United States Patent

[11] 3,582,700

[72] Inventor George O. Hendry
Napa, Calif.
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[73] Assignee Cyclotron Beam Ertraction System
Berkeley, Calif.

[54] **CYCLOTRON BEAM EXTRACTION SYSTEM**
5 Claims, 8 Drawing Figs.

[52] **U.S. Cl.** **313/62,** 328/234
[51] **Int. Cl.** **H05h 13/08**
[50] **Field of Search** 313/62; 328/234

[56] **References Cited**
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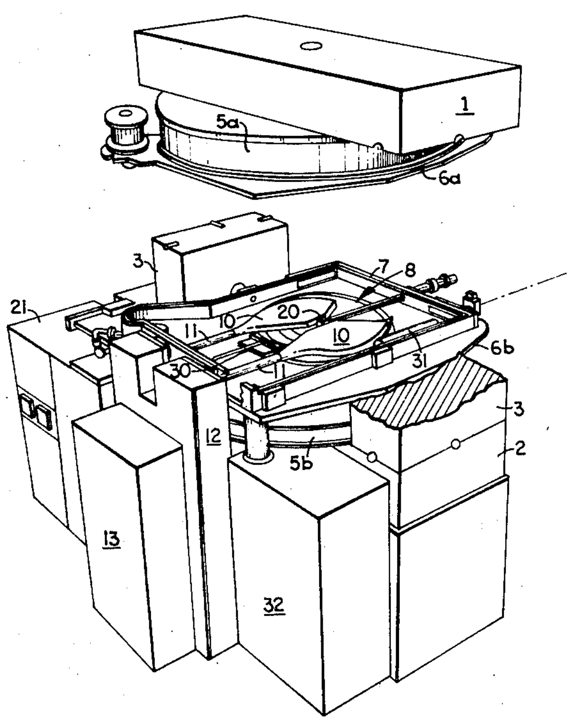
3,024,379 3/1962 Verster 313/62

Primary Examiner—Raymond F. Hossfeld
Attorney—Eckhoff and Hoppe

ABSTRACT: A method and apparatus for extracting a high-quality beam from an isochronous cyclotron by electrostatic deflection of a beam of charged particles from orbit and subsequent exposure of the beam within the evacuated region of the cyclotron to a reverse gradient in the normally declining fringe magnetic field.



