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Hendry

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[54] **ELECTROSTATIC EXTRACTION METHOD AND APPARATUS FOR CYCLOTRONS**

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[52] **U.S. Cl.** **313/62;** 328/234
[51] **Int. Cl.** **H05l 13/08**
[58] **Field of Search** .... 313/62; 328/234; 250/49.5 ME

[56] **References Cited**

UNITED STATES PATENTS

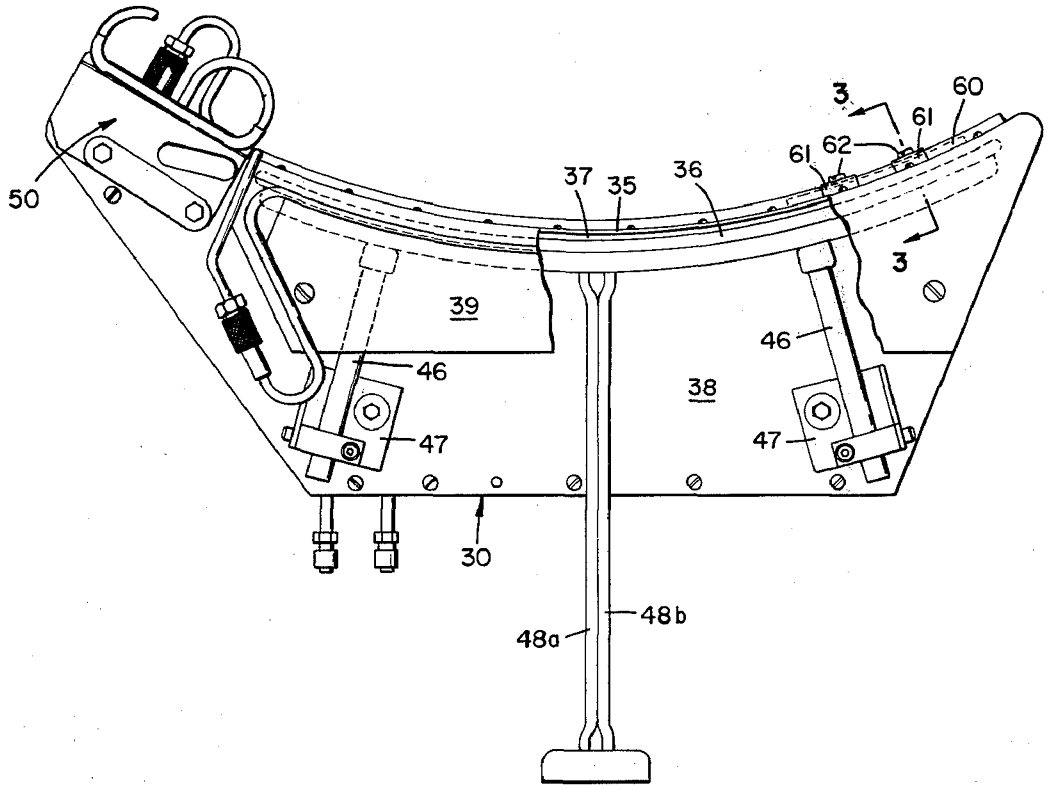
3,382,391	5/1968	Reich	313/62
3,398,308	8/1968	Steimel	313/62
3,582,700	6/1971	Hendry	328/234
3,624,527	11/1971	Hudson	313/62

Primary Examiner—James W. Lawrence
Assistant Examiner—B. C. Anderson

[57] **ABSTRACT**

A method and apparatus for electrostatically extracting high beam currents at improved energy from small diameter, high magnetic field cyclotrons by deflecting particles from their trajectory within an electrostatic field traversing an extraction channel wherein magnetic material immediately adjacent to the inside of at least a portion of the channel first reduces the fringe field and then reverses its normal gradient to assist in extraction and to focus the extracted beam radially with respect to the center of the cyclotron.

