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Hudson et al.

[11] **3,867,705**

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[54] **CYCLOTRON INTERNAL ION SOURCE WITH DC EXTRACTION**

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

[51] **Int. Cl.** **H05h 7/08**, H05h 13/00

[58] **Field of Search** 328/233–238; 313/62

[56] **References Cited**

UNITED STATES PATENTS

3,624,527	11/1971	Hudson	313/62 X
3,794,927	2/1974	Fleischer et al.	328/324 X

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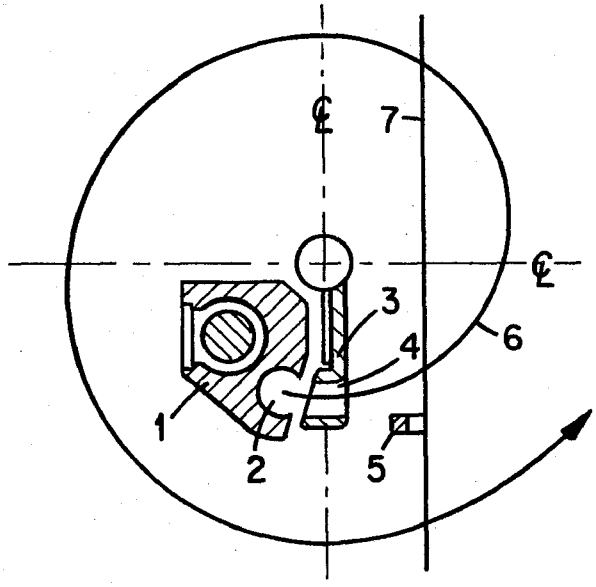
[57] **ABSTRACT**

An apparatus is provided for increasing the intensities of heavy ion beams accelerated in isochronous cyclotrons at high harmonics (5th harmonic or greater) of the orbit frequency. The small intensities normally obtained at high harmonics are significantly increased by the addition of a dc ion extraction system to the cyclotron ion source. Use of the dc extraction system has increased beams of $^{40}Ar^{3+}$ on the 5th harmonic and $^{20}Ne^{1+}$ on the 7th harmonic from nanoamperes to microamperes.

