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THE THREE-STAGE MP ACCELERATOR UPGRADE PROGRAM AT BROOKHAVEN NATIONAL LABORATORY*

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Introduction

The three-stage tandem accelerator facility at Brookhaven National Laboratory (BNL) consists of two model MP tandem Van de Graaff accelerators, serial numbers 6 and 7,[1] arranged in line so that MP-6 can inject negative ions up to 10 MeV energy into MP-7 providing a three-stage mode of operation. The injector accelerator, MP-6, may also be used as a standard two-stage accelerator having been equipped with an external ion source and target room facility.

An article in the special issue of "Nuclear Instruments and Methods" on large electrostatic accelerators edited by D. A. Bromley reviewed the performance and accelerator improvements of the Brookhaven National Laboratory (BNL) three-stage tandem facility through mid 1974.[2] This paper will describe improvements since that report and current operating status and performance.

The BNL Tandem staff had originally designed, constructed, and installed into the MP-6 high voltage terminal an off-axis, direct-extraction duoplasmatron negative ion source for the initial three-stage operation in 1969[3] and has now upgraded the three-stage performance by the installation of a terminal mounted negative ion source based on the cesium sputter principle as originally developed by R. J. Middleton.[4,5] In addition both accelerators have new stainless steel acceleration tubes and other improvements that allow for negative operation of MP-6 to 10 MV and positive operation of MP-7 to 13.25 MV. Improvements in operation have now provided record electrostatic accelerator heavy ion energies for the research program of 125 MeV $^{16}O^{8+}$ 200 MeV $^{32}S^{16+}$ and 255 MeV $^{63}Cu^{19+}$.

MP-7 Improvements

Acceleration Tubes, Resistors, and Column Improvements

A major acceleration tube upgrade program for both accelerators, MP-6 and MP-7, was undertaken early in 1976. The special small 8" diameter stainless steel acceleration tubes that were used to provide an interim upgrade capability in MP-7 were removed and reconditioned for subsequent installation in MP-6, the injector accelerator, and new large diameter 14 inch stainless steel tubes[2,6,7] were installed in MP-7.

The new accelerator tube sections are equipped with separate resistor strings so that the only connections between tube and column are made at the end of each tube section. This separated gradient arrangement increases accelerator tube protection during terminal discharges and provides improved electrical stability. Figure 1 is a photo of acceleration section #5 that shows both the column and tube resistors mounted in place. Both tube and column resistors[8] are equipped with additional single spark gaps for further protection against surging as shown.

In the standard HVEC design the tube electrodes and diagonal column elements are connected by springs which have proved to be quite unreliable in an SF_6 environment. There are also vertical gradient rods (Fig. 1) that are spring loaded into position rather than being securely fastened. All of these spring-type connections have been replaced by a bolted or riveted contact and the tube connections have been eliminated by the separate resistor strings as previously described. These modifications represent an extensive effort because there are over 4,000 connections, but in the end, guarantee much more stable operation and a complete elimination of miscellaneous column sparking, breakdown and corrosion.

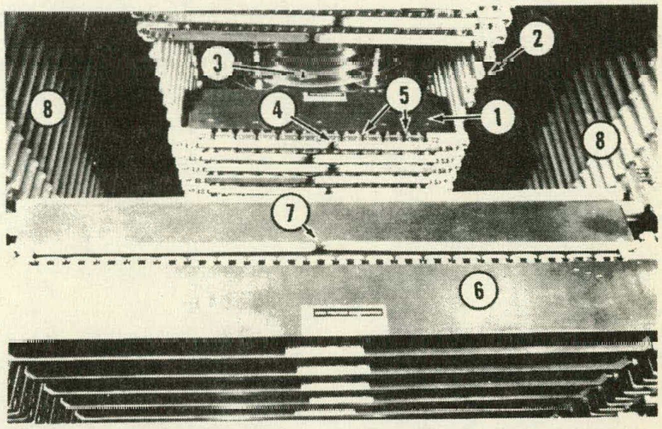

Fig. 1 Photo looking up at tube section #5. The tube resistors, 1, are mounted on support rods, 2, which are fastened on each side of the tube electrodes, 3, auxiliary spark gaps, 4, limit overvoltage on resistor gaps, 5. The column resistors, 6, are mounted on the column girders below the acceleration tube and are also provided with auxiliary spark gaps, 7. Vertical gradient bars, 8, on each side of the column enclose and shield the tube electrostatically.

