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A 3He++ RFQ Accelerator for the Production of PET Isotopes

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Abstract

Project status of the $3He^{++}$ 10.5 MeV RFQ Linear Accelerator for the production of PET isotopes will be presented. The accelerator design was begun in September of 1995 with a goal of completion and delivery of the accelerator to BRF in Shreveport, Louisiana by the summer of 1997. The design effort and construction is concentrated in Lab G on the Fermilab campus. Some of the high lights include a 25 mA peak current $3He^{+}$ ion source, four RFQ accelerating stages that are powered by surplus Fermilab linac RF stations, a gas jet charge doubler, and a novel 540 degree bending Medium Energy Beam Transport (MEBT). The machine is designed to operate at 360 Hz repetition rate with a 2.5% duty cycle. The average beam current is expected to be 150-300 micro amperes electrical, 75-150 micro amperes particle current.

HISTORY

The current project is a continuation of a SDIO funded effort between SAIC and University of Washington (UW) that began in 1990.[1] The use of a 3He RFQ linear accelerator to replace cyclotrons could have several advantages: no need for enriched target material, lower shielding requirements, high reliability, and ease of maintenance and operation. The project was revived in 1995 with the addition of two collaborating institutions, Fermilab and Biomedical Research Foundation of Northwest Louisiana (BRF). Fermilab is the managing partner and has the prime responsibility for building and commissioning the accelerator. SAIC is also part of the accelerator development team and will ultimately be responsible for operation of the accelerator when it is delivered to BRF late summer 1997. UW and BRF are the collaborators responsible for radiochemistry experiments which are projected to be carried out for an additional two years after the accelerator is commissioned at the BRF facility in Shreveport, Louisiana. The project is funded by the Department of Energy.

THE ACCELERATOR

The initial SDIO funded project was a linear 8 MeV $3He^{++}$ accelerator that would utilize three RFQ's in series. The first RFQ was chosen to operate at 212 MHz to improve capture efficiency and accelerate the 3He beam to 1 MeV where it would be stripped to a doubly charged state for more efficient acceleration in the subsequent RFQs. The following two RFQs operate at 425 MHz and require some longitudinal matching of the beam. Initial attempts to bunch rotate the beam with an RF cavity after the charge stripper failed due to the charge neutralized character of the beam.

The high average current of the accelerator requires a robust ion source. Efforts to create a doubly charged ion source were abandoned as they were beyond the scope and funding available for the project. The ion source used is a duoplasmatron that can be operated on both 4He and 3He. The source can be started and commissioned with 4He with 3He used one it has stabilized. (3He cost is $100/liter, consumption is approximately one liter per day.) Initial problems with filament burn out were overcome when the Nickel gauze was replaced with Molybdenum. Operation with 360 Hz, 2.5% duty cycle and 25 mA peak current single charge is routine. The Low Energy Beam Transport (LEBT) consists of two small steering magnets and a 5 inch beam diameter solenoid.

During the period when the project was stopped due to lack of SDIO funding and picked up again by the DOE, it was also decided to increase the energy of the beam to 10.5 MeV in an attempt to make target cross sections more viable for production of the desired isotopes and the target window (separating the targets from the accelerator vacuum) more robust. This project was not resumed on a green field as the funding for the project was limited to $10 million, needed to utilize as much of the original SDIO equipment as possible, and had to include the two years of chemistry research. The decision to increase energy necessitated a fourth RFQ for the system. The design was similar to the existing segmented vane RFQs and operates at 425 MHz.[2,3] One of the problems with the original project was a source of reliable RF power. Four surplus RF stations were available at Fermilab following the upgrade of the Fermilab Linac to side coupled cavities in 1993. The Continental Electronics RF stations served the FNAL linac faithfully for a quarter of a century and now have found a new use in the PET project. The 212 MHz station was easily converted from the 201 MHz frequency of the Fermilab Linac. The power amplifiers for the 425 MHz systems were purchased from the former GTA project at Los Alamos. We were fortunate in that the GTA amplifiers utilized the 4616 tetrode of the existing linac stations. A few mechanical changes were required to integrate the hardware into the existing relay rack enclosures. Each RF system is capable of a minimum of 120 KWatts of pulsed RF power at the rated duty cycle and repetition rate.

The charge doubler design centers on using a gas jet. The idea of using thin foils for stripping the second electron from the $3He^{+}$ beam were quickly dismissed as the thickness of the foils would be too thin to be mechanically robust. A novel idea of using an automotive fuel injector has proven to be a reliable and inexpensive solution to the problem.[4]

The linear appearance of the machine changed once the final energy was increased. The problem of longitudinal matching between RFQ's needed to be overcome and required a

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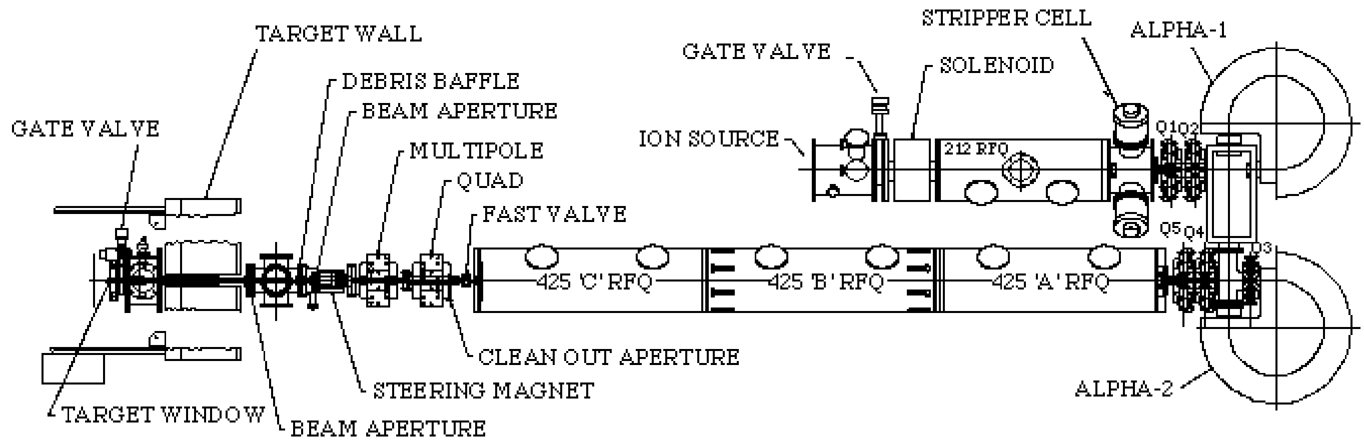

Figure 1. Layout of 10.5 MeV $3He^{++}$ PET accelerator.

non RF solution. A matching section between 212 & 425 MHz RFQs utilizes a 540 degree bend consisting of seven quadrupoles and two "alpha" 270 degree dipoles.[5] This Medium Energy Beam Transport (MEBT) changed the layout of the machine to bend back on itself. (figure 1) A side benefit is the overall length of the machine was reduced and would easily fit into both the development area at Fermilab and the facility at BRF. The magnets for the MEBT and LEBT were designed and manufactured at Fermilab's Technical Support Division.[6] The final transport stage is the High Energy Beam Transport (HEBT) which utilizes a quadrupole, multipole and steering magnets from the original project to expand and control the beam to the required 2.5x10 centimeter size of the Havar target window.

A number of support systems have been specifically designed for the project. The Low Level RF system utilizes the VXI platform and provides amplitude, phase, and frequency control for all four RF systems. Frequency tuning of the RFQs is accomplished by modulating the phase of the IQ modulator removing the need for individual VCOs. The RFQs are thermally tuned via a closed loop water cooling system for each RFQ consisting of a Neslab chiller and custom electronics. The diagnostics package is complete with a number of current torroids, segmented Faraday apertures,

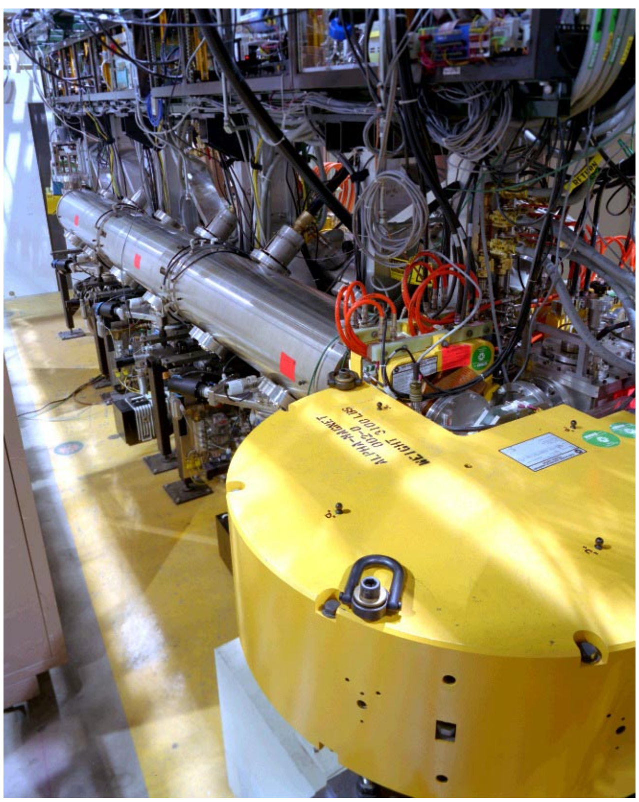

Figure 2. View of 425 MHz RFQs and alpha 2 magnet of the MEBT.

