Status of the Uranium Upgrade of ATLAS

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Abstract

The ATLAS Positive Ion Injector (PII) is designed to replace the tandem injector for the ATLAS heavy-ion facility. When the PII project is complete, ATLAS will be able to accelerate all ions through uranium to energies above the Coulomb barrier. PII consists of an ECR ion source on a 350 KV platform and a very low-velocity superconducting linac. The linac is composed of an independently-phased array of superconducting four-gap interdigital resonators which accelerate over a velocity range of .007c to .05c. The PII project is approximately 75% complete. Beam tests and experiments using the partially completed PII have demonstrated that the technical design goals are being met. The design, construction status, and results of recent operational experience using the PII will be discussed.

Introduction

The ATLAS superconducting linac [1] is the largest heavy-ion post-accelerators. The range of ion species which may be accelerated by ATLAS is limited to mass A < 127 by characteristics of the 9-MV tandem injector and to beam currents of typically a few particle nanoamperes for the heavier ions. The Positive Ion Injector project [2,3] will replace the ATLAS tandem electrostatic injector with a new injector which will greatly increase the beam current for all ions and extend the mass range of ATLAS to include uranium.

The Positive Ion Injector project combines an ECR source and pre-linac bunching system with a superconducting linac to produce a new class of low-velocity accelerator. The elements of PII are shown in figure 1. Design studies indicated that such a low-velocity injector would provide sufficient velocity to match the remainder of the ATLAS linac for ions of all masses. These calculations also predicted beam quality similar to that of lighter ions from the present ATLAS tandem injector.

Construction has proceeded in several phases. First, the technology for a very low-velocity superconducting linac was developed [4,5,6]. At the same time an ECR source was designed and built on a high voltage platform [7,8]. The source, beam transport and bunching system, and a small (3.5 MV) portion of the linac were completed and beam tested in early 1989 [9]. In the first half of 1990, the system was operated with 7 MV of linac installed. PII will be completed in late 1991 when the linac is enlarged to 12 MV. This final injector will accelerate uranium ions up to more than 1 MeV/A, enough for ATLAS to accept the beam and further accelerate it to ≈ 8 MeV/A.

Elements of the PII System

<u>ECR Source and High-Voltage Platform.</u> The ECR source is a typical 10 GHz source which was designed to operate on a 350-KV platform. Provision for radial access to the plasma region facilitates introducing solid source materials (in the form of wire, for example) into the plasma. To provide good beam bunching and longitudinal beam quality, the platform voltage must be stable to better than 1 part in 10^4.

Construction of the ECR source and high-voltage platform was completed in 1987. The source has been used since then both for beam tests and for several atomic physics experiments [7,8]. Some important results are that: 1) a variety of beams have been produced from solid samples with very high efficiency, 2) more than 1 eμA of $^{238}U^{24+}$ has been produced, and 3) the voltage on the high voltage platform is sufficiently stable for excellent beam quality.

<u>Beam Bunching.</u> The two-stage bunching system is similar to that used for tandem injection of ATLAS. The first stage is a gridded-gap four-harmonic buncher with a fundamental frequency of 12.125 MHz. The amplitude of the first stage is adjusted to form a time waist about 35 m

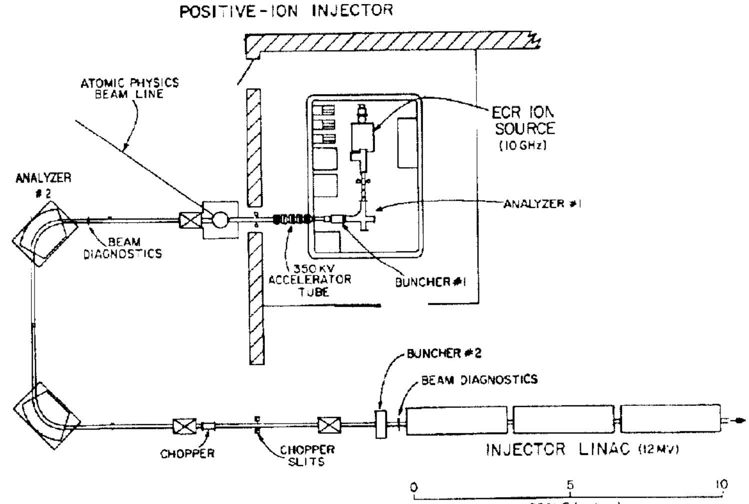

Fig. 1. Layout and major elements of the positive ion injector(PII).

downstream, near the second stage buncher. The second buncher is a two-gap normal-conducting spiral-loaded resonator operating at 24.25 MHz, which forms a time waist ≈ 1 m downstream, near the first resonator in PII.

Development of new detection techniques[10] was necessary in order to study bunching of these low velocity ions. To date, the best bunching result is a measured 1.2-nsec FWHM for an $^{40}Ar^{12+}$ beam with the first stage buncher. The second stage buncher then formed a 130-psec bunch at a detector 55 cm downstream. This time spread is remarkably small for such a low energy beam (0.05 MeV/A).