Photomultiplier Voltage Conditioning Monitors

Photomultiplier tubes have been installed at some window ports of the accelerator to detect any light generated in the vicinity of the mid-section of each of the eight acceleration tubes, similar to the system developed by the University of Rochester.[9] This method of observing the illumination produced by the micro discharges resulting from the voltage conditioning process within the acceleration tubes appears to be one of the most sensitive for monitoring the conditioning phenomena. This system allows for the machine to be voltage conditioned at a maximum possible rate commensurate with minimizing the possibility of initiating terminal sparks that can cause serious damage.

Post Stripper Installation

A second foil stripper, or post stripper, was installed at the 3/4 terminal potential point in the dead section between tube sections 5 and 6 in the high energy end of the accelerator. The initial performance of the post stripper both with terminal gas and foil stripping has been reported elsewhere.[10,11] Over the last year of operation, dual-foil stripping has been used extensively for many different heavy ions and has greatly extended the performance capability of the facility, as will be described in more detail in Section IV on accelerator performance. Besides the obvious improvement in yield and energy for

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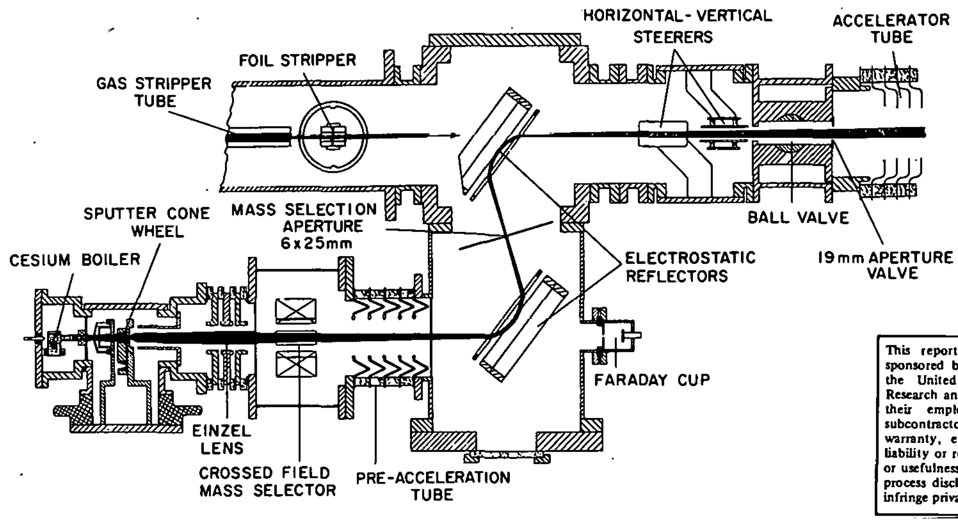

Fig. 2. Negative Ion Sputter Source arrangement within the high voltage terminal; see text for details.

heavy ions like ^{32}S, ^{35}Cl, ^{63}Cu, etc. it has also been found that $^{12}C^{6+}$ and $^{16}O^{8+}$ yields can be increased by factors of two or three over single stripper yields.

Since the presence of carbon foil fragments in some acceleration tubes contributed to premature tube failure, special shrouds were installed that completely encloses the stripping foil changer mechanism with entrance and exit apertures only large enough to pass the beam. These shrouds have effectively eliminated the migration of foil fragments into the acceleration tubes and also serve as excellent shields against possible air current foil damage during foil loading operations.

Two-Stage Sputter Ion Source

A Middleton-type sputter ion source[5] has been the main source used in support of the heavy ion research program. The original Extrion Mark II UNIS Source was replaced by an improved model, Mark VI,[12] which is much simpler in construction and easier to use, but still required some modifications in order to achieve reliable operation. The quick change capability of the source from one heavy ion to another, the excellent yield of most heavy ions produced, and the long-term reliability has changed the nature of the research program. It is now common for the operation schedule to call for two or more different ions during an eight-hour shift period. On one occasion ten different ions were provided during one shift for calibration purposes. This dynamic and rapid change capability allows the accelerator to be used more efficiently in support of the research program. When questions arise from preliminary analysis of data utilizing one kind of heavy ion, they can be checked quickly by producing other ions the scientist may need for comparisons.

