01-222R1(A) - BEAM DIAGNOSTICS AND HIGH TRANSMISSION OPERATION OF ATLAS

Principal Investigators: R. C. Pardo, Physics
P. N. Ostroumov, Physics

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Purpose: Two major R&D issues to be addressed for the RIA site specific proposal are: i) the demonstration of proper diagnostic tools to tune the accelerator for the weak beam intensities that must be dealt with for very exotic species at RIA and ii) the ability of ATLAS to provide the additional acceleration with minimal losses in these radioactive isotopes. Both items are critical for RIA.

Approach: The longitudinal tune of the RIA accelerators is critical for the success of RIA. For the driver linac, a good longitudinal tune directly impacts the ability to accelerate the drive beam with minimal losses and allow hands-on maintenance of most components. For the re-acceleration of the radioactive beams, a good longitudinal tune is necessary to achieve the maximum transmission efficiency and maintain beam quality. Two new diagnostic techniques have been developed to address these goals. First a new bunch shape monitor system has been developed and tested at ATLAS. Second a new technique for measuring beam arrival time using a superconducting cavity has been investigated. Both techniques are being studied and have actually been used to tune beams at the ATLAS linac to study their properties and assess their applicability for actual operations.

Technical Progress and Results: This LDRD program examined factors affecting transmission through ATLAS and the diagnostics needed to insure proper tuning of the machine for weak beams. A diagnostic station for weak beams was developed using secondary emission of electrons from a thin foil, masks and position sensitive detection via high-resolution CID camera to determine the position, shape and emittance of the beams. The device was tested successfully with very low energy beams at the Dynamitron. The diagnostic station developed in this program can form the basis for similar stations at RIA.

Bunch Shape Monitor. A new device for the measurement of a CW heavy-ion beam time profile with resolution ~20 picosecond has been constructed and successfully commissioned on ATLAS. Secondary electrons are produced when a primary beam hits a tungsten wire to which a potential of -10 kV is applied. The electrons are accelerated by the target voltage, collimated and passed through the rf field of the deflector. The deflector is a quarter-wave parallel-wire line resonator with the electrode plates installed at the maximum of the rf electric field. The deflector operates at 97.0 MHz and is synchronized with the master oscillator of the linac.

Detection of the secondary electron beam is done with a combination of a phosphor screen and a light sensitive detector. A monochromatic CCD (charge coupled device) is sufficient for detecting the light signal. A dual multi-channel plate (MCP) detection system was used to obtain high gain. The dual MCP system has a combined maximum gain of 4×10^7. About 0.5 mm behind the second MCP there is a type P-20 phosphor plate. It is biased at 3 kV relative to the MCP output to convert the accelerated electron’s energy into photons of predominantly 560 nm wavelength. Upstream of the MCP plates a grid with 90% of transmission is installed. By biasing the grid up to –1 kV parasitic low energy secondary electrons can be prevented from producing a background signal. The secondary electrons are produced as beam scatters from a tungsten wire with a diameter of 0.17 mm installed on a U-shape holder connected to a linear motion actuator.

The BSM control system is implemented using the software package LabVIEW. The system controls operation of the HV and rf power supplies, the stepper motor and the CCD camera. The electronics within the camera allow the CCD sensors to be read out using the RS-170 standard of rastering images. The signal is amplified and then fed into a PCI-1408 frame grabber circuit board.

This type of registration device has several advantageous: wide dynamic range of measurements and real time observation of the bunch time profile. Bunch center fluctuations in time or with respect to the reference rf phase can be observed on-line. Time resolution of the BSM depends on two main parameters: 1) the width of secondary electron beam image without the rf fields and 2) rf voltage amplitude. The rf voltage can be easily increased in order to improve the resolution while the width of the electron beam image depends on the properties of the secondary electrons and beam optics between the wire and phosphor screen. Numerical simulations of secondary electron beam motion from the thin wire to the location of the MCP were carried out with the code Simion 7 for the case when the rf voltage is not applied. The simulations show that the electron beam shape on the screen is mainly defined by the angular distribution of emitted electrons. In experiments we observed an asymmetric shape of the electron beam distribution that is probably related to the complex interaction of the primary beam hitting the edge of the wire tangentially.

