THE ATLAS INTENSITY UPGRADE: PROJECT OVERVIEW AND ONLINE OPERATING EXPERIENCE*

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Abstract

ATLAS, the world's first accelerator to use RF superconductivity for ion acceleration, has undergone a major facility upgrade with the goals of significantly increased stable-beam current for experiments and improved transmission for all beams. The dominant components of the upgrade are a) new CW-RFQ to replace the first three low-β resonators, b) a new cryostat of seven β=0.077 quarter-wave resonators demonstrating world-record accelerating fields, c) an improved cryogenics system, and d) the retirement of the original tandem injector. This latest upgrade followed closely on the earlier development of a cryostat of β=0.14 quarter-wave resonators. The reconfigured ATLAS system has been in operation for over one year and its performance after the upgrade will be presented.

INTRODUCTION

ATLAS (the Argonne Tandem Linac Accelerator System) is the world's first superconducting accelerator for ions. ATLAS began as a proof-of-principle project in the early 1970s to demonstrate that a superconducting resonator's field amplitude and phase could be controlled with sufficient precision to enable the acceleration of ions [1]. In order to continue to meet current requirements of the experimental program, ATLAS has been continuously upgraded to provide the tools necessary to remain at the forefront of nuclear science.

A key component in ATLAS's continuing success has been the constant improvements to the facility including the evolution of best practices in constructing and operating superconducting resonators as well as new techniques for ECR ion source operation. Those developments are seen in the different classes of resonators that have been developed at Argonne and the new techniques in superconducting RF (SRF) technology that have been applied and the world best performance of the CARIBU ECR charge breeder ion source. From the split-ring resonator which was capable of approximately 3 MV/m accelerating field, to the quarter-wave resonators used in the Positive Ion Injector section of ATLAS installed in the early 1990s, and now to the fully helium immersed; pure niobium quarter-wave resonators used in an energy upgrade of the facility in 2009 as well as the most recent new upgrade to the center (Booster) section of ATLAS in 2014, one sees a continuing progression of state-of-the-art SRF technology now culminating in routine accelerating fields of up 8 MV/m.

This paper describes the overall facility operating performance and goals achieved in three major improvement projects going back to 2009. The goals of these projects are to improve the linac performance by increasing the maximum available beam current and improving the overall beam transmission and efficiency in order to increase beam currents for radioactive beams and high current stable beam operations.

PROJECTS OVERVIEW

In the last 6 years, the ATLAS accelerator has undergone a number of improvements that are aimed at addressing the current and future needs of the nuclear science community. These changes to the ATLAS accelerator have provided significant performance improvements in both accelerating fields and beam transmission. Thus four major accelerator improvement activities have been implemented at ATLAS in the past few years:

1. A new cryostat of seven quarter-wave (β=0.14) resonators has been installed as the last ATLAS cryostat restoring the maximum beam energy to approximately 21 MeV/u for the lightest ions and approximately 10 MeV/u for unstripped ^{238}U.

2. A new, room-temperature CW radio frequency quadrupole (RFQ) linac has been installed as the first accelerating resonator in the linac. It replaces three of the original, very low-velocity, superconducting resonators of the Positive Ion Injector (PII) Linac. This project has improved the overall bunching efficiency so that approximately 80% of the DC source current can be captured into a high-quality beam for acceleration through ATLAS.

3. A second new cryostat of seven quarter-wave (β=0.077) resonators has been constructed to replace three cryostats of split-ring resonators in the middle section (booster) of the ATLAS linac. These resonators are achieving world-record accelerating field performance for low-beta resonators, and reducing the total resonator count in the linac (from 64 to 51) while maintaining the total accelerating voltage. The center portion of the original ATLAS cryogenic system has been completely rebuilt, the beam optics in the center section of the ATLAS accelerator was redesigned and improved, and new shielding was installed to accommodate the higher intensity stable beams that are now available.

The ATLAS facility floor plan and identification of the location of these projects is shown in Figure 1.

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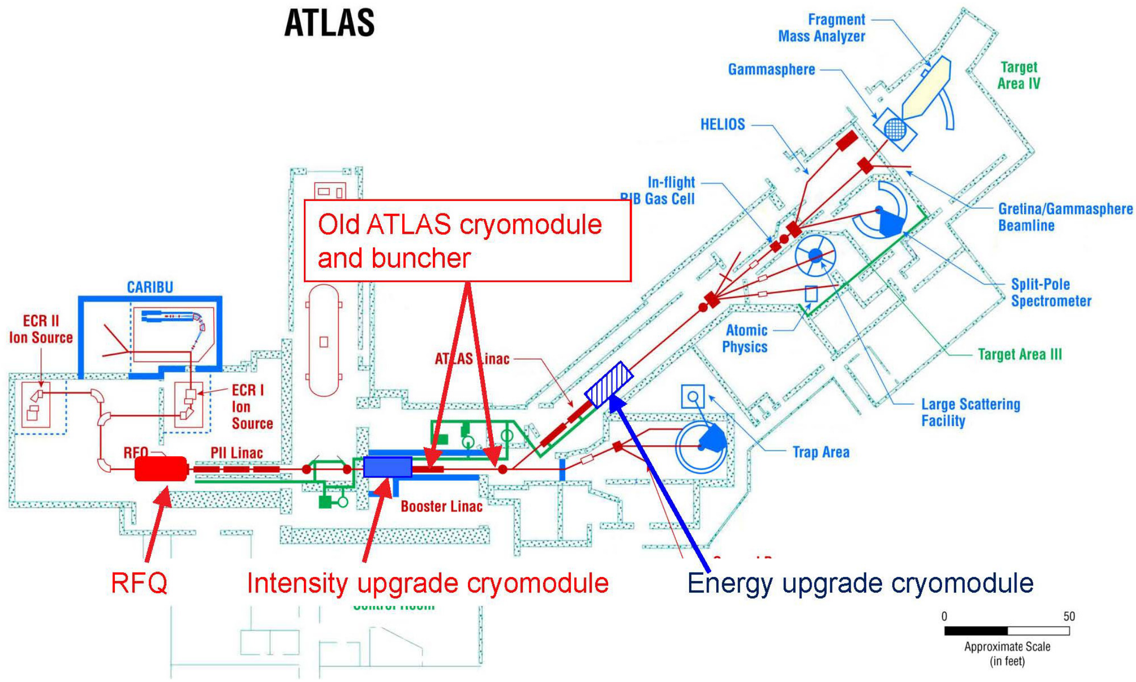

Figure 1: Floor plan of ATLAS showing the location of the major improvement projects discussed in this paper. The tandem injector, now retired, is shown but now disconnected from that ATLAS accelerator.

ENERGY UPGRADE CRYOSTAT

The energy upgrade cryostat with seven 'high' beta (β=0.14) cavities was completed and installed in 2009. The details of the resonator and cryostat design and commissioning performance can be found in reference [2]. Since then the resonators have provided over 2000 hours of accelerated beam for research.

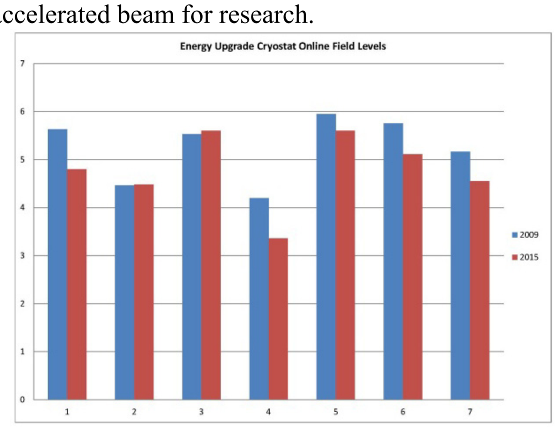

Figure 2: Comparison of on-line resonator field performance of the β=0.14c QWR energy upgrade project resonators between 2009 and 2015. The average accelerating field performance in 2009 was 5.2 MV/m compared to 4.8MV/m in 2015.

The adoption of independent insulating vacuum and internal resonator/beamline vacuum space has greatly improved the long-term resonator online performance. After six years no clear degradation in field performance can be observed. The chart in Figure 2 compares the 2009 resonator commissioning performance and the present 'normal' operating performance for these resonators. One does notice that there is approximately a 10% decrease between the maximum commissioning fields achieved in 2009 and those routinely achieve today. But this decrease is due to desiring reliable operation and achieving a certain level of 'safety' with regard to the VCX PIN diode system. At this point, the field level in these resonators is limited by the power handling capability of the VCX system.

EFFICIENCY AND INTENSITY UPGRADE PROJECT

The Intensity and Efficiency Upgrade Project for ATLAS is designed to address the need for efficiently accelerating all beams (radioactive and stable) and to retire old split-ring resonators which have been in operation for over 35 years. Here 'efficient' means the highest possible transmission and bunching efficiency through the accelerator to target for all beams. The original PII linac design used quarter wave resonators that had a matched velocity as low as 0.009c. Only one resonator had such a low matched velocity but this resonator nearly doubled the beam energy from the ion source in a 10 cm total distance. The resonator was a 'split' drift tube design creating a 4-gap structure [3]. The beam optics of this one resonator created a small acceptance window and functioned in an alternating phase focusing mode. The result was significant emittance growth and loss of beam due to the mismatch condition in this early stage of acceleration. Therefore transmission through the PII linac was typically 60-65% and the transmission through the rest of the accelerator and beam transport was 80-85% at best.

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Radio Frequency Quadrupole

The details of the design and commissioning performance of the RFQ linac can be found in reference [4]. The RFQ operates at 60.625 MHz, with a maximum vane voltage of 70 kW in CW mode. It is the first RFQ in the U.S. to operate on-line in CW mode and one of a very few in the world at this time. The RFQ is designed to accelerate ions with M/Q<7 from 30 to 295 keV/u.

The RFQ came into operation in January of 2013 and has now provided approximately 8000 hours of beam acceleration since then. Overall reliability has been over 92%. Up to the present, the highest M/Q beam delivered used an M/Q ~6.7.

The RFQ uses a novel high precision temperature control system to tune the RFQ eigenfrequency to the master oscillator. This system has worked extremely well but the original high resistivity water system caused electrolytic erosion in some parts. That system has recently been separated into two parts with only a small system that is required to cool the tetrode final stage tube of the RF transmitter requiring high resistance water.

The limitation on high field operation required for M/Q of 7 seems to partially be due to outgassing of the RFQ at high fields. Improved pumping is expected to be installed by the end of 2015 to improve reliability at the highest fields.