3 Claims, 4 Drawing Figures



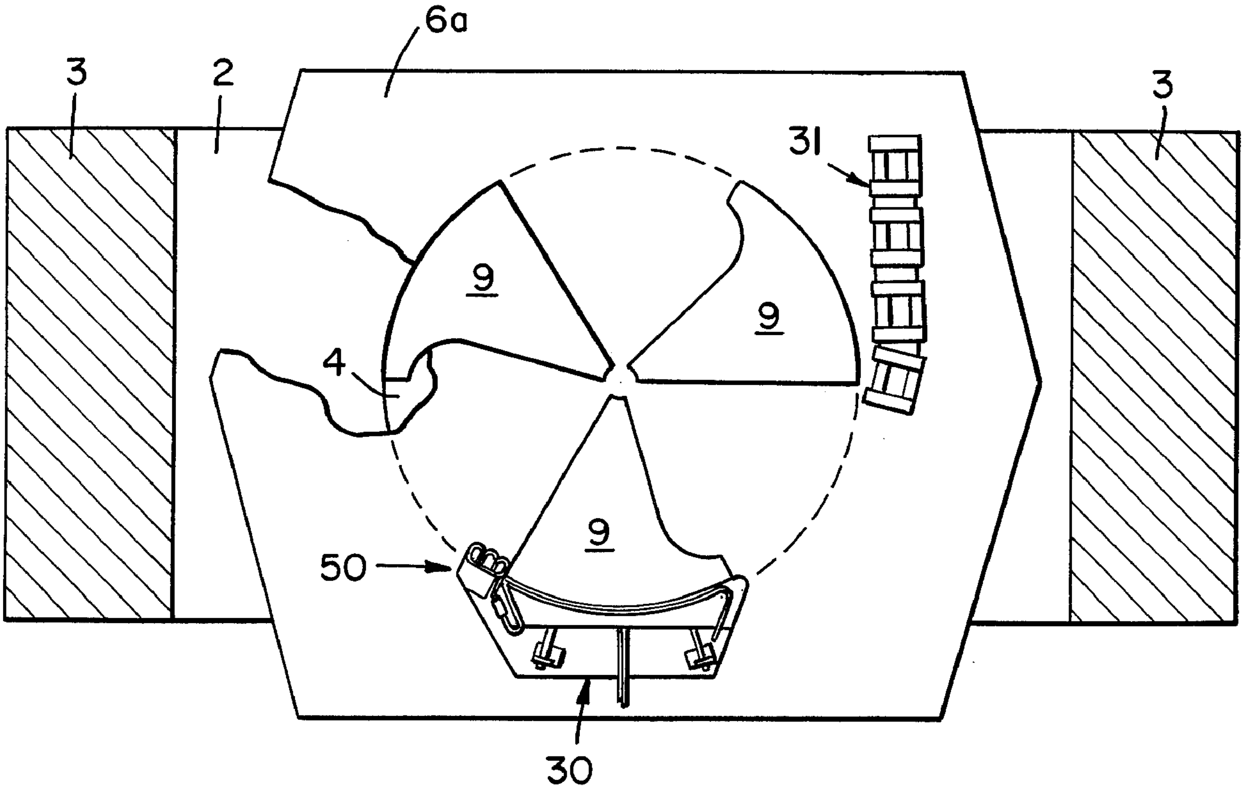

6a
3
2
3
31
9
9
4
9
50
30

FIG_1

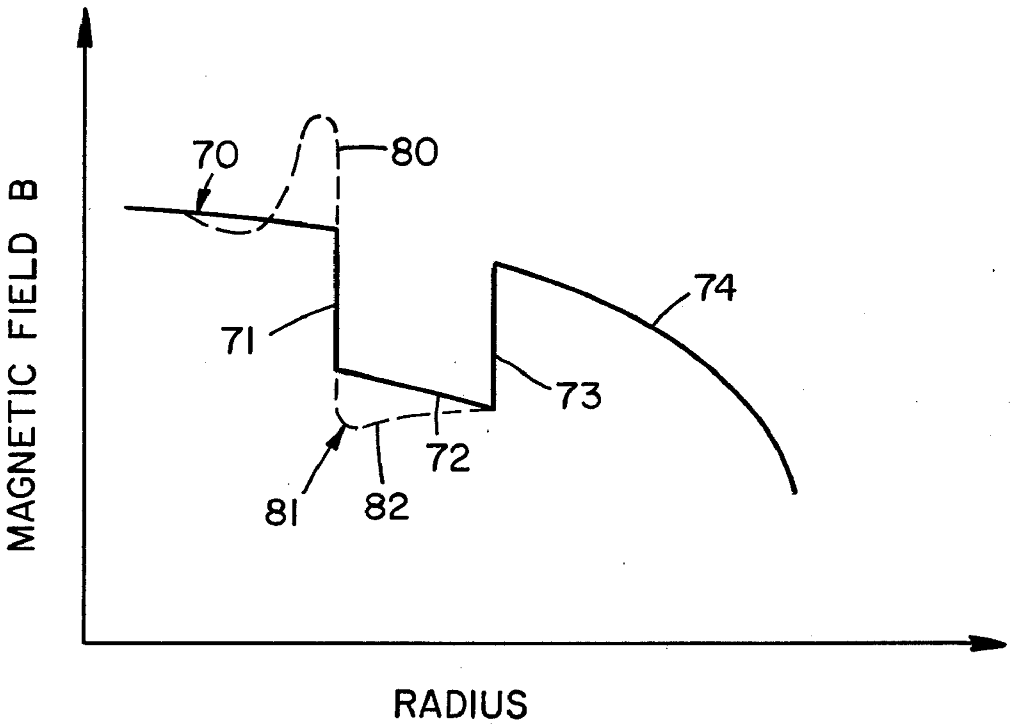

MAGNETIC FIELD B
70
80
74
71
73
72
81
82
RADIUS

FIG_4

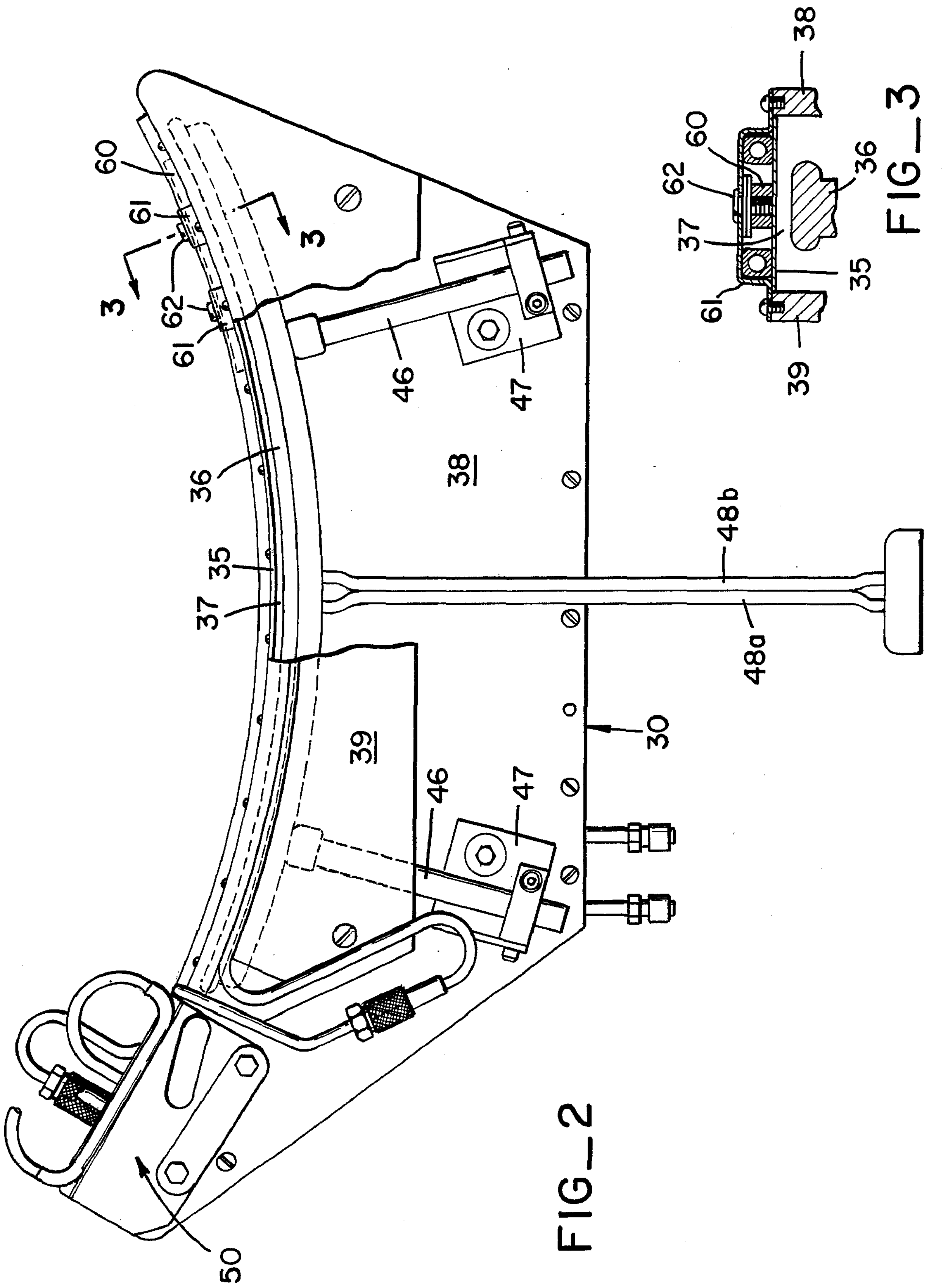

60
61
62
3
61
3
36
35
37
38
39
46
47
48b
48a
30
50
38
60
62
37
36
35
61
39

FIG_2

FIG_3

ELECTROSTATIC EXTRACTION METHOD AND APPARATUS FOR CYCLOTHRONS

This invention relates generally to beam extraction from cyclotrons and more particularly to a method and means for extracting a high-energy high quality beam from small diameter isochronous cyclotrons.

One object of this invention is to increase the amount and quality of beam current available from a small diameter, high magnetic field isochronous cyclotron.

Another object of this invention is to provide a method and means for enabling electrostatic deflection of a beam of higher energy particles from an isochronous cyclotron of any fixed diameter.

Other objects and advantages of this invention will become apparent from a consideration of the following description in connection with the accompanying drawings wherein

FIG. 1 is a partially schematic cross-sectional view of a typical isochronous cyclotron at its median plane;

FIG. 2 is a plan view of the electrostatic deflection assembly of this invention;

FIG. 3 is a cross-sectional view of a portion of the electrostatic deflection assembly taken along line 3—3 of FIG. 2; and

FIG. 4 is a curve plotting fringe magnetic field strength (B) of the cyclotron against radius in the region of the extraction radius.