2 Claims, 3 Drawing Figures



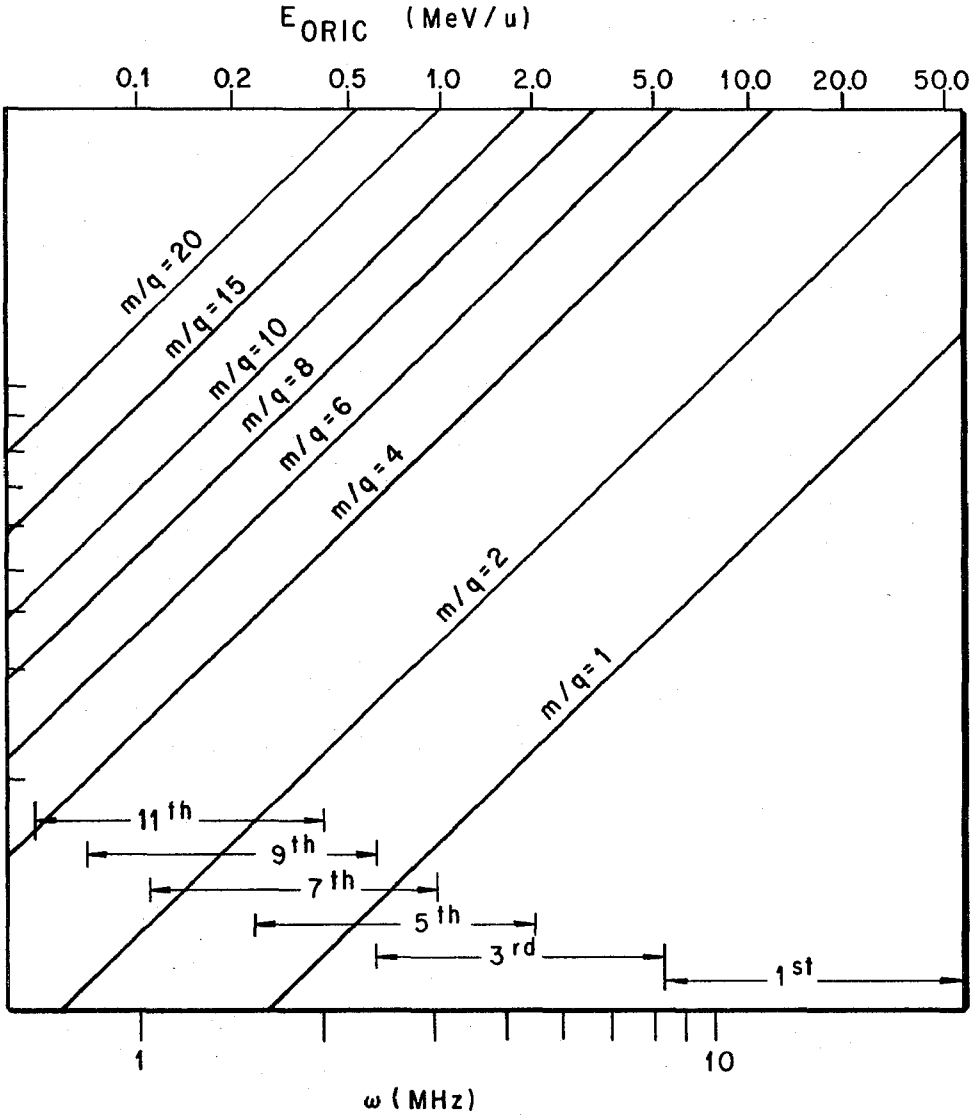


Fig. 1

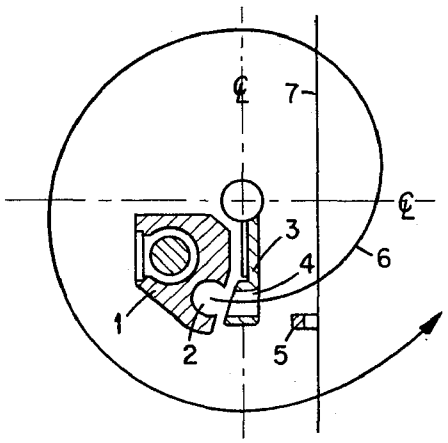


Fig. 2

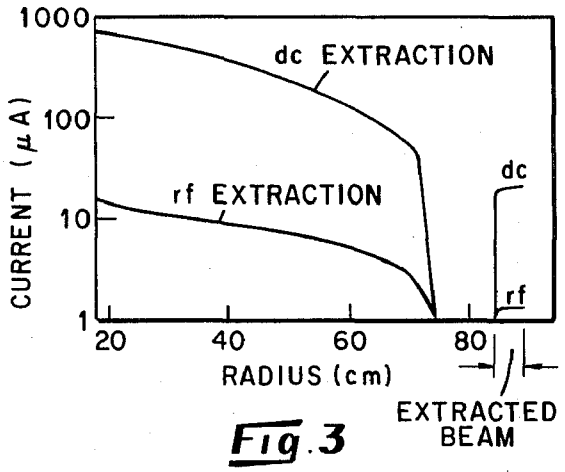


Fig. 3

CYCLOTRON INTERNAL ION SOURCE WITH DC EXTRACTION

BACKGROUND OF THE INVENTION

This invention was made in the course of, or under, a contract with the United States Atomic Energy Commission.

The present invention was conceived for use with isochronous cyclotrons such as the Oak Ridge Isochronous Cyclotron (ORIC) now in experimental use at the Oak Ridge National Laboratory. Details of the structure and operation of the ORIC system may be obtained from *Nuclear Instruments and Methods*, 18, 19, Nov. 1962, pp. 46–61, 159–176, 303–308, and 601–605; from U.S. Pat. No. 3,624,527 issued Nov. 30, 1971; and from the Oak Ridge National Laboratory Electronuclear Division Annual Progress Report No. ORNL-3630, dated June 1964, pp. 38–62.

In isochronous cyclotrons, a variable radio-frequency (rf) system is used for the acceleration of a large range of mass-to-charge particles. As the mass-to-charge ratio (m/q) of individual ions is increased, the angular rotation frequency of the particle decreases. In the ORIC, when the m/q ratio is about four, the particle angular rotation frequency is less than the lower frequency limit of the rf accelerating system, and the high m/q ions do not retain the proper phase for acceleration. It is well known, though, that the acceleration of high m/q ions is made possible through the use of the technique of acceleration on a higher harmonic of the rf frequency. In ORIC, ions have been accelerated on harmonics as high as the 9th. FIG. 1 shows typical m/q ratios that can, in principle, be accelerated in the ORIC.

A serious problem with accelerating on the higher harmonics is the large amount of beam current (intensity) that is lost. The problem of intensity decrease with increase in harmonic is discussed, for example, in the published proceedings of the Fifth International Cyclotron Conference, Butterworths, 318 (1971). The beam current decrease is ascribed by the present inventors to the crossing of the first or initial accelerating gap. The explanation is as follows: In order for the ion beam to cross the first acceleration gap during operation at high harmonics, the beam must start when the voltage is low, and this leads to low intensity from the ion source. If the m/q ratio is further increased, a point will be reached where no beam will cross the gap because there is not enough time available prior to voltage reversal.

Thus, there exists a need for some method or means for increasing the intensities of heavy ion beams accelerated in isochronous cyclotrons at high harmonics of the orbit frequency. The present invention was conceived to meet this need in a manner to be described hereinbelow.