MP-6 Improvements

The injector accelerator, MP-6, had been equipped with standard large diameter aluminum tubes since the beginning of the facility, with all previous upgrade efforts concentrated on MP-7. When the MP-7 small diameter stainless steel acceleration tubes were upgraded to the large diameter stainless steel tubes, the smaller tubes were reconditioned and installed in MP-6 as an interim upgrade. Since the positive voltage operation is limited to the maximum negative capability (10 MV negative at present) in order to maintain optimum reliability for injector operation, separate resistor strings for the tube sections are not necessary.

Terminal Ion Source Improvements

The advent of the Middleton-type sputter ion source for two-stage operation considerably reduced the utilization of three-stage operation because of the limited selection of available heavy ions from the terminal off-axis duoplasmatron and the inability to quickly change from one ion species to another. Several years of development, modifications, and improvements to achieve a reliable two-stage operation with sputter sources have indicated the main design elements necessary for a high voltage terminal system. Such a system, utilizing a Hiconex negative ion source,[4] was designed, constructed, successfully bench tested, installed in MP-6, the injector accelerator, and used successfully in support of the research program. The entire electrical power-interlock system for the terminal source was also redesigned and upgraded for the new source installation.

The original terminal source was mounted off axis at an angle of 90° to the beam direction and injected onto the axis with a special electrostatic reflector which was also transparent for the normal two-stage beam.[15] The sputter source, because of its prolific production of both carbon and oxygen ions as well as many other negative ions throughout the periodic table, requires a crossed-field analyzer for appropriate mass analysis in order to avoid loading the accelerator with large numbers of unwanted ions when particular desired ions are being produced. The basic source design make the assembly too long for 90° off-axis mounting as it would protrude outside of the high voltage terminal enclosure. Therefore a new installation was designed so that the ion source axis is parallel to the beam axis but offset beneath it approximately 40 cm as shown in Fig. 2. The heavy ion beam is extracted with 20 KV, focussed, mass analyzed, preaccelerated 80 kilovolts, and then reflected through two 106° bends onto the beam axis with symmetric electrostatic reflectors similar to that originally used but with twice the available aperture. A Faraday cup is provided in line with the source beyond the first 106° reflector so that proper mass selection and focussing can be provided before injecting the beam into the acceleration tube. The layout of the components including an outline of

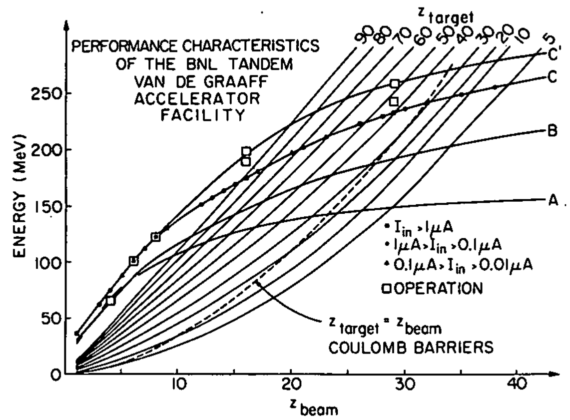

Fig. 3. Heavy ion performance characteristics for the upgraded BNL tandem facility compared to previous capability.

the beam envelope is shown in Fig. 2. The beam optics are arranged for a crossover between the two reflectors through a 0.6 x 2.5 cm slit aperture which provides excellent cesium vapor isolation between the source and the acceleration tubes and in the 0.6 cm direction determines the mass resolution of the crossed field analyzer which is approximately 1 part in 5.

The oven-ionizer system used in sputter sources provides the basic reliability and long life, but can always fail at an unpredictable time and could result in the instantaneous release of gram quantities of cesium vapor into the ion source vacuum system and associated components, including the acceleration tubes. This possibility has been reduced in this terminal source design by the two reflections and small beam defining aperture between the reflectors.

Open Belt Charging Arrangement

Part of the MP-6 upgrade was the installation of a new belt, replacing the original belt which had been operated for 26,740 hours. The belt was installed with a radical modification of the belt guide configuration similar to that devised by M. Letournel[14] which is presently in use in the Strasbourg MP-10 accelerator. The basic idea is to reposition the guides from their normal position where they rub the belt lightly to a clearance of one to two cm so that the belt runs completely free. The only column components in contact with the belt in this modified arrangement are the charging and pick-off screens and the belt pulley motor and generator. The new belt arrangement has operated satisfactorily since its installation (2000 hours) and has not experienced any spark damage to date similar to the performance experienced by Letournel, however, terminal voltage has been limited to 9 MV negative and 10 MV positive where little if any belt damage would be expected. Since the belt is no longer rubbed by the belt guides the production of belt dust is greatly reduced.

Present Performance

The new acceleration tubes in MP-7 have been demonstrated to operate smoothly in excess of 13 MV and experiments have been carried out at 13.15 MV. Under normal operating conditions the accelerator can be conditioned from 10 MV or less to 12 MV in approximately 1 hour/MV and 13 MV in 2 hours/MV. The regulating gas is a mixture of 47% SF_6 - 42% N_2 and 11% CO_2 at 9-10 atmospheres.

The performance of the overall upgraded three-stage facility is shown in Fig. 3. Curve A represents the most probable charge state beam energies attainable with a 13 MV tandem. Curve B shows the performance of the three-stage two-stripper BNL Facilility before the present major upgrade program. Curve C is the performance after upgrading. These curves correspond to the most probable charge state components, but usually less intense higher energy components can be used. Curve C' corresponds to higher energy components such that the intensity is 10 particle nanoamps (6.2 x 10^{10} particles/second) for injected beams (I_{in}) of 1 mocroamp. The solid points on curve C represent ion species that have actually been obtained at BNL and all of which are available from the injector. Most of the missing ion species have simply not been requested in the past and several of them are expected to become available in the future. The open square points represent scheduled beams used to date in the research program since the completion of the upgraded three-stage facility.

The curves labelled Z_{target} = 5,10....90 show beam energy necessary to overcome the Coulomb repulsion to allow a collision between given beam and target nuclei to take place. The vertical distance from a point on a Z-target curve defined by a particular Z beam up to the performance curves A,B,C, and C' defines the range of energy above the Coulomb barrier available for inducing nuclear reactions with heavy ions. The large number of possible nuclear reactions that can be studied at many different energies together with the extreme precision, convenience and flexibility of this type of accelerator make the BNL Tandem Van de Graaff Facility a uniquely powerful tool for light and heavy ion research.

References

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1. Model MP tandem Van de Graaff accelerator manufactured by the High Voltage Engineering Corp., Burlington, MA 01803.
2. P. Thieberger and H. E. Wegner, NIM 122 (1974) 205.
3. J.A. Benjamin et al., IEEE Trans. Nucl. Sci. NS-18.
4. Negative ion sputter source model 832 manufactured by the General Ionex Corp., Ipswich, MA 01938.
5. R. Middleton and C. T. Adams, Nucl. Inst. & Meth. 118 (1974) 329.
6. Stainless steel acceleration tube section type D-TU-773(1) and type D-TU-779(7), manufactured by the High Voltage Engineering Corp., Burlington, MA 01803.
7. J.D. Larson, NIM 122 (1974) 53.
8. Tube resistor 800 megohm type C-22-561-0800, column resistor, 800 megohm, type D-CR-414-0800, manufactured by the High Voltage Engineering Corp., Burlington, MA 01803.
9. K.H. Purser et al., NIM 122 (1974) 159.
10. P. Thieberger et al., NIM 122 (1974) 291.
11. P. Thieberger and H.E. Wegner, NIM 126 (1975) 231.
12. Universal negative ion source, Mark II, VI manufactured by Varian/Extrion Div., Gloucester, MA 01930.
13. J.D. Larson and J.A. Benjamin, RSI 39 (1968) 272.
14. M. Letournel, private communication.