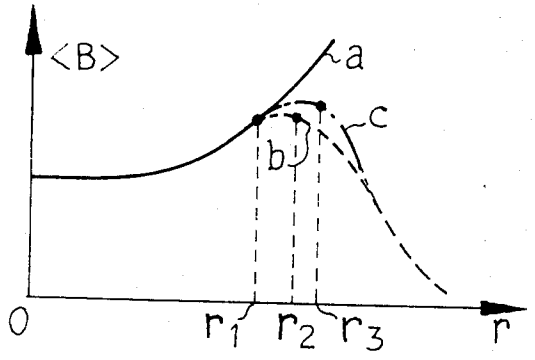


Fig. 1

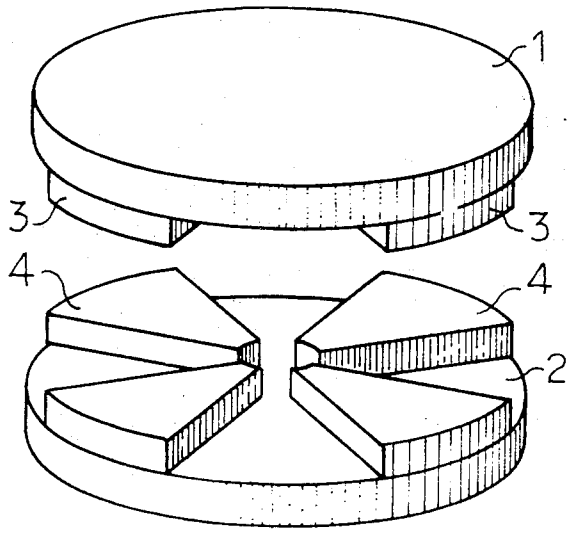


Fig. 2 PRIOR ART

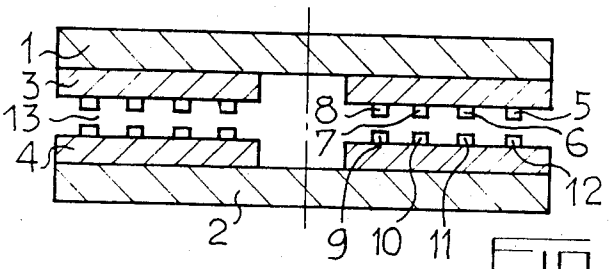


Fig. 3 PRIOR ART

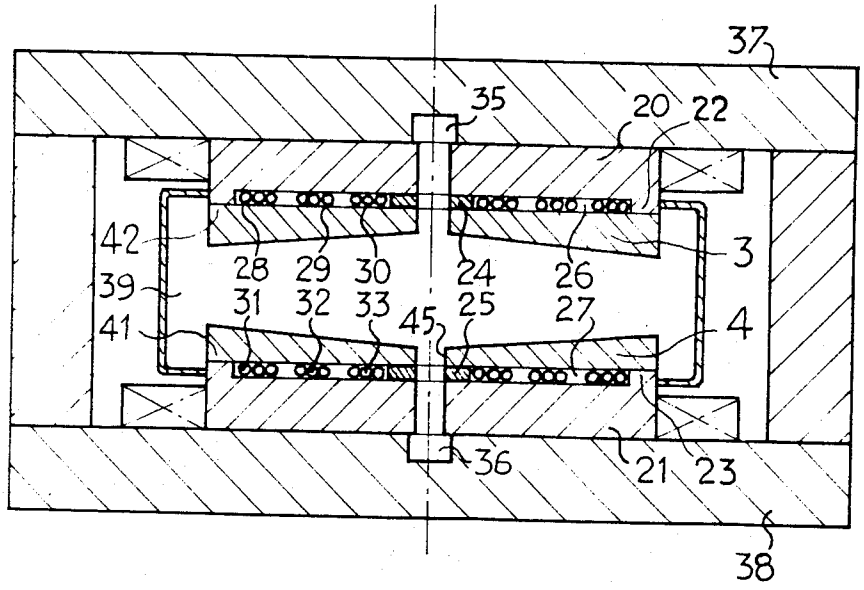

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FIG. 4

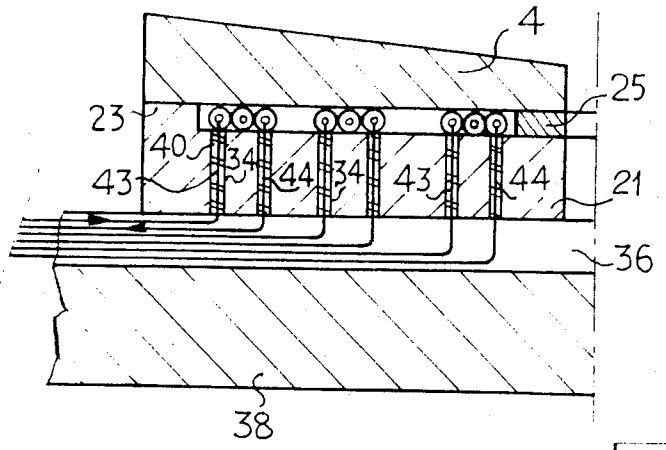

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FIG. 5

MAGNETIC FOCUSING DEVICE FOR AN ISOCHRONOUS CYCLOTRON

In an isochronous cyclotron, the magnetic flux density B calculated along an equilibrium trajectory of the particles, and considering a 360° rotation of said trajectory, should obey the law :

$$B = \frac{B_0}{\frac{\sqrt{\omega_0^2 r^2}}{c^2}}$$

where B_0 is the flux density at the centre of the cyclotron, r the mean radius of the trajectory, c the velocity of light and ω_0 the cyclotron angular frequency of the particles namely $\omega_0 = q\ B_0/m$, where q/m is the ratio between the charge and the mass of the particle. The cyclotron will operate satisfactorily if the radia frequency $\omega = q\ B_R/m$ of the particles, in the successive trajectories, is equal to the frequency ω_0 of the H.F. acceleration power source, that is to say if the measured magnetic flux density B_R at a given point in the trajectory is equal to the theoretical magnetic flux density B calculated at that point.

However, a substantial variation in the magnetic field is generally observed in the neighbourhood of the edges of the polepieces of the electro-magnet. This variation is dependent upon the structure of the polepieces and upon their magnetic saturation, thus upon the magnetomotive force of the electromagnet.

In accordance with the present invention, the special configuration of the polepieces, enables these drawbacks to be overcome.

The object of the invention is a magnetic focusing device for particle accelerators of the isochronous cyclotron type, capable of exciting within a main air gap a controlled magnetic field, said device comprising : a soft magnetic yoke, a first circular soft-iron plate protuding from said yoke and having a first face, a second circular soft-iron plate protruding from said yoke and having a second face facing said first face, first and second sets of soft magnetic sectors building up said main air gap and respectively carried by said first and second faces, and correcting means, a first annular spacing being provided between said first face and said first set of magnetic sectors **1**, a second annular spacing being provided between said second face and said second set of magnetic sectors **1**, said correcting magnetic means being positioned within said annular spacings.

The invention will be better understood and other of its features rendered apparent, from a consideration of the ensuing description and of the drawings relating thereto, in which :

FIG. **1** simultaneously shows the variations in the theoretical magnetic flux density (curve *a*), the variations in the flux density obtained in the main air gap when using conventional pole pieces (curve *b*) ; and the variations in magnetic flux density obtained in the main air gap with pole pieces in accordance with the invention (curve c). The variations are sketched in relation to radius of said pole pieces.

FIGS. **2** and **3** illustrate a conventional pole piece design currently used in isochronous cyclotrons.

FIG. **4** illustrates an electro-magnet equipped with pole pieces in accordance with the invention.

FIG. **5** illustrates a detail of a pole piece in accordance with the invention.

In the various figures, similar element have been indicated by the same references.

FIG. **1** shows, versus the radius r of the particle trajectory : the theoretical values of the magnetic flux density required for the proper operation of an isochronous cyclotron, and the measured magnetic flux density produced by a conventional electro-magnet (curve *b*), and the measured magnetic flux density produced by an electro-magnet equipped with pole pieces in accordance with the invention (curve *c*).

The limiting radius of this particle trajectory is fixed by the phase-shift which can be tolerated between the accelerating voltage and the instant of penetration of the particle within said accelerating source. However, this phase-shift is due in major part to the difference which exists between the measured magnetic flux density and the theoretical flux density, when moving away from the centre of the pole pieces.

The structure of the pole pieces in accordance with the invention makes it possible to obtain, for a larger radius (*c* curve in FIG. **2**), a measured magnetic field strength which closely fits to the theoretical magnetic field strength, thus allowing a larger limiting radius.

In order to make it easier to understand the object of the invention, pole pieces of the kind conventionally employed in isochronous cyclotrons, have been illustrated in FIG. **2**.

These pole pieces are constituted by two circular plates **1** and **2** of magnetic material (soft iron), respectively carrying a projecting first set of soft magnetic sectors **3** a second set of soft magnetic sectors **4**. The sectors **3** fixed to four plate **1** and four sectors **4** fixed to the plate **2** are shown in the example chosen here. These sectors are located opposite one another. Annular, concentric coils **5, 6, 7, 8** are arranged below sectors **3** as FIG. **3** shows, the centre of curvature of these coils being coincidental with the centre of curvature of the plate **1**. Similarly, annular concentric coils **9, 10, 11** and **12** respectively identical to the coils **5, 6, 7** and **8** and disposed in opposite fashion, are arranged on the sectors **4** fixed to the plate **2**. The spacing between the two sets of coils constitutes the main air gap **13** of the electro magnet.