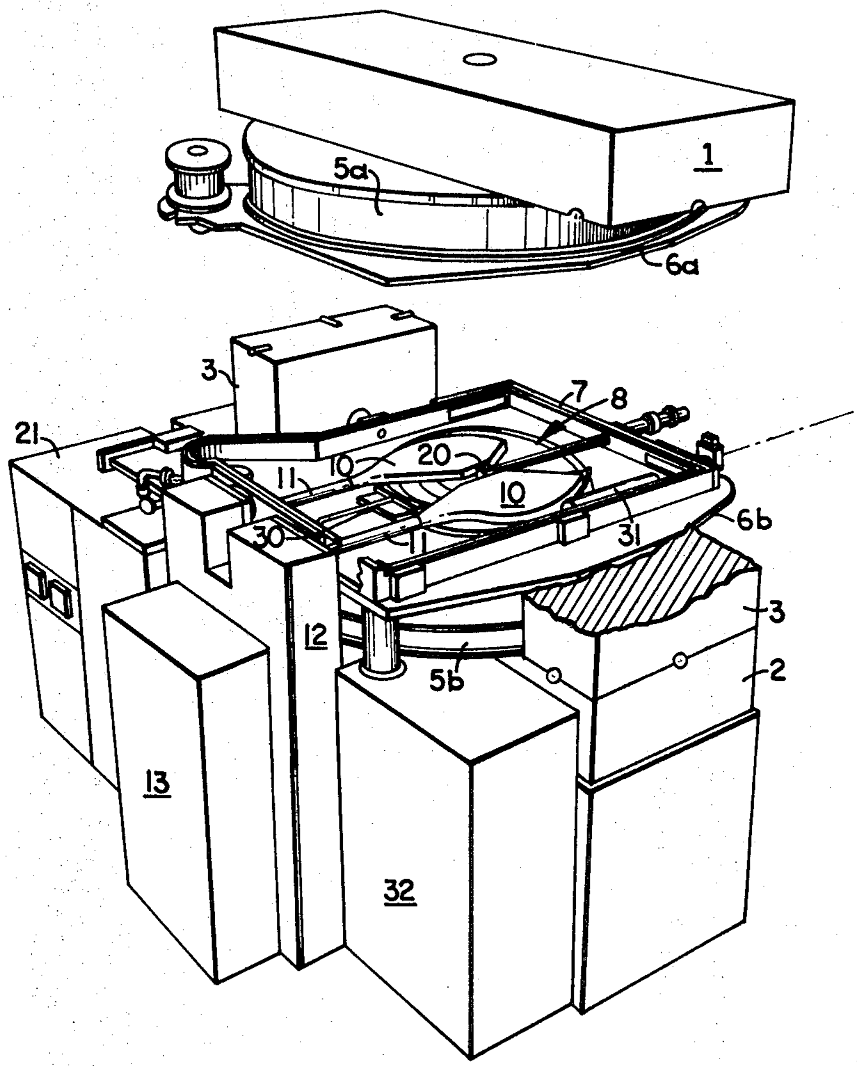


FIG_1

INVENTOR.
GEORGE O. HENDRY
BY Eckhoff and Hoppe
ATTORNEYS

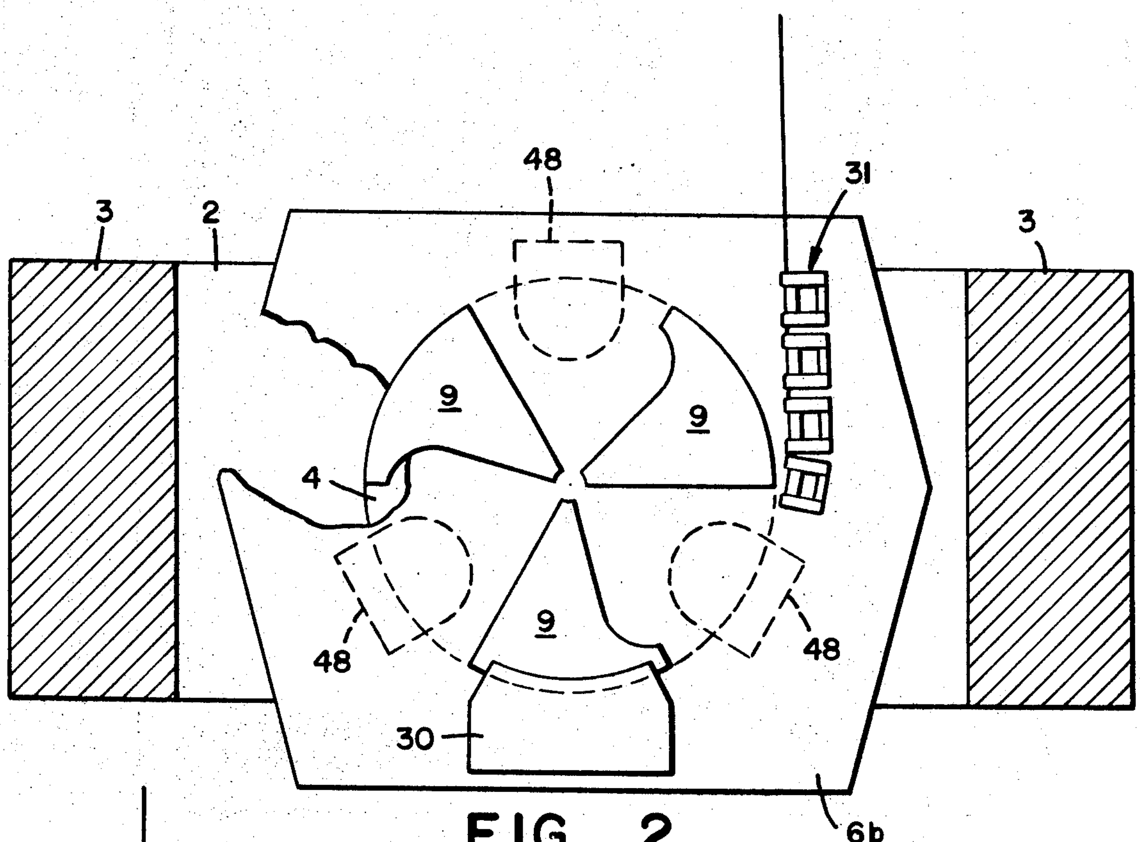


FIG_2

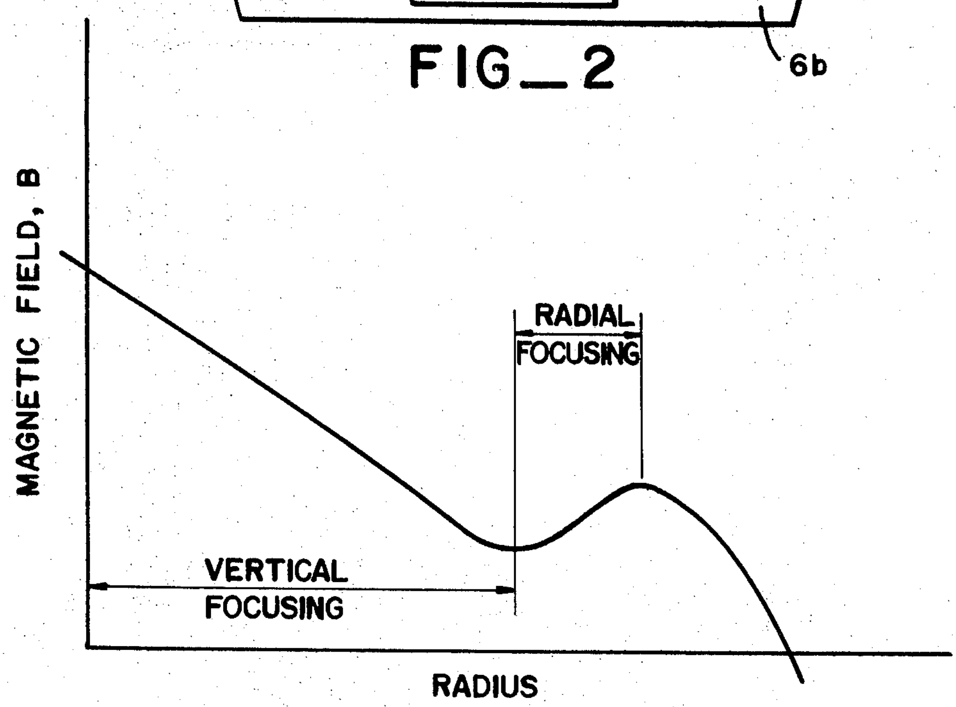


FIG_8

INVENTOR.
GEORGE O. HENDRY
BY Eckhoff and Hoppe
ATTORNEYS

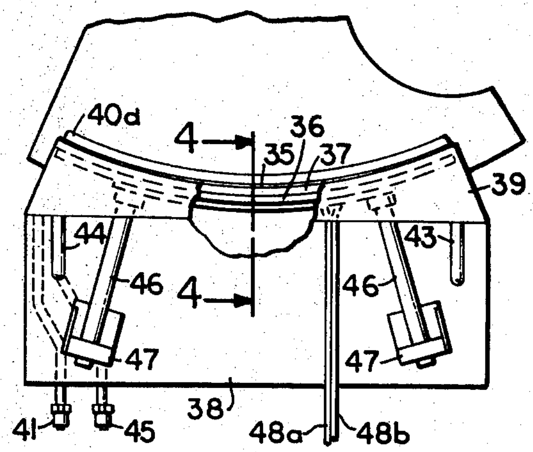


FIG_3

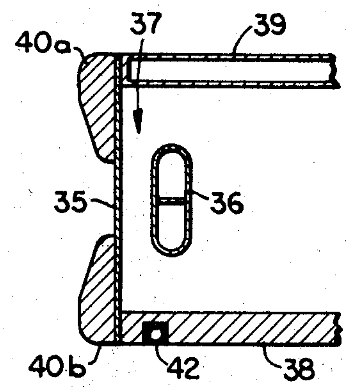


FIG_4

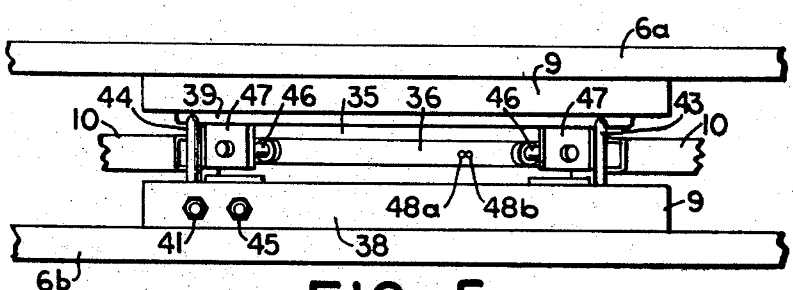


FIG_5

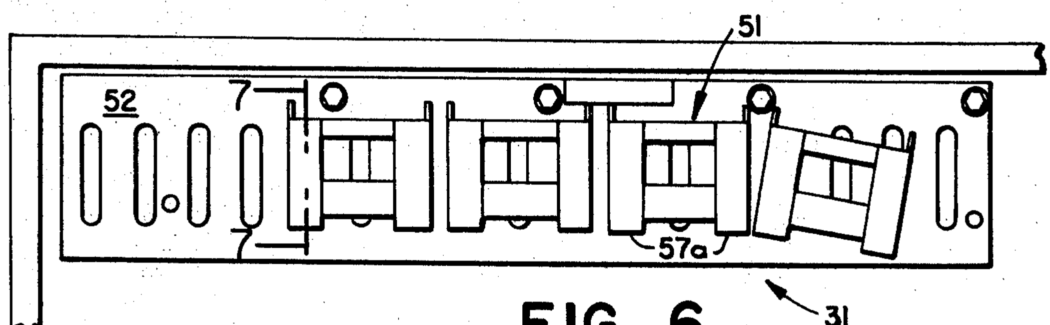


FIG_6

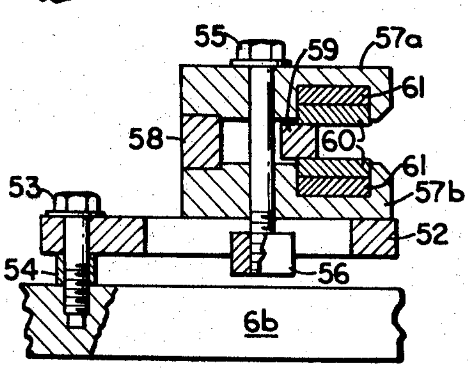


FIG_7

INVENTOR.
GEORGE O. HENDRY

BY Eckhoff and Hoppe
ATTORNEYS

CYCLOTRON BEAM EXTRACTION SYSTEM

This invention relates generally to beam extraction from isochronous cyclotrons and more particularly to a method and means for extracting a high-quality radially focused beam from such cyclotrons.

One object of this invention is to provide a high-quality beam from an isochronous cyclotron.

Another object of this invention is, within the vacuum tank of an isochronous cyclotron, to radially focus the extracted beam which normally defocuses in the fringe magnetic field of the cyclotron.