<u>The Injector Linac.</u> The injector linac is formed from four types of independently-phased, four-gap accelerating structures. The linac is based on the fact that short, high-gradient superconducting accelerating structures can be closely interspersed with short, powerfully focusing superconducting solenoids. The rapid alternation of radial and longitudinal focusing elements maintains the beam in much the same way as does a Wideroe-type rf structure with magnetic lenses in the drift-tubes, but with the added flexibility of independently controlled, modular elements which allows the velocity profile to be tailored to the selected ion species.

The construction sequence of PII has been based on the flexible velocity profile of an independently-phased resonator linac. The design goal of the PII is for efficient acceleration of ions with a charge-to-mass ratio of 0.1. It was possible to configure the linac to usefully accelerate highly charged light ions with as few as five resonant cavities. This capability has allowed the features of the linac to be tested as each cryostat is completed.

At present 10 of 18 resonant cavities have been completed and are operational. Accelerating field levels obtained in off-line tests average above 4 MV/m. The average on-line level is 3 MV/m, the original design goal, but is presently limited by characteristics of the fast-tuning system and is not believed to be a fundamental limit. The lowest velocity resonator (β = .008), has repeatedly been operated with beam at gradients above 6 MV/m.

The performance of the complete PII injector linac as a function of mass is shown in Figure 2. The different curves result from differing assumptions on charge states from the ECR ion source and, therefore, different beam currents.

Beam Tests and Operation

The highly adaptable nature of the linac has permitted a series of beam tests as construction of the low-velocity linac has proceeded. This has included several periods of actual operation of ATLAS injected with the PII system.

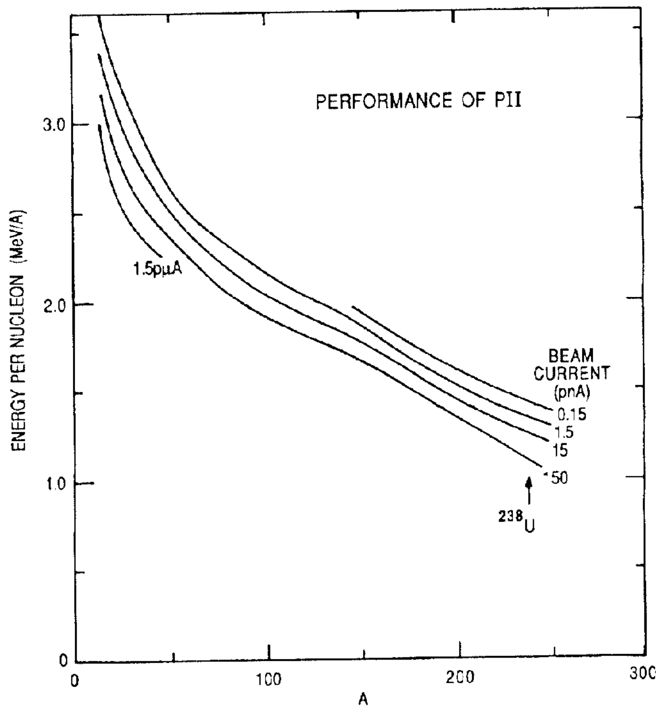

Fig. 2. Expected PII output energy as a function of mass and beam current. The different curves assume different charge states and, therefore, beam currents from the ECR ion source.

First beam through PII was obtained in February 1989, with a 3.5 MV configuration of the linac. A 1μA beam of $^{40}Ar^{12+}$ was accelerated to as much as 36 MeV. In the course of these tests the beam was injected into ATLAS, accelerated to 173 MeV, and used for a brief (6 hr) experiment. Another series of tests were performed in 1990, with a 10-resonator, 7 MV configuration of the PII linac.

A variety of beams have been accelerated with PII, including $^{3}He^{2+}$, $^{13}C^{4+}$, $^{16}O^{6+}$, $^{40}Ar^{12+,13+}$, $^{83}Kr^{17+}$, $^{86}Kr^{15+}$, and $^{92}Mo^{16+}$. In addition to beam tests of PII, the system has delivered beam to the ATLAS linac for tests and for several experiments totaling more than four weeks.

Operation of the PII system has been characterized by excellent reliability and stability. Even in these early tests, all elements of the system typically ran for extended periods, several days, with little or no operator intervention.

A primary goal for the new injector has been to achieve beam quality competitive with that of the tandem, especially in longitudinal phase space. Measured longitudinal emittance, ϵ_Z, of several beams is shown in Table I. These tests demonstrate that the beams from PII have substantially smaller longitudinal emittance than similar tandem beams, and that PII sets a new standard of quality for heavy-ion beams.

Conclusion

The results of beam tests to date indicate that all design goals for the PII system will be met. Tests of the partially completed system already demonstrate that the combination of an ECR ion source with a low-velocity superconducting linac provides an alternative to tandem electrostatic accelerators that is not only cost-effective, but can also provide improved beam quality and increased beam current.

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TABLE I
Measured Longitudinal Emittance

Ion	Stripping Post-Injector	ϵ_Z(keV-nsec) Tandem	PII
$^{3}He^{2+}$	no		$<1\pi$
$^{16}O^{6+}$	no	15π	
$^{16}O^{8+}$	yes	20π	
$^{40}Ar^{12+}$	no		5π
$^{58}Ni^{10+}$	no	30π	
$^{58}Ni^{19+}$	yes	40π	
$^{86}Kr^{15+}$	no		19π

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