FIG. **4** illustrates an electro-magnet equipped with circular pole pieces or plates **20** and **21** in accordance with the invention.

These plates **20** and **21** are respectively provided, along the periphery of their mutually opposite faces, with projecting annular rings **22** and **23** of rectangular cross-section, these rings being integral with these plates.

The peripheral parts **41** and **42** of the magnetic material (soft iron) sectors **3** and **4** are attached onto these rings, the apices **45** of these sectors being oriented towards the centre of the carrying plates **20** and **21**. These sectors **3** and **4** are maintained parallel to the plates **20** and **21** which respectively support them, by means of spacers **24** and **25** of non-magnetic material, aluminum for example, the thickness of said spacers being substantially equal to the height of the rings. Thus, first and second annular spacings **26** an **27** are respectively obtained between the sectors **3** and **4**, and each of the plates to which they are attached. these spacings constitute secondary air gaps, within which are arranged respective annular windings **28, 29, 30** and **31, 32, 33** of insulated metallic wires. The input and output ends **43** and **44** of these windings pass through holes **34** drilled in the plates. These holes **34** are drilled parallel to the axis of the circular plates in

a manner shown in FIG. 5. The plates 20 and 21 pertain to the vacuumtight walls of the evacuated chamber 39 and the holes 34 are sealed off through the medium of epoxy resin beads 40 which fix the ends of the wires in the holes 34. The wire ends, after crossing the plates 20 and 21, enter grooves 35 and 36 milled in the yokes 37 and 38 of the electro-magnet. The evacuated chamber 39 is thus completely free from any coils or wires.

The magnetic focusing device in accordance with the invention makes it possible to achieve a suitable magnetic flux density in the neighbourhood of the periphery of the polepieces, the saturation phenomenon being in this case very weak.

The soft-iron sectors 3 and 4 as shown in FIGS. 2 and 3, and also those shown in FIGS. 4 and 5, are all designed to produce vertical focusing of the particle beam through the creation of alternate regions wherein the flux density is alternately high and low. The profile of these sectors, as FIGS. 4 and 5 show, is calculated in order to produce a measured magnetic field which is as close as possible to the theoretical magnetic field. In the present embodiment, the distance separating the sectors 3 and 4 facing one another, decreases from the centre of the pole pieces towards their periphery.

Thus, the two identical sets of concentric annular coils, known as correcting coils, which are conventionally arranged below sectors 3 and 4 and located within the main air gap, as shown in FIG. 3, are replaced, in the device in accordance with the invention, by windings located within the secondary air gaps 26 and 27 respectively built up between plates 20, 21, and sectors 3, 4 as FIG 4 shows. These windings make it possible to locally correct the discrepancies existing between the theoretical magnetic field and the measured magnetic field, these discrepancies being due to saturation of the magnetic material and to mechanical imperfections in the electro-magnet.

In accordance with the invention, the number and proper choice of the position of these two sets of windings make it possible to very substantially reduce the rapid variations of the magnetic field value.

The invention is not limited to the example which has been described and illustrated here ; in particular, the sectors may have other profiles. The same applies to the correcting rings 22, 23 of plates 20, 21, which rings may have a section differing from that indicated hereinbefore.

What we claim is :

1. A magnetic focusing device for particle accelerators of the isochronous cyclotron type, capable of exciting within a main air gap a controlled magnetic field, said device comprising : a soft magnetic yoke, a first circular soft-iron plate protruding from said yoke and having a first face, a second circular soft-iron plate protruding from said yoke and having a second face facing said first face, first and second sets of soft magnetic sectors building up said main air gap, said first and second sets of soft magnetic sectors being respectively carried by said first and second faces, and correcting means, a first annular spacing being provided between said first face and said first set of magnetic sectors, a second annular spacing being provided between said second face and said second set of magnetic sectors, said correcting magnetic means being positioned within said annular spacings.

2. A device as claimed in claim 1, wherein said correcting means comprise at least one pair of annular identical windings respectively located within said first and second annular spacings ; said annular windings being centered in relation with said faces.

3. A device as claimed in claim 1, wherein said correcting means comprise at least two concentric pairs of annular identical windings, constituted with insulated metallic wires.

4. A device as claimed in claim 1, wherein said sets of magnetic sectors are coupled to the edges of said plates through magnetic conducting elements.

5. A device as claimed in claim 4, wherein said magnetic conducting elements are circular rings integral with said plates.

6. A device as claimed in claim 4, wherein the apices of said sectors are mechanically coupled to said face through spacers of non-magnetic material.

7. A device as claimed in claim 1, wherein said plates comprise vacuumtight means for providing control of said correcting magnetic means.

8. A device as claimed in claim 2, wherein the ends of said windings pass through holes of said plates , said holes being sealed by vacuumtight means.

9. A device as claimed in claim 1, wherein the distance separating said two sets of soft magnetic sectors decreases from the apices of said sectors towards their edges.

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