The BSM was installed at the ATLAS beamline 4.06 m downstream of the last SC resonator of the Booster. Tests of the BSM were done with 10 -100 pnA $^{58}Ni^{15+}$ ions from the Booster section of the ATLAS. The beam energy was adjusted from 6.5 to 7.2 MeV/u. A typical electron beam image focused on the screen is about 1 mm width. The time resolution for these tests was 40 ps, set in order to observe the full bunch on the screen. Higher resolution can be achieved by increasing the rf voltage.

For the measurement of the longitudinal emittance of the beam several last resonators of the Booster except the very last one were turned off. The last resonator was used as a rebuncher. From the measurements of the bunch longitudinal profiles for different levels of rf field in the rebuncher, the rms widths of the bunch were calculated. A ray-tracing code was used to fit the simulated bunch widths to the measured data. In this procedure the initial ellipse parameters of the beam in longitudinal phase space are adjusted to obtain the best fit to the measured data. The rms longitudinal emittance of the $^{58}Ni^{15+}$ beam was measured to be 2.6 π keV/u-nsec.

High Transmission Operation at ATLAS. To obtain a high percentage of beam transmission through either the RIA linac or ATLAS, the resonator RF phases must be properly set in order to accept the beam from the LEBT ion source/bunching system and to maintain the beam properties throughout the linac. The most difficult region to properly configure is the initial matching region into the linac and the early beam acceleration region up to approximately 1.5 MeV/u. This year a new beam tuning procedure was developed that employs downstream superconducting resonators to measure the beam phase at that location. By making phase (arrival time) measurements as a function of the phase angle of the last accelerating resonator the beam-resonator phase angle can be determined and properly set for proper matching of the beam. This technique has been implemented at ATLAS and has resulted in a significant improvement in the setup accuracy of the PII linac. Total transmission through the PII linac (including the bunching efficiency) now is typically 65% and has been as high as 75% of the DC beam.

During the past year, studies have been undertaken to improve the performance of the LEBT for the PII injector of ATLAS. The PII LEBT has been studied with regard to various mechanisms of beam loss with the present system. As a result of those studies, the LEBT has been carefully realigned from the ECR-I ion source to the PII linac, and a study of beam losses due to vacuum conditions in the LEBT has been undertaken. These studies have resulted in significantly improved transmission for beams from ECR-I.

Another major improvement in transmission occurred when it was realized that low-velocity highly-charged heavy ions can experience losses of up to 30% of the original beam over distances of approximately 5 meters due to charge exchange, even with pressures as low as a $5X10^{-7}$ Torr. To reduce those losses to negligible values the beamline pressure must be maintained at values less than $1X10^{-8}$ Torr. Improvements have been made so that beamline pressure is now typically $5X10^{-9}$ Torr resulting in less than 1% losses for charge exchange.

Overall these improvements in the low-energy beam transport system and the resonator tuning procedure has allowed ATLAS to achieve a total transmission efficiency of 35% from the ion source to target for a beam of ^{54}Fe in a recent experiment at ATLAS. This represents a 50% increase in transmission efficiency from the best previously obtained.

Specific Accomplishments:

Publications:

N.Y. Vinogradov, P. Billquist, P.N. Ostroumov, R.C. Pardo, M. Portillo, S.I. Sharamentov, G.P. Zinkann, Bunch Shape Measurement of CW Heavy-Ion Beam., paper presented at XXI International Linac Conference (LINAC2002), Gyeongju, Korea, August 19-23, 2002.

S. Sharamentov, R. Pardo, P. Ostroumov, B. Clifft, G. Zinkann, 'Super-Conducting Resonator as Beam Induced Signal Pickup,' submitted to the 2003 Particle Accelerator Conference.