Still another object of this invention is to provide method and means within the fringe field of an isochronous cyclotron to develop a reverse gradient in that field to radially focus an extracted beam of charged particles.

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

FIG. 1 is an overall perspective view of a small compact isochronous cyclotron which employs the extraction system of this invention;

FIG. 2 is a partially schematic sectional view of the cyclotron of FIG. 1 at its median plane;

FIG. 3 is a detailed plan view of the electrostatic deflection means of the cyclotron of FIG. 1;

FIG. 4 is a sectional view of the electrostatic deflection means taken along line 4—4 of FIG. 3;

FIG. 5 is a rear elevational view of the electrostatic deflection means of FIG. 3;

FIG. 6 is a top view of one embodiment of radial focusing means useful in the described system;

FIG. 7 is a cross-sectional view of the radial focusing means taken along line 7—7 of FIG. 6; and

FIG. 8 plots fringe magnetic field strength versus orbital radius to show the effect of the system of this invention on the magnetic field of the cyclotron.

FIG. 1 illustrates the general layout and components of a small diameter, azimuthally varying field, isochronous cyclotron with the top part of the magnet assembly raised for clarity of illustration. The described machine includes a main DC electromagnet including the upper iron yoke slab **1**, a lower iron yoke slab **2**, two interconnecting iron legs **3** and two cylindrical iron pole bases **4**, one on each of the upper and lower yoke slabs respectively, and one of which is shown on FIG. 2. These iron components are doweled and assembled into a unitary magnetic core.

An upper water-cooled DC magnet coil **5***a* embraces the upper pole base and a lower magnet coil **5***b* embraces the lower pole base **4** within legs **3**. The pole tips are warp plates **6***a*, **6***b* bolted to the pole bases which, with sidewalls **7**, form the vacuum tank **8** within which 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. FIG. 2 illustrates one set of the shaped hill pieces **9** on the lower warp plate **6***b*. A corresponding set bolts to the warp plate **6***a* over the upper pole base **4**.

