IEEE Transactions on Nuclear Science, Vol.NS-22, No.3, June 1975

A ROTATABLE COLD CATHODE PENNING ION SOURCE*

M. L. Mallory and E. D. Hudson
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830

Summary

A rotatable cold cathode Penning ion source has been designed and is now operating in the Oak Ridge Isochronous Cyclotron (ORIC). Previous sources for positive heavy ions have been severely limited in lifetime by cathode sputtering and buildup of sputtered cathode material. The new ion source extends the cathode lifetime by a factor of ∿ 6. The source cathodes are discs of tantalum, 7/8 in. in diameter and 3/8 in. thick. Upon completion of an ion source "burn" at one position on the circular edge of the cathode discs, each disc is rotated to an unused position for the next "burn." Provision exists for continuous rotation of the cathodes. The plasma collimating holes, where the sputtered cathode tantalum is deposited, also are on discs with six possible positions. The new source has resulted in increased accelerated beam currents and greater stability for heavy ions. The source has also been used to produce light ion beams (H, D, α) over a wide range of intensities.

Introduction

The ion source type used for the production of high charge state heavy ions in accelerators is presently the Penning ion source.[1] One of the technical problems of this ion source is the cathode lifetime. For example, the ion source maintenance time (537 h) on the Oak Ridge Isochronous Cyclotron (ORIC) amounted to ∿ 8% of the total machine time for the year 1973.[2] The majority of this ion source maintenance time was due to the limited lifetime of the ion source cathodes. The ALICE[3] accelerator staff solves this lifetime problem by mounting multiple ion sources on a mechanical positioning rack and moving a complete new ion source into position. The UNILAC[4] accelerator provides multiple identical injection systems. These latter solutions, which require large areas for the ion source, are not practical for cyclotrons.

In cyclotrons, the internal ion source is limited in size by the radius gain per turn. Off the median plane of the cyclotron the geometry constraints on the ion source dimensions are not as severe. It was proposed that the cathode lifetime could be increased by replacing the present cathode with a tantalum disc and rotating the disc into a new position when needed.[5] The design and testing of the rotatable cathode ion source for ORIC are described in the following sections.

Source Design

The source head for the rotatable cathode ion source is shown in Fig. 1. The cathodes are discs of tantalum, measuring from 7/8 in. to 3/4 in. in diameter and 3/8 in. thick. Opposite the cathode disc is located the plasma collimator on which the sputtered tantalum from the cathode deposits and eventually creates a short circuit between the cathode and the anode. The present design can position up to six plasma collimator holes into operating place. The cathode is mounted on a stainless steel shaft that has water cooling up to 1/2 in. from the cathode. The shaft is inserted through a nylon and ceramic insulator that has pump-out openings located at various positions along its length. The motors for rotating the cathodes and for changing positions of the plasma apertures are located on the atmosphere side of the ion source.

The ion source arc chamber is a cylinder 5/8 in. in diameter and 1 1/2 in. long, and can be removed easily. This allows arc chambers of various metals to be used, as is done for producing metal ion beams.[6] The ion source head has various cover plates, which provide access to all ion source components, and quick disconnects for all water and gas lines. A photograph of the ORIC ion source is shown in Fig. 2.

D.C. Test Facility Experience

The ion source test facility was used at several stages in the development of the rotatable cathode ion source. These included the initial feasibility tests of rotating cathodes, the testing of the first source for the cyclotron, and testing of a second model of the source on which improvements were made before being incorporated into the cyclotron.

In the first tests, the ion source was used with rotatable cathodes but without the multiple hole plasma collimators and it was found that the discharge could be easily maintained for cathode rotational speeds up to one revolution per minute. Figure 3 shows a cathode that has rotated for 27 h with an argon arc. The arc characteristics are essentially the same as the cold cathode ion source[1] but it is easier to strike an arc if the cathodes are not rotating. The lifetime of the ion source under these conditions was limited by the buildup of sputtered tantalum on the plasma collimator. The addition of the multiple plasma aperture device increased the lifetime.

During commissioning tests in the ion source test facility a number of changes were made to improve reliability and ease of operation. In particular, a section of nylon insulator was replaced with a ceramic insulator in the ion source housing near the arc, where a high temperature environment exists.

ORIC Operating Experience

Installation of the rotatable cathode ion source on ORIC required a major modification of the ion source insertion mechanism, and required the cyclotron to be shut down for a two-month period starting in late May 1974. The ion source has now been in use for more than six months and is producing all beams with the same intensity as obtained with the previous ion sources. The ion source conversion has resulted in improvements in several areas. A new ion source positioner now provides more reproducible location of the source in the center of the cyclotron. The arc chamber design of the new source provides greater clearance for the first orbits of all beams. The arc chamber is easily replaceable and allows conversion to metal beams quite simply by inserting an arc chamber of the desired metal. (Iron, nickel, and copper have been tried.)

In the first tests of the rotating cathode ion source, a beam variation was detected and correlated with the rotation of the cathodes. The cathodes now operate in a stationary position during an ion source "burn" and are rotated to a new position at the completion of a burn. This mode of operation does not

*Work supported by the US ERDA under contract with the Union Carbide Corp.

change the time between maintenance periods of the ion source since this period is dependent upon the sputtered tantalum buildup at the entrance to the plasma collimating holes. The beam variations are under investigation in the ion source test stand.

Inclusion of multiple pumpout passages along the insulator were found to be necessary to eliminate electrical breakdown due to localized high pressure regions.

Difficulties have been experienced when the arc appears to shift position from the arc plasma chamber to the edge of the plasma collimator. When this happens, the plasma collimator melts, causing source failure. Temporarily better cooling for the plasma collimator disc is being obtained by mounting it in direct contact with a cool surface. A new design has larger spacing between the cathode edges and the plasma collimator edges. Also, the cathode configuration has been modified to provide better controlled cooling. These modifications have been successfully tested.

The new source design has led to new information about source operation and indicates a possible operational mode that will lead to increased beam intensity. Near the end of the source lifetime, the intensity is observed to increase dramatically ($\sim$10). The ability to rotate the cathode has allowed experiments that prove the effect is due to the tantalum cathodes (Fig. 4). Simulation of the eroded holes by premachined holes in the cathodes did not produce the desired increase in beam current. Insertion of partially burned cathodes that had been removed from a previous run resulted in initial increased beam intensity. It has been found that only one cathode needs to be pre-burned to gain the increased intensity. This allows a new cathode to be installed on one side and to strike an arc easily. This suggests that alternately stepping the cathode position after each burn (see Fig. 5), when the plasma collimator is rotated, will allow operation at greater intensity during the ion source lifetime.

Light Ions

Since there is no provision for hot filaments in the new ion source, light ion beams must now be obtained with the rotatable cathode ion source. Previous experiments had shown that the cold cathode source produced large intensities of light ion beams that were not easily controllable by electrical means. A system of controls utilizing source gas dilution with nitrogen has been developed. The ion source slit size was first adjusted for the desired maximum beam intensity (20 μA). For protons, the slit is 0.010 x 0.250 in. To lower intensity, nitrogen gas is fed into the source through a second gas line. By this technique the intensity of the extracted beam is quickly and easily controlled to a few nanoamperes.

Acknowledgements

We would like to thank R. K. Goosie for the engineering design and supervision of fabrication of the prototype ion source, and J. W. Hale for his help in the initial testing. Also, we thank M. B. Marshall and the ORIC operating staff for their fine cooperation in the tests on the cyclotron.

References

1. E. D. Hudson, et al., IEEE Trans. Nucl. Sci., NS-18, No. 3, 113 (1971).

2. E. D. Hudson, et al., Physics Division Annual Progress Report, Dec. 31, 1973, ORNL-4937, p. 103.

3. E. Baron, et al., AIP Conference Proceedings, No. 9, Cyclotrons - 1972, p. 243, American Institute of Physics (1972).

4. Ch. Schmelzer, Conference Proceedings, Reactions Between Complex Nuclei, p. 585, North-Holland, Amsterdam (1974).

5. J. R. J. Bennett, IEEE Trans. Nucl. Sci., NS-19, No. 2, 48 (1971).

6. E. D. Hudson, et al., Nucl. Instr. and Meth., 115, 311 (1974).

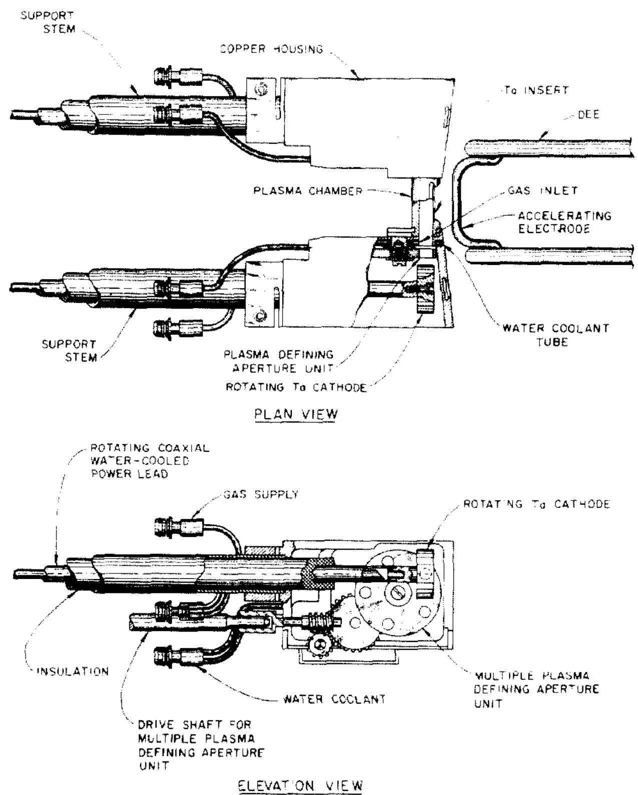

Fig. 1. A schematic drawing of the source head of the rotatable cathode ion source. The cathodes can be rotated and the plasma collimator has multiple apertures which can be changed remotely.

Fig. 2. The rotatable cathode ion source head. Normally located in the center of the cyclotron, the source head is mounted on a dual-stem structure that contains the drive shafts for the rotatable cathodes. The source head has many access ports with covers for quick maintenance.

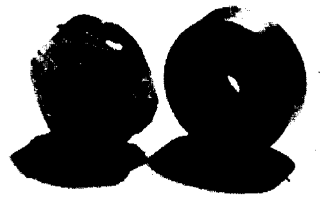

Fig. 3. New and used cathodes for the rotatable cathode ion source. The cathode is a disc of tantalum, 7/8" in diameter and 3/8" thick. The used cathode has operated for 27 h.

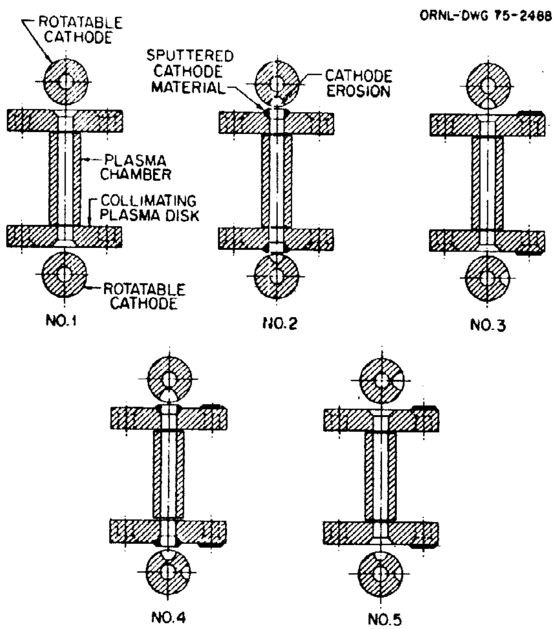

Fig. 5. Five views are shown of the rotatable cathodes, collimator discs, and plasma chamber for a proposed mode of operation to increase the cyclotron beam intensity. (1) The cathodes and collimating discs at the beginning of an ion source burn. (2) The eroded cathodes and the collimating discs with sputtered tantalum near the end of an ion source burn. (3) The collimators and only one cathode are rotated for the next burn. This cathode arrangement allows the arc to be struck easily and also results in increased beam near the end of the source life. (4) The cathodes and collimator discs near the end of the second burn. (5) The cathodes and collimator discs positioned for the beginning of the third burn.

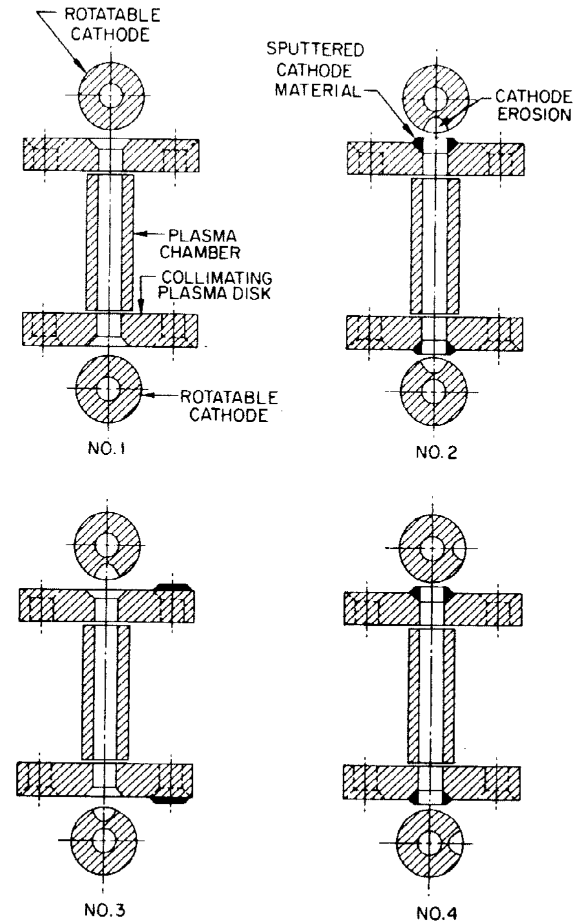

Fig. 4. Views of the rotatable cathodes, the plasma chamber, and the collimating plasma discs during an experiment to find the cause of beam increase as the source ages are shown. (1) The cathodes and collimating discs at the beginning of an ion source burn. (2) The eroded cathodes and the collimating discs with sputtered tantalum when the beam intensity has increased. (3) Rotation of the plasma collimators produced the same beam intensity as obtained in view 2. (4) Rotation of the cathodes resulted in operating at the initial beam intensity as obtained in view 1.