RECENT DEVELOPMENTS AT THE HOLIFIELD HEAVY ION RESEARCH FACILITY

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Introduction

The Holifield Heavy Ion Research Facility (HHIRF) accelerator system consists of a 25URC tandem electrostatic Pelletron[1] and the Oak Ridge Isochronous Cyclotron[2] (ORIC). The Pelletron was manufactured by the National Electrostatics Corporation (NEC) and placed into routine operation in 1982. It was the first large accelerator to be constructed in a folded configuration. The design terminal potential is 25 MV. To date, 66 isotopes of 36 elements from H to U, have been provided for the experimental program. Of this number, 27 isotopes were provided using ORIC as an energy booster in coupled operation.

ORIC was completed in the early 1960s as a versatile accelerator with variable energy for both light and heavy ions. ORIC was designed as a $K = ME/Q^2 = 100$ cyclotron and can operate at $K = 105$. In the 1960s, ORIC was used mostly for light ion production. In the 1970s, the experimental program shifted to heavy ions and in the late 1970s, ORIC was modified to be an energy booster for the tandem accelerator using a foil stripping injection system. In 1988, the internal ion source was decommissioned.

Recent developments have concentrated on improving the Pelletron voltage performance and improving ion source capabilities. Presently, the Pelletron can operate for long periods at 24 MV. This improved voltage performance has allowed heavier mass beams to be accelerated for nuclear structure studies in both the tandem-only mode and coupled mode. Table 1 lists some heavy beams recently accelerated in coupled operation. The lead beam was the first coupled operation using foil stripping in the tandem terminal.

Table 1. Heavy beams accelerated in coupled operation.

Ion	25URC Charge	25URC Voltage	ORIC Charge	MeV/ Nucleon
^{148}Nd	8+	23.8	32+	4.73
^{150}Sm	8+	23.8	32+	4.67
^{156}Gd	9+	22.0	36+	5.61
^{208}Pb	17+	22.9	44+	4.70

Ion source developments have concentrated on the construction of a multiple-sample, cesium-sputter, negative-ion source and a high-intensity-pulsed, magnetic-multi-cusp, plasma-sputter, negative-ion source. In addition, a positive-ion ECR source for the tandem terminal is presently under consideration.

Compressed Geometry Acceleration Tubes

A program to replace the original acceleration tubes with tubes of a compressed geometry design was begun in 1985. In this design, which utilizes a modified NEC high-gradient 17-cm-long tube section, the 3-cm-thick heatable aperture assembly provided as part of the original installation was replaced with an aperture assembly of essentially zero length. With this change, seven tube sections can be installed in the space previously occupied by six, increasing the effective insulator length by a factor of 7/6 = 1.17. Following initial design work, 7% of the tubes were replaced as a test in June 1986. Another 26% were replaced in November 1986 and in November 1987, the tube changeover was completed.

The immediate effect of the compressed-geometry acceleration tube installation has been to increase the voltage capability of the accelerator by approximately 3 MV. This improvement is illustrated in Fig. 1 where terminal voltage distributions before and after the tube change are compared. Specifically, the improved terminal voltage capability of the accelerator has enabled the HHIRF to provide beams with energies and intensities which would not otherwise have been possible. Examples of such beams are 225.3 MeV ^{16}O and 500 MeV ^{90}Zr directly from the Pelletron and the very heavy beams from coupled operation listed in Table 1.

Presently, the tandem accelerator can be routinely operated for long periods at 24 MV. A scheduled experiment has been completed at 25.0 MV and the tandem has operated stably at 25.5 MV. It is believed that replacement of the corona point voltage grading system with a resistor system may allow the accelerator to routinely operate at 26 MV.

Negative Ion Sources

Two negative ion sources are presently under construction. Figure 2 shows the multiple-sample cesium-sputter source which can remotely select any one of 60 samples for negative ion production. The samples are contained on the outer surface of three rings of 20 samples each. Construction of this source was motivated by the desire to select and frequently change samples without the presently required 30-minute disruption in accelerator operation. In addition, the source has a three-electrode structure with a high perveance of 8×10^{-9} A/V$^{3/2}$ giving large positive cesium ion currents. The three-electrode system also permits the sample to be independently biased relative to the ionizer, giving improved beam transmission, since the ions will be extracted from a less divergent field.

The second source, shown in Fig. 3, is a radial-geometry, magnetic-multi-cusp, plasma-sputter, negative-ion source which can produce high-intensity pulsed and dc beams over a wide spectrum of atomic and molecular species.[3] This source is modeled after those used at LANL and KEK to generate intense pulsed beams of H$^-$ ions. Recent work at BNL and the University of Tsukuba has shown that these sources can also produce mA pulsed negative heavy ion beams for synchrotron injection.[4] The source also is expected to produce mA dc beams.

Tandem Terminal ECR Source

Many ECR sources have been built worldwide and are used for cyclotron injection, linac injection, and for

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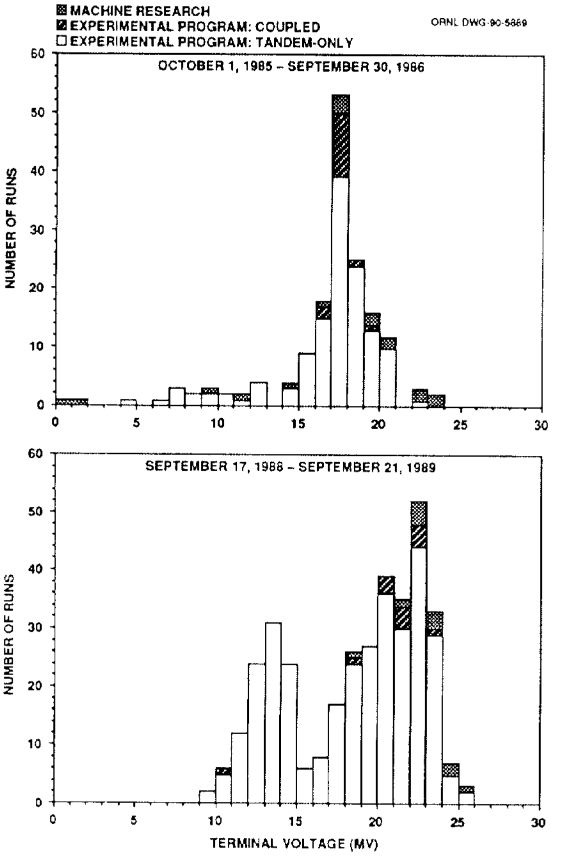

Fig. 1. The number of runs as a function of terminal potential for one-year periods before and after the installation of compressed geometry tubes.

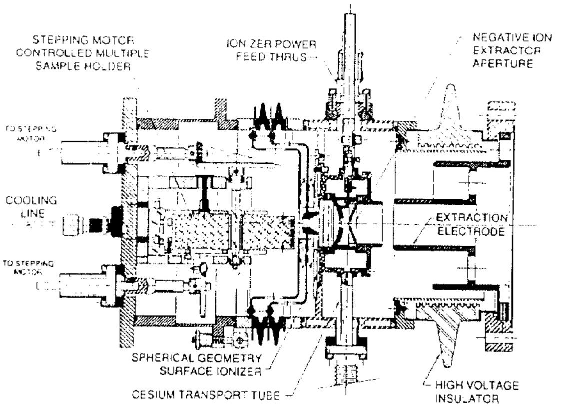

Fig. 2. Schematic drawing of the multiple-sample cesium sputter negative ion source.

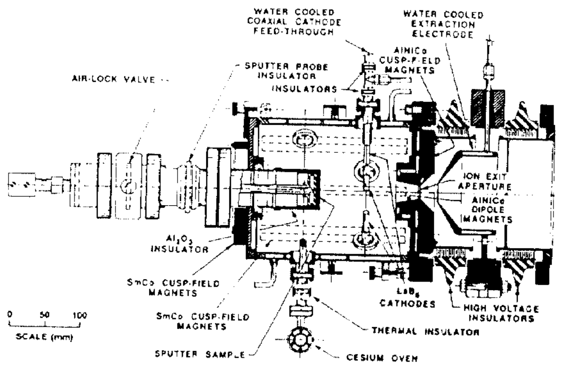

Fig. 3. Schematic drawing of the axial-geometry, plasma-sputter, negative ion source.

atomic physics research. The installation of an ECR source in the tandem terminal has also been studied. Such an ECR source would produce more intense currents of higher charge states for acceleration down the high-energy tube than can be obtained with conventional negative-ion sources and terminal-foil stripping. This improved performance is particularly important for very heavy beams with coupled operation.