A pair of hollow 120° dees **10** within the vacuum tank provides a radiofrequency accelerating field. The dee stems **11** connect via conductor means to resonator tank **12**. Oscillator **13** supplies radiofrequency energy to the dees. An ion source **20** supplies ions for acceleration in the central region between the two dees **10**. Ion source **20** in the described embodiment may use ion-heated cathodes to generate ions in the central region as described in "A Small Cold-cathode High-intensity Cyclotron Ion Source" by D. K. Wells in IEEE Transactions on Nuclear Science, June 1967, pages 70—71. Vacuum means as at **21** evacuates the interior of vacuum tank **8**.

The DC magnet provides a field within the machine which increases with increasing radius. Cyclic acceleration of the ions emitted from ion source **20** in the central region is achieved by the hollow dee electrodes **10** within the magnetic field between the pole bases of the magnet. The high-voltage radiofrequency energy supplied to the dees **10** alternately reverses the field across the gaps between them each time the emitted ions revolve 180°. Accordingly, at each gap crossing the ions accelerate through the existing potential difference between the two dees. Each ion coasts at constant speed within the interior region of each dee free from the electric field while the uniform magnetic field bends its path into a semicircle. At each acceleration step the radius of the orbit for each ion increases so that the particle ultimately spirals out to the boundary of the magnetic field. That field guides the particle radially many times through the radiofrequency electric accelerating field and, thus, its final energy is the sum of the individual energies gained at each crossing of the dee gaps.

Vertical focusing of the orbiting ions in the described cyclotron is provided by the three hill sectors **9** of increasing curvature which develop sectors of stronger field alternating with intermediate sectors of weaker field. The hill and valley regions at their boundaries develop a component of magnetic field which directs orbiting ions that may be off the median plane back toward the median plane as has been described by L. H. Thomas in *Physics Review* (1938) Volume 54, page 580.

All of the foregoing is generally known in the cyclotron art. In the described embodiment the extraction system comprises electrostatic deflection means **30**, located between the dees **10** and a magnetic channel **31** which receives and radially focuses a beam of ions deflected by the electrostatic deflection means. High-voltage DC power supply **32** supplies a constant high-voltage potential to electrostatic deflection means **30**. The potential is negative for positively charged ions and vice versa.

An embodiment with a negative potential is shown in FIGS. 3—5. The electrostatic deflector assembly mounts at the median plane of machine between the dees **10** and overlying a hill piece **9** of the main magnet. The deflection means **30** comprises a 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) by power supply **32**. The septum **35** and deflector electrode **36** define between them a shaped electrostatic channel **37** with a high electric field gradient which, when traversed by a beam of orbiting particles, forces the ions to move to a larger radius where they no longer are held to a circular path by the main magnet.

The septum and deflector electrode are carefully shaped and located so that the extracted beam remains centered in the channel as it moves to greater radius. Both mount upon a water-cooled nonmagnetic baseplate **38** pivotally mounted on one of the hill pieces **9**. The septum **35** is clamped to the baseplate **38** and an upper cooling plate **39** by means of heat-conductive clamp bars **40***a*, **40***b*, respectively. Coolant admitted at inlet **41** circulates through conduit **42** imbedded in baseplate **38**, through tube **43** into upper cooling plate **39** in series and then leaves through return tube **44** and outlet **45**.

A pair of alumina insulators **46** cantilevered from brackets **47** support the hollow copper deflector electrode **36** from baseplate **38**. The electrode is also cooled by coolant supplied to its interior through hollow electrical conductor **48***a* and returned through hollow electrical conductor **48***b*. These same conductors **48***a*, **48***b* provide the high electrical potential to the electrode from power supply **32**.

The baseplate **38** of the deflector means can be pivoted by remote means, not shown, operable outside the vacuum tank to locate the entrance to the electrostatic channel **37** for maximum beam extraction efficiency.

Normally as ions accelerate from ion source **20** to the extraction radius, each oscillates in both the radial and vertical directions. The magnitude of these oscillations is kept small by the magnetic field to limit particle losses. The period of the oscillations is determined by the magnetic field but phase is generally random. These incoherent oscillations give height and width to the cross section of any single turn of beam current. High extraction efficiency in the described cyclotron is achieved by making the magnitude of the peak to peak amplitude of this incoherent radial oscillation similar to the spacing of septum **35** and deflector electrode **36** which define the electrostatic channel **37**.

In addition to the described oscillation, harmonic coils excite an oscillation where all ions are in phase by creating a "bump" at one azimuth in the main magnetic field. The magnetic "bump" separates adjacent turns of beam current at the peak amplitude of this coherent oscillation. Separation is progressively larger as the amplitude of oscillation increases as a function of the number of times the beam traverses the "-bump." If the oscillation were allowed to grow excessively, the beam would be lost. But the oscillation is allowed to grow only to the extent that the turn spacing is of sufficient magnitude to jump the septum. The beam, as a consequence, is very effectively steered into the electrostatic channel.