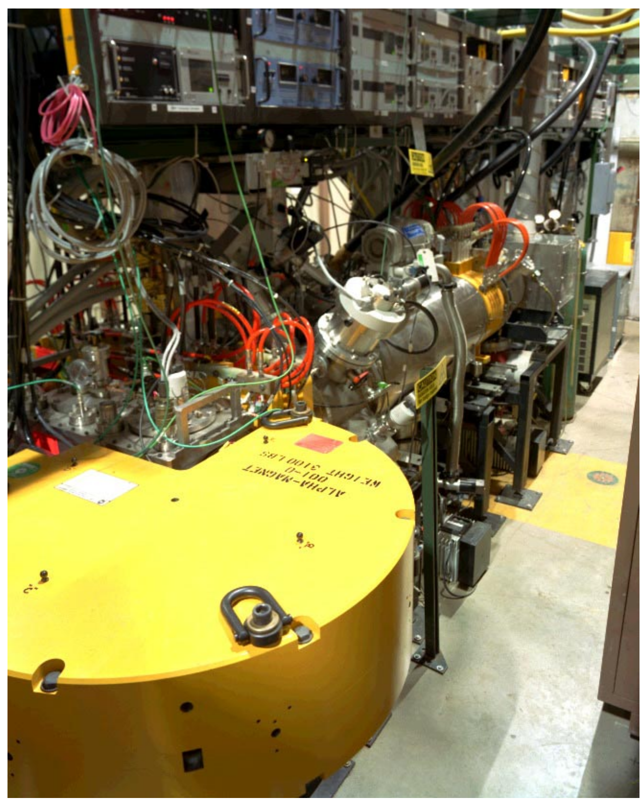

Figure 3. View of Ion Source, 212 MHz RFQ, Charge Stripper, and alpha 1 magnet of the MEBT.

multiwire profile monitors, thermocouples, vacuum monitors, movable target beam collimaters and targetry instrumentation. A complete Low Conductivity Water (LCW) and chilled water system are part of the stand alone design that will be shipped to the BRF facility. The control system is based on the Internet Rack Monitor (IRM) that was developed for the FNAL linac upgrade.

The entire accelerator was designed with mobility in mind as it must be transported to Shreveport after initial commissioning at Fermilab. All relay racks and RF stations are easily picked up by forklift and will be shipped with electronics intact. The major challenge will be disassembly of system cabling. The footprint at Fermilab is identical to that in Shreveport with the exception of the Anode supplies for the RF stations.

PERFORMANCE RESULTS

Work on designing and building the accelerator began on September 1, 1995. The first six months were dedicated to characterizing the equipment from the original project and converting RF stations. It was noticed early in the project that the "light weight" requirement imposed by the SDIO funding was a source of trouble. The vacuum vessels were constructed from Aluminum and provided little shielding from x-rays produced by the RF fields in the RFQs. This problem was mitigated by placing the RFQs in 1-5/16 inch thick stainless steel vacuum enclosures. (See figure 2 &3)

The ion source has been running trouble free at full duty cycle, peak current of 25 mA, for several months with only one filament change. Cold start up time is minutes. The timing system has been set up to allow different triggering of the source and RF systems, allowing full flexibility in duty cycle while not compromising source performance.

A severe leak in the water channels of the RFQ vanes has cause an appreciable amount of delay in the project. The vanes are constructed of 7075 Aluminum which is highly sensitive to corrosion. The water cooling channels have corroded sufficiently to cause a leak to the main vacuum vessel. This problem was temporarily fixed with the use of a casting impregnation solution. All vanes for all RFQs needed to be re-fabricated. Teflon coating of the water passages and water treatment have been implemented to retard corrosion. The replacement 212 MHz RFQ is currently being fabricated.

The MEBT was commissioned over a period of weeks and found not to have any serious space charge effects. This was the most controversial aspect of the project and was rewarding to experience success.

Commissioning of the RFQ systems has proven to be a little tricky in that all of the RF stations and RFQs have a slightly different personality. The surplus linac stations have been modified to make them identical. The control system software has made operations simple. All four RF stations can be turned on and at resonance in a matter of minutes.

The HEBT has been installed and beam has been delivered to a Faraday cup in the vault. Measurements of shielding efficiency are in progress.

The current status of the machine is 6 mA peak, 25 microamperes average (electrical) 10.5 MeV beam has been accelerated to the target vault at the 120 Hz repetition rate. Increasing the duty cycle and current are the main focus of commissioning. Efforts now are directed to improving operational performance and reliability.

A six week radiochemistry program is just underway. The intent is to do a wide array of targeting of various materials at Fermilab in an attempt to fully assess the radiation produced and the shielding necessary to allow occupancy near the accelerator and target vault.

The accelerator will be shipped to the BRF facility where it will be installed in a specially prepared room in the building's physical plant. The shipping, assembly and re-commissioning at BRF is expected to take approximately two months. After that time, the accelerator will be made available for PET isotope production research. As the accelerator is not FDA approved, isotopes produced by this accelerator will not be used in the clinical PET center.

ACKNOWLEDGMENTS

The extremely tight schedule and funding for the project required a talented group of people to carry it out. The members of the collaborating institutions have shown a dedication and professionalism that has made this ambitious project a reality.

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