The expected performance improvement from a terminal ECR source, emphasizing a ^{208}Pb beam, is illustrated in Figs. 4 and 5. Figure 4 shows the expected ^{208}Pb current available in the high-voltage terminal of an electrostatic machine as a function of charge state. Results for six cases are shown. The three lower curves are for tandem accelerators at 6, 12, and 24 MV with foil strippers. As the terminal voltage increases from 6 to 24 MV, the peak charge state for an equilibrium distribution from foil strippers increases from 9 to 17 and the corresponding beam energy increases from 0.29 to 2.16 MeV/nucleon. Equally important, the higher beam energy for stripping increases the foil lifetime and, hence, current from 10 pnA to 35 pnA. For the results of Fig. 4, a foil lifetime of 30 minutes was required, assuming beam-current-lifetime products of 1.4, 2.8, and 5.6 pμA-min for 6-, 12-, and 24-MeV lead beams, respectively, using 5 μg/cm^2-thick, glow-discharge-slackened foils.[5] Clearly, the beam currents available from foil stripping are foil-lifetime limited.

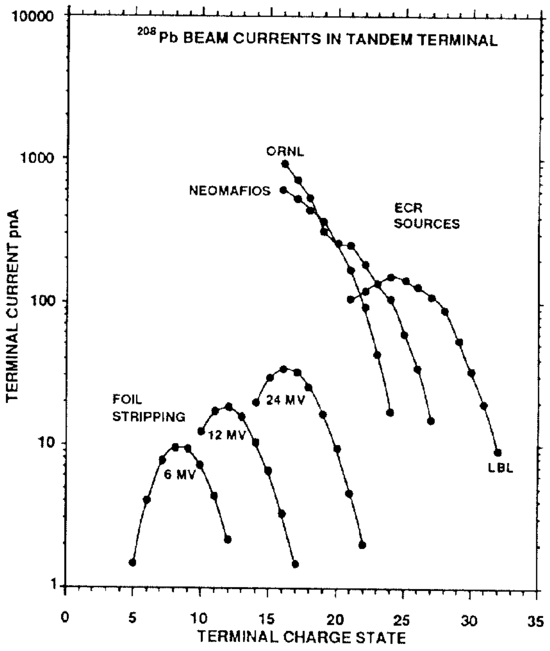

Fig. 4. Comparison of expected ^{208}Pb beam currents in the terminal of a tandem accelerator between conventional negative ion injection with foil stripping and a terminal ECR source.

The upper curves in Fig. 4 are for three terminal ECR sources: (1) Measured Bi currents from the all-permanent magnet, lower power, compact, 8-GHz NEOMAFIOS source;[6] (2) Measured Au currents from the ORNL 10.6-GHz source;[7] and (3) Measured Bi currents from the large, high-power, 6.4-GHz LBL source with a 700°C oven vapor feed.[8] For any given charge state, an ECR source can produce at least 20 times more beam current in the terminal than conventional negative ion source operation with conventional foil stripping.

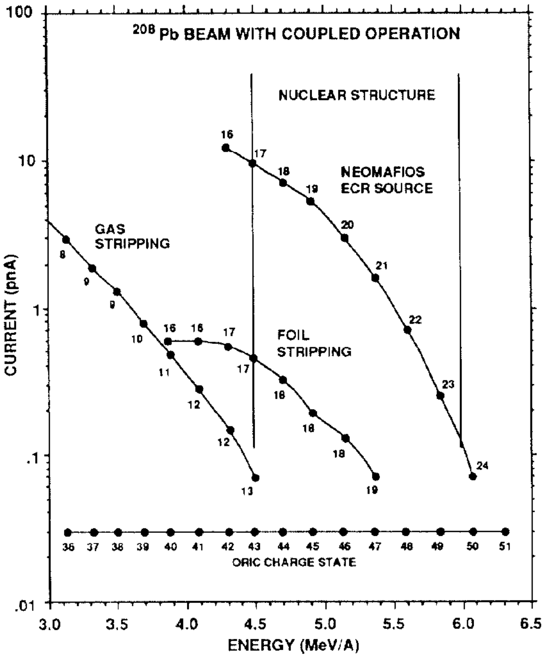

Fig. 5. Expected ^{208}Pb beam currents from the tandem and ORIC operated in coupled mode.

A lead beam with an energy between 4.5 and 6.0 MeV/nucleon, and an intensity in the order of one pnA, is of strong interest for nuclear structure physics. Such a beam can be produced in coupled operation using ORIC. The product of the transmission, charge-state fraction, and bunching factor through ORIC is about 5%. Consequently, to deliver one pnA of beam on target would require about 40 pnA of beam in the tandem terminal, assuming a 50% beam loss in the high-energy tube. As shown in Fig. 4, 40 pnA of lead cannot be obtained at 24 MV with the present foil lifetime limits. However, the three ECR sources all produce at least 40 pnA of beam over a wide range of charge states. The charge states of interest for ORIC injection are between 17+ and 24+.

The determination of the ORIC output energy is somewhat complicated. Injection is achieved by stripping from the tandem charge state to a higher charge state Q through an injection foil. The maximum energy/nucleon from ORIC is then given by $E/M = 105\ (Q/M)^2$. Consequently, the maximum energy from ORIC is determined by the charge state Q from the injection foil, which is energy dependent and determined by the tandem energy which, in turn, is determined by the tandem terminal charge state. These relationships are illustrated for ^{208}Pb in Fig. 5, which shows the maximum current one can obtain from ORIC as a function of energy. Three curves are shown: conventional tandem operation with a terminal gas stripping and foil stripping, and tandem operation with an ECR source using the NEOMAFIOS results. The numbers on the curves give the terminal charge state, whereas the bottom scale gives the ORIC charge state Q. The energy range of greatest interest is also shown. Clearly, the installation of a terminal ECR source would allow the HHIRF coupled accelerators to produce lead beams for nuclear structure physics with intensities above one pnA.

Figure 6 shows a proposed NEOMAFIOS-like ECR source and beam transport in the tandem terminal mounted in a horizontal plane above the highest casting.

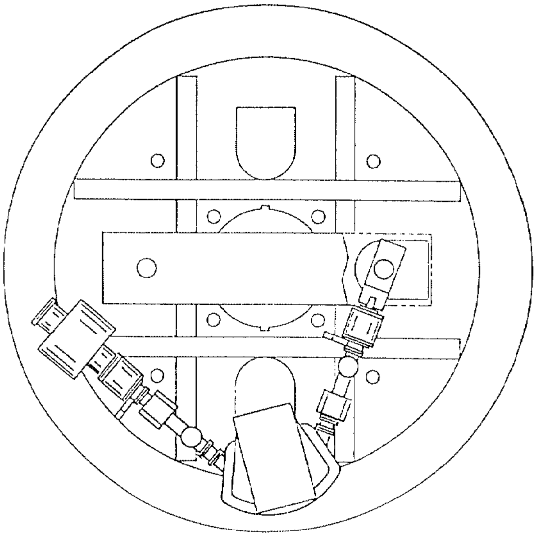

Fig. 6. Top view of the 3.9-m-diameter terminal of the HHIRF tandem accelerator with the proposed ECR source and beam transport system.

The tandem terminal has a diameter of 3.9 m. The ECR system is estimated to have an installed weight of less than 11,000 pounds and require less than 30 kW of power. About 38 kW of power is available.

The beam transport system between the ECR source and the high-energy tube would transport the expected 30 π mm·mrad·MeV$^{1/2}$ emittance from the source into the corresponding 96 π mm·mrad·MeV$^{1/2}$ acceptance of the high-energy tube. The source potential would be at 50 kV positive with respect to the terminal voltage. An einzel lens would focus the beam from the source to the object focus of a 40-cm radius, 110°, double-focusing dipole magnet. Variable apertures and Faraday cups would be located at both the object and image positions of this magnet which would select a single charge state to be focused by a second einzel lens through an electrostatic mirror. This mirror would bend the ions downward by 90° to merge the beam into the existing optics system. A double-drift bunching system between the electrostatic mirror and high-energy tube would prepare the beam for the ±3° phase acceptance of ORIC. The installation of an ECR source in the tandem terminal seems readily achievable.

References

1. J. K. Bair et al., IEEE Trans. Nucl. Sci. NS-22, (1975) 1655.
2. J. A. Martin et al., Proc. of Eleventh Cyclotron Conference, Tokyo, Japan, (1985) 38.
3. G. D. Alton et al., Rev. Sci. Instr. 61 (1990) 342.
4. G. D. Alton et al., NIM A270 (1988) 194.
5. R. Auble and D. M. Galbraith, Proc. of Ninth Conf. on Target Development, Gatlinburg, TN (1980).
6. R. Geller, private communication (1989).
7. F. W. Meyer and J. W. Hale, Proc. of 1987 IEEE PAC, Washington, D.C. (1987) 319.
8. D. J. Clark and C. M. Lyneis, Proc. of Fourth Conf. on ECR Sources, Grenoble, France (1988).