Three pairs of harmonic coils **48** are located on the pole bases of the magnet at 120° intervals inside the vacuum tank, one on each pair on opposite sides of the median plane. On of each pair appears schematically in FIG. **2**. The coils are Y-connected electrically with a delta configuration formed by three resistors interconnecting adjacent ones of the coils on the same side of the median plane. The current through the coil pairs is then a function of, and the azimuthal position of the magnetic "bump" is determined by, where the DC coil supply connects at an 180° spacing to the delta. The magnitude of the "bump" is a function of the magnitude of the coil current.

After leaving the electrostatic channel **37** the extracted beam of ions follows a path of increasing radius. The precise radius of curvature is a function of the decreasing strength of the fringe field. As indicated on FIG. **8** the decreasing gradient results in good vertical focusing, but the extracted beam normally nonlinearly defocuses radially with this same declining gradient.

In the described embodiment the magnetic channel **31** illustrated in detail in FIGS. **6** and **7** receives the beam of ions deflected by electrostatic deflection means **30** and focuses the beam radially. FIG. **8** shows that the fringe magnetic field strength, B, normally decreases with radius. Although the beam is focused vertically as a result of this decreasing gradient, the beam defocuses radially. Magnetic channel **31**, however, provides a reversal in the magnetic field gradient at that portion of the curve designated radial focusing in FIG. **8**. The increasing magnetic field developed by iron in magnetic channel **31** refocuses the beam radially.

The magnetic channel in the illustrated embodiment comprises a series of aluminum brackets **51** which hold a pair of iron bars on opposite sides of the median plane of the machine. These iron bars concentrate the lines of force in the fringe magnetic field and thus increase the field strength at the channel location. Each bracket comprises a baseplate **52** bolted to the bottom warp plate **6*b*** by a nonmagnetic capscrew **53** and nonmagnetic spacer **54**. Nonmagnetic bolt **55** and nut **56** secure a pair of nonmagnetic jaws **57*a*, 57*b*** to baseplate **52**. The jaws are spread by nonmagnetic lever bar **58** at one end and channel spacer **59** at their middle. The open ends of each of jaws **57*a*, 57*b*** carry iron bars **60** which are mounted in the jaws upon nonmagnetic shims **61**.

The specific magnetic channel disclosed is for illustrative purposes only. The describe reversal in gradient of the fringe magnetic field can be accomplished by other means such as similarly placed electromagnet coils.

It will also be apparent to those skilled in the art that other modifications may be practiced and equivalents substituted for those specific elements described above which are within the scope of the invention defined by the appended claims.

I claim:

1. A method for extracting a beam of charged particles orbiting in an isochronous cyclotron within a guiding magnetic field and evacuated region comprising

deflecting particles from orbit at an extraction radius near the fringe of said magnetic field by exposing them to an electrostatic field which increases in radius; and

then within the fringe of said magnetic field and evacuated region exposing the deflected beam to a region of magnetic field having an increasing gradient to radially focus the beam of particles.

2. The method of claim **1** including the further step of initially

separating adjacent turns of said orbiting particles by creating coherent oscillation of the particles within the turn at said extraction radius having a maximum amplitude at about said radius.

3. Apparatus for extracting a beam of charged particles orbiting in an isochronous cyclotron within a guiding magnetic field and evacuated region comprising

electrostatic deflection means defining, at an extraction radius near the fringe of said field, an electrostatic field which increases in radius to deflect particles from orbit; and

magnetic channel means, within said evacuated region and receiving said beam of deflected particles, which develops a region of increasing gradient in the fringe of said magnetic field to focus said beam radially.

4. Apparatus according to claim **3** further comprising

harmonic coil means creating coherent oscillation of the orbiting particles at said extraction radius with its maximum amplitude at the entrance to said electrostatic field.

5. The apparatus of claim **3** wherein the magnetic channel means comprises

corresponding magnetic elements above and below the median plane of the cyclotron along a portion of the curved path of the beam within said median plane.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,582,700 Dated June 1, 1971

Inventor(s) George O. Hendry

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

On the cover sheet [73] "Cyclotron Beam Ertraction System" should read -- The Cyclotron Corporation --. Column 3, line 19, "On" should read -- One --.

Signed and sealed this 7th day of March 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents