DEVELOPMENT OF THE HRIBF 25-MV TANDEM ACCELERATOR AS A RIB
ACCELERATOR

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The Holifield Facility 25URC tandem accelerator will begin accelerating radioactive ion beams (RIBs) for nuclear structure and astrophysics research in 1996. This paper addresses the development of the accelerator to allow optimum operation with the particular challenges associated with RIBs. New diagnostics for ultra-low-intensity beams are being installed and the terminal potential stabilization system is being studied to optimize control with these low beam intensities. A new resistor-based voltage-grading system has resulted in more stable operation, as well as allowing operation at the very low terminal potentials which are required for some astrophysics experiments. Also addressed is beam transmission optimization, particularly at low terminal potentials, and operation of the accelerator at high terminal potentials.

1. Introduction

On June 30, 1992, the Holifield Heavy Ion Research Facility (HHIRF) was shut down as an operating national users' facility for heavy ion physics research and

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a new construction project was started to reconfigure the existing accelerator system and develop a first-generation RIB facility [1,2]. Radioactive atoms for the new Holifield Radioactive Ion Beam Facility (HRIBF) will be produced by fusion reactions in an Isotope Separator On-Line (ISOL)-type target-ion source assembly using intense light-ion beams from the Oak Ridge Isochronous Cyclotron (ORIC). The radioactive atoms will be converted to negative ions either directly in a negative-ion source or by charge exchange following positive ionization. After acceleration to 200-300 keV from a high-voltage platform, these negative ions will be injected into the HRIBF 25-MV tandem accelerator [3-5] for acceleration to final energies. Beams up to mass 76 amu can be accelerated to energies greater than 5 MeV/nucleon. This project, to produce proton-rich RIBs for nuclear physics and astrophysics research, is nearing completion.

With ORIC as the primary accelerator, the existing tandem accelerator was chosen for the secondary accelerator because of its availability. Tandem accelerators, however, do possess excellent characteristics for RIB accelerators. Characteristics that are particularly suited to the acceleration of RIBs are large phase space acceptance for the injected beam, good transmission efficiency, simplicity and reliability, the ability to accelerate singly-charged d.c. injected beams of low-charge-state, high-mass ions with low initial velocity, and excellent accelerated beam quality [6]. The remainder of this paper will address the development of the HRIBF tandem accelerator for optimum performance in accelerating RIBs.

2. Radioactive Beam Characteristics

While radioactive ion beams have different characteristics based upon their method of production, they have several general characteristics that are different from the stable ion beams that have been accelerated in tandem accelerators in the past. Typically, RIBs have very low intensities compared to stable beams produced in the same types of ion sources, have the potential for producing radioactive surface contamination within the accelerator, and may be produced in combination with stable isobars. The most challenging characteristic is isobar separation which, in the HRIBF design, will be done before injection into the tandem accelerator. Radioactive contamination of surfaces inside the tandem accelerator and associated components is not considered a problem due to the very low intensities of the accelerated beams and selection of beams with attention to relatively short half-lives and daughter half-lives. Low beam intensity requires some changes to, and development of, the tandem accelerator to best optimize stability, tuning, and transmission.

3. Tandem Accelerator

3.1 Introduction

The 25URC tandem accelerator was placed into routine operation in 1982 and operated for the HHIRF national users' program until July 1992. Although it has been described previously [7-10], the primary features of the accelerator will be reviewed. Shown schematically in Fig. 1, the tandem accelerator is a model 25URC Pelletron accelerator manufactured by the National Electrostatics Corporation (NEC). The accelerator, which is insulated with pure SF_6 at

pressures up to 0.7 Mpa (gauge), was designed to operate at terminal potentials up to 25 MV with analyzed beam intensities up to 1 pA (6.2×10^{12} particles/s). The five dead sections in the column structure are each equipped with vacuum pumps. A CAMAC-based digital control system is used to provide virtually all control and monitoring information which is transmitted on six bit-serial highways. Some of the original components of the accelerator, including the acceleration tubes, have been replaced and some minor components, such as electron traps, have been removed.

3.2 RIB Injection

Injection energy of ions from the stable ion injector can be varied from 100-550 keV, with 300 keV being the typical injection energy. Constraints on available space for the RIB injector high-voltage platform limit the injection energy from this platform to approximately 350 keV with 200-250 keV being more probable for day-to-day operation. Use of an electrostatic quadrupole lens in the low-energy acceleration tube of the tandem accelerator, at one-third the distance from entrance to exit, allows the normalized phase space acceptance of the accelerator to be insensitive to injection energy, if the injection system can provide a beam waist at the entrance of the low-energy acceleration tube which is approximately equal in diameter to the beam waist at the terminal stripper [11]. In practice, this condition cannot be satisfied over a wide range of injection energies because only one lens was provided between the mass-analyzing magnet and the entrance of the low-energy acceleration tube [12]. The position of this lens provides optimization for an injection energy of 300 keV and cannot be easily moved. A measurement of the effect of lowered injection energy on

transmission efficiency for seven beams showed that the injection energy could be lowered to 200 keV without a significant effect on transmission efficiency [6].

The new RIB injection line uses the viewport on the existing mass-analyzing magnet (BM 13-1) as shown in Fig. 2. RIB injection is thus accomplished without switching magnets; however, the residual field in the mass-analyzing magnet will require neutralization. The design of the RIB injection line optics results in a beam waist at the image plane of the existing mass-analyzing magnet, so the subsequent transport and acceleration of RIBs should be completely analogous to that of stable beams.

3.3 Voltage Performance and Stability

In the period 1982-1992, development of the accelerator with respect to voltage performance was focused on operation at high terminal potentials. The most significant effort in this period was replacement of the original acceleration tubes with tubes of a compressed geometry design [13]. With this change, seven tube sections could be installed in the space previously occupied by six, thus increasing the effective insulator length per unit column length by a factor of $7/6 = 1.17$. Operationally, the effect of this change was to increase the maximum terminal potential with beam to 25.5 MV. With RIBs, the ability to operate at high terminal potentials will continue to be important, particularly for nuclear structure experiments which require acceleration of heavier nuclei to energies of the order of 5 MeV/nucleon.

In contrast to the requirements of nuclear structure, research in nuclear astrophysics typically requires beams of low energy, in some cases, as low as

2-3 MeV. In the past, operation at low terminal potentials was a particular problem for the 25URC accelerator because of the use of a point-plane corona-discharge voltage-grading system. The grading currents observed in corona systems, especially after extended use, are typically quite small (a few μA) with the result that the perturbing effect of spurious ionization-induced currents in the insulating gas can be significant. As the terminal potential is lowered, the grading currents become even smaller and the column tends to be graded by capacitance rather than the corona currents. Shorting sections of the column increases the grading currents, but in general, perturbs beam transport through the column. Thus, shorting of the column can only be used to a limited extent. For example, to achieve 1 MV on the terminal by shorting, at least 25 of the 27 units must be shorted. To address this, and other problems, the corona voltage-grading system was replaced in June 1994 with a resistor-based system.[14] In initial tests, operation with this system has been smooth and beam was quickly provided for target development studies at terminal potentials up to 20 MV. As a result of the improved voltage grading provided by the resistor-based system, it is believed that the maximum terminal potential capability of the accelerator will also be improved. It is expected that voltage tests to confirm this belief will be conducted in 1996.

In the first test of low-voltage operation with the new resistor-based system, the overall transmission efficiency for a ^{16}O beam was measured in the beam energy range 50.3 to 2.3 MeV [15]. The essential result of these measurements is that the accelerator can be operated at a terminal potential of 1 MV, without shorting units or changing the SF_6 pressure, to produce 2.3-MeV beams. Overall beam transmission efficiency at 2.3 MeV was only a factor of two lower than the usual transmission efficiency, and it is probable that this efficiency

could be improved with possible shorting of some units and further development.

The tandem accelerator terminal potential is controlled by a feedback loop which includes a capacitive pickoff, and either a generating voltmeter (GVM) or energy-analyzing slit currents, or both. The stability of the terminal potential is, in general, excellent with typical estimated RMS values of a few hundred volts. A new terminal potential stabilization system was installed in 1991 which allows operation using the GVM only, with minimal operator intervention; therefore, there is no minimum beam intensity requirement. To provide even better stability, GVM preamps will probably be needed to eliminate some noise that is in the present system.

3.4 Beam Diagnostics

Beam intensities are now measured with Faraday cups which are equipped with logarithmic amplifiers having a lower limit of about 100 picoamperes. Initial RIB intensities are expected to be below this limit and also below the limit of other devices, such as beam profile monitors, etc., in the experimental beam lines. Therefore, the concept for a new beam diagnostic system [16] was developed. This new system will be used throughout the RIB injection system, the tandem accelerator, and the experimental beam lines as a tuning aid for beam current measurement in the range from a few particles per second to at least one microampere. The system combines a Faraday cup and a continuous dynode electron multiplier (CDEM) to achieve this range. The present logarithmic amplifiers will be replaced with Keithley logarithmic amplifiers with a dynamic range of 10^{-12} to 10^{-4} amperes. The electron suppressers for selected

Faraday cups will be controlled so that the suppresser voltage may be turned off or made positive to provide amplified current readings.

Beam currents less than one picoampere will be measured by counting either ions or secondary electrons with a CDEM. A metal target will be placed in the beam and the CDEM will count either electrons or Rutherford backscattered ions, depending on the intensity of the beam. For ion beam currents less than 10^5 ions per second (16 femtoamperes), the CDEM entrance will be biased to attract electrons and these secondary electrons will be counted. The entrance bias will be reversed for the 10^4 to 10^7 ions per second range so that electrons, but not Rutherford backscattered ions will be repelled. The total bias for the CDEM is always positive and its value is kept the same in either mode.

The same effects can be accomplished by appropriately biasing the target rather than the entrance of the CDEM; however, a moveable target was designed to eliminate confusion from beta emitters that may be deposited on the target. Biasing a movable target is much more complicated, so the movable target is grounded and the CDEM entrance is biased. Figure 3 shows a simplified schematic of the movable target system. Tests on both the fixed and movable systems show them to work as expected. CDEM systems inside the tandem accelerator will initially have the simpler fixed-target systems.

3.5 Control System

The CAMAC-based control system initially provided with the tandem accelerator has been very reliable, but is difficult to modify and is now becoming outdated. In particular, the control computers are vintage 1970 and are core-memory-

limited. The plan for controlling the accelerator in the future is to keep the CAMAC controls, but to communicate with them via a new control system which has been implemented as a part of the RIB project. This new system, which is based on a commercial product from VISTA Control Systems, Inc. [17], will allow much greater flexibility, as well as integration of all facility accelerator control systems. Tandem accelerator controls should be added to the VISTA system in the next year.

4. Discussion

The HRIBF tandem accelerator is an excellent RIB accelerator because of the beam quality inherent to the accelerator. The tandem accelerator has been optimized for tuning and transmission of very low-intensity beams by the modifications described. As the first RIBs are produced, development will continue to improve the accelerated beam, especially transmission efficiency. Many of the ions of interest to the astrophysics community have masses below 50 amu. The apparent transmission efficiency for the tandem accelerator low-energy acceleration tube, in this mass range, has always been lower than expected. Future studies will be focused on understanding and alleviating this problem. Low voltage transmission will also be improved as more experience is gained in tuning these low-energy beams.

Radioactive surface contamination of tandem accelerator components is not probable, primarily because of the low intensity of RIBs, but also because atoms with very long half-lives or daughter half-lives will not be used. As the facility goes into high-intensity production in the coming years, radioactive surface

contamination may become a problem. If this occurs, shielding will be placed on critical components, including magnet vacuum chambers.

Although the design of the RIB injection line accounts for isobar separation before injection into the tandem accelerator, it may be possible to also use the existing energy-analyzing magnet as a mass separator.[6] With the addition of a quadrupole lens upstream of the energy-analyzing magnet, it is believed that a mass resolution, with terminal gas stripping, of 1 part in approximately 20,000 (full-width-half-maximum) could be achieved. It remains to be seen whether this modification will be necessary.

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Figure Captions:

Fig. 1. A simplified schematic drawing of the Oak Ridge 25-MV tandem accelerator.

Fig. 2. A simplified schematic drawing of the intersection of the stable-ion-injection beam line and the RIB injection beam line.

Fig. 3. Simplified drawing of the moveable-belt target system used for low-intensity diagnostics.

References

- [1] "A Proposal for Physics with Exotic Beams at the Holifield Heavy Ion Research Facility," eds. J. D. Garrett and D. K. Olsen (ORNL, February 1991).
- [2] D. K. Olsen et al. in Proceedings of the Workshop on the Production and Use of Intense Radioactive Beams at the Isospin Laboratory, edited by Jerry D. Garrett (Joint Institute for Heavy Ion Research, Oak Ridge, TN, Oct. 7-10, 1992), pp. 375-415.
- [3] C. M. Jones et al., Nucl. Instr. and Meth. A268 (1988) 308.
- [4] J. K. Bair et al., IEEE Trans. Nucl. Sci. NS-22 (1975) 1655.
- [5] C. M. Jones, Proceedings of the 3rd Int. Conf. on Electrostatic Accelerator Technology, Oak Ridge, TN (Apr. 1981) p. 23.
- [6] C. M. Jones, R. C. Juras, M. J. Meigs, and D. K. Olsen, Proceedings of the Particle Accelerator Conference, (Washington, D. C., May 17-20, 1993), pp. 1660-1662.
- [7] C. M. Jones, Rev. Phys. Appl. 12 (1977) 1353.
- [8] J. B. Ball, IEEE Trans. Nucl. Sci. NS-30 (1983) 1363.
- [9] C. M. Jones et al., Nucl. Instr. and Meth. A244 (1985) 7.

- [10] J. A. Martin et al., Proceedings of the 11th International Conference on Cyclotrons and their Applications, ("Ionics, Tokyo, 1987), pp. 38-45.
- [11] J. D. Larson and C. M. Jones, Nucl. Instr. and Meth. 140 (1977) 489.
- [12] W. T. Milner et al., IEEE Trans. Nucl. Sci. NS-22 (3) (1975) 1697.
- [13] C. M. Jones, D. L. Haynes, R. C. Juras, M. J. Meigs, and N. F. Ziegler, Nucl. Instr. and Meth. A276 (1989) 413.
- [14] D. L. Haynes, C. M. Jones, R. C. Juras, and M. J. Meigs, Nucl. Instr. and Meth. A320, (1992) pp. 400-402.
- [15] "New Resistor Voltage Grading System at the Oak Ridge National Laboratory 25URC Tandem Accelerator; Installation and First Experience," M. J. Meigs, D. L. Haynes, C. M. Jones, and R. C. Juras, Proceedings of the 28th Symposium of Northeastern Accelerator Personnel, Kalamazoo, MI, Oct. 12-15, 1994, to be published.
- [16] "A New Beam Intensity Monitoring System with Wide Dynamic Range for the Holifield Radioactive Ion Beam Facility," M. J. Meigs, D. L. Haynes, C. M. Jones, and C. T. LeCroy, Proceedings of the Particle Accelerator Conference, Dallas, TX, May 1-5, 1995, to be published.
- [17] "Control System for the Holifield Radioactive Ion Beam Facility," B. A. Tatum, R. C. Juras, and M. J. Meigs, Ibid.

HHIRF TANDEM ACCELERATOR