SUMMARY OF THE INVENTION

It is the object of the present invention to provide some means for increasing the intensities of heavy ion beams accelerated in isochronous cyclotrons at high harmonics of the orbit frequency, and particularly at the 5th harmonic or greater.

The above object has been accomplished in the present invention by the addition of a dc ion extraction system to the cyclotron ion source, resulting in significant

increases in the small intensities normally obtained at high harmonics in the cyclotron.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a graph depicting the higher harmonic modes of operation of an isochronous cyclotron that must be used to enable the acceleration of high mass-to-charge ions.

FIG. 2 is a cross-sectional view of the ion source region in the center of a cyclotron that illustrates the dc accelerating slit of the present invention.

FIG. 3 is a graph showing the improvement in measured beam current obtained with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

As mentioned above, FIG. 1 illustrates resonance conditions for various m/q ions in the ORIC. As the m/q value becomes larger, the rf frequency must operate on a higher harmonic and this range of harmonic operation is indicated by the 1st to 11th arrows. It should be understood that FIG. 1 shows typical m/q ratios that can, in principle, be accelerated in the ORIC.

With reference now to FIG. 2, a graphite dc accelerating electrode 3 provided with an extraction slit 4 is placed at the centerline of the dee system between the ion source 1 and the rf accelerating slit 5 mounted on the dee 7. This necessitates moving the ion source arc chamber 2 just slightly off the centerline from where it would normally be. The accelerating electrode 3 is supported from an axially inserted tube. It is possible to compensate for the off-centered source position by adjustment of the harmonic and trim coils of the magnet.

Since the graphite electrode 3 is heated to incandescence by the beam, its supporting mechanism must be capable of withstanding high temperatures. Both tantalum and stainless steel mechanisms have been used. An insulator, not shown, that mounts the supporting mechanism is polyethylene and is protected from axial discharges by a stainless steel shield. Voltages to −15 kv are typically applied to the dc electrode 3. The normal voltages of 0 kv on the ion source 1 and −70 to −80 kv on the dee 7 have been retained. A particle starting from the ion source arc chamber 2 is indicated by the orbit 6.

In the operation of the present invention in the ORIC, an initial velocity is given to the ions by the dc accelerating electrode 3. This performs two functions: it provides a larger current from the ion source since the current depends on the extraction voltage gradient to the 3/2 power; and it substantially shortens the gap crossing time so that harmonic operation becomes less critical. Furthermore, this method of dc extraction from the ion source makes the same amount of beam available for acceleration at any initial phase. This might well be valuable where the magnetic field is not perfectly isochronized, forcing what would be an unfavorable starting phase if dc extraction from the source were not used.

The first successful runs with the dc electrode 3 were with 5th and 7th harmonic beams and resulted in beam intensities substantially larger than ever achieved before. For example, beams of $^{40}Ar^{3+}$ on the 5th harmonic and $^{20}Ne^{1+}$ on the 7th harmonic have been increased from nanoamperes to microamperes by the use of the dc extractor electrode of the present invention

in the ORIC. A graph of the current as a function of radius, with and without the dc electrode **3**, is shown in FIG. **3** for a $^{20}Ne^{1+}$ beam on the **7**th harmonic. It should be noted that the internal cyclotron beam with the dc electrode **3** is larger than the rf extracted beam by a factor of about **40.** The extracted dc beam is larger by a factor of about **15.**

In the search for superheavy elements, a reasonable charge state for a superheavy ion necessitates operation (in ORIC) at a high harmonic such as h=**11.** The acceleration of "microamperes" of ions on this harmonic is now for the first time possible with the dc extractor on the cyclotron ion source as described above. It should be noted that high mass-to-charge ions are of considerable interest in, for example, radiation damage studies of materials for controlled thermonuclear reactors.

This invention has been described by way of illustration rather than by limitation, and it should be apparent that it is equally applicable in fields other than those described.

What is claimed is:

1. In an isochronous cyclotron provided with a magnetic field, an internal ion source provided with an arc chamber, a variable radio-frequency (rf) system including an rf accelerating slit for withdrawing ions from said arc chamber, said rf system effecting the acceleration of said ions through said cyclotron as guided by said magnetic field, and an ion beam extraction system for extracting a desired separated ion beam from said cyclotron, the improvement comprising a slotted dc accelerating electrode positioned between the exist of said ion source arc chamber and said rf accelerating slit, and a source of substantially large negative voltage connected to said dc accelerating electrode, whereby, during operation of said cyclotron, heavy ion beams being accelerated in said cyclotron on harmonics from the **5**th to the **11**th harmonic have their beam intensities increased from nanoamperes to microamperes by use of said dc accelerating electrode in said cyclotron.

2. The cyclotron set forth in claim **1**, wherein said large negative voltage is at a selected value up to −15 kv.

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