This invention relates to electrostatic extraction methods and apparatus, for example, like those known for isochronous cyclotrons generally disclosed in U.S. Pat. No. 3,582,700 entitled Cyclotron Beam Extraction System and in copending application Ser. No. 118,751 entitled Improved Cyclotron Beam Extraction filed on Feb. 25, 1971 by George O. Hendry and Dale K. Wells, now U.S. Pat. No. 3,725,709. The external beam current of the isochronous cyclotrons therein described for a fixed cyclotron diameter can be produced at higher energy, increased in amount and improved in quality by the present invention wherein magnetic material is placed along at least a portion of the electrostatic deflection channel. The magnetic material concentrates the lines of magnetic force of the fringe field of the cyclotron, first to reduce that field at the electrostatic deflection channel and thereby assist in deflection and second to reverse the fringe field gradient so that it tends to focus the extracted beam of particles radially with respect to the center of the cyclotron.

FIG. 1 illustrates the orientation of the electrostatic deflection assembly of this invention with respect to the other components of a typical small isochronous cyclotron at its median plane. A main d-c electromagnet defines a magnetic guide field for the particles orbiting within the evacuated region of the cyclotron. The main d-c magnet includes a lower yoke slab **2**, a pair of interconnecting iron legs **3** and two cylindrical iron pole bases **4**, the lower one of which is shown in FIG. **1**. In the described embodiment the lower pole tip is warp plate 6b that, with sidewalls and with a similar upper warp plate, forms a vacuum tank within which charged particles are accelerated in the machine.

Three shaped hill pieces **9** mount on each of the warp plates in corresponding locations to produce the azimuthally varying field necessary for isochronous operation. A pair of hollow 120° dees within the vacuum tank provides a radio frequency accelerating field and an ion source supplies ions for acceleration in the central region of the cyclotron between the two dees all as is more fully described in U.S. Pat. No. 3,582,700.

In the described embodiment the extraction system includes electrostatic deflection means **30** and a magnetic channel **31** which receives and radially focuses a beam of ions deflected by the electrostatic deflection means. Also a preseptum unit **50** mounts adjacent to the electrostatic deflection means **30** at the extraction radius and precedes it with respect to the path of orbiting particles as is more fully described in copending application Ser. No. 118,751 now U.S. Pat. No. 3,725,709.

FIGS. 2–3 show the improved electrostatic deflection assembly of this invention in detail. It includes a thin curved tungsten septum **35** maintained at ground potential and a curved deflector electrode **36** which is held at a high negative potential (for positively charged, accelerated particles). The septum **35** and deflector electrode **36** define between them a shaped electrostatic deflection channel **37** with a high electric field gradient which is located so it increases in radius with respect to the center of the cyclotron. When traversed by the orbiting particles segregated by the preseptum **50,** the electrostatic field forces the particles to move to a larger radius where they no longer are held in a circular path by the main magnet.

The septum and deflector electrode are carefully shaped and located so that the segregated beam remains centered in the channel as it moves to greater radius. Both mount upon a water cooled non-magnetic base plate **38** on one of the hill pieces **9** as shown in FIG. **1.** The septum **35** clamps to the base plate **38** and an upper cooling plate **39.** A pair of alumina insulators **46** cantilevered from brackets **47** support the hollow copper deflector electrode **36** from base plate **38.** Electrode **36** is cooled by water coolant supplied to its interior through hollow electrical conductor **48***a* and returned through conductor **48***b*. The same conductors **48***a*, **48***b* provide high negative potential to the electrode from its power supply.

After leaving the electrostatic channel **37** the beam of extracted particles follows a path of increasing radius and is focused radially by magnetic channel **31.**

While output beam currents in the order of 50 microamperes of 22 MeV protons can be obtained in a 30 inch cyclotron with the described electrostatic deflection means alone, an improvement in external beam energy for the same cyclotron diameter in the order of 50 microamperes at 30 MeV protons can be obtained by placement of magnetic material inside at least a portion of the electrostatic deflection channel **37.** As is more particularly shown in Figs. **2** and **3,** this magnetic material can be in the form of an iron bar **60** clamped to septum **35** at its terminal end from which the extracted beam leaves channel **37.** In the described embodiment, for example, iron bar **60** is secured to the septum **35** by a pair of clamps **61** to which it is held by cap screws **62.**

The presence of the magnetic material concentrates the lines of force of the fringe magnetic field of the machine through it, first to reduce the fringe field just radially beyond it and to assist the electrostatic deflection and second to reverse the gradient of the fringe field and focus the extracted particles radially with respect to the center of the cyclotron.

For example, in FIG. **4** the curve **70** shown in solid lines depicts the normal fringe magnetic field (B) plotted against the machine radius in the region of the extraction radius. At the entrance to the electrostatic channel **37**, the electric field across it normally reduces the net fringe field as shown in the vertical portion **71** of the curve **70**. The net field then has a normally reducing gradient as at **72** of the same slope as the fringe field would have without the effect of the uniform electrostatic field. At the terminal end of the channel the electrostatic field no longer has any effect and the net fringe field returns verticallly at **73** to its normal value along curve **74**.

With the magnetic material of this invention in place, however, the normal fringe field in the region of the extraction radius is modified as shown in hidden lines in FIG. **4**. The net field increases as at **80**, then drops vertically along **71** to a value **81** less than that normally reached without the iron in place. Then, the normally decreasing gradient through the channel at **72** is reversed so that, as one moves radially, the net field has an increasing gradient as at **82** to the end of the channel where the curve resumes the same shape **73** as in normal operation.

The specific iron placement of this invention is shown for illustrative purposes only. The iron bar may vary in size or shape or may extend further along the septum. In practice it has been found that the iron should extend as far as possible along the channel to produce the effects described, but should not be so long as to have the internally orbiting particles impinge upon it which are not segregated by the septum and preseptum and directed through the electrostatic channel. Those and various other modifications will be apparent to those skilled in the art within the scope of the invention defined in the following claims.

I claim:

1. Improved apparatus for electrostatically deflecting a beam of charged particles at an extraction radius in

the fringe magnetic field of an isochronous cyclotron comprising

means defining an electrostatic field across a deflection channel at the extraction radius, the location of said field increasing in radius with respect to the center of the cyclotron; and

magnetic material positioned inside and adjacent to at least a portion of said channel to reduce the cyclotron fringe field at the channel and to focus the beam of charged particles radially with respect to the center of the cyclotron, by concentrating the lines of magnetic force of said fringe field inwardly of but immediately adjacent to said channel to reduce said fringe field and then to reverse the normally decreasing field gradient in said channel.

2. The apparatus of claim **1** wherein the means defining an electrostatic field includes a thin curved septum and a curved deflector electrode which define between them a shaped deflection channel with a high electric field gradient across it and the magnetic material is positioned along inside of at least a portion of said septum.

3. An improved method for electrostatically deflecting a beam of charged particles at an extraction radius in the fringe magnetic field of an isochronous cyclotron comprising the steps of

defining an electrostatic field within a channel at the extraction radius which increases in radius with respect to the center of the cyclotron; and

placing a magnetic member along at least a portion of said channel to concentrate the lines of magnetic force of said fringe field inwardly of but immediately adjacent to said channel to reduce said fringe field and then to reverse the normally decreasing field gradient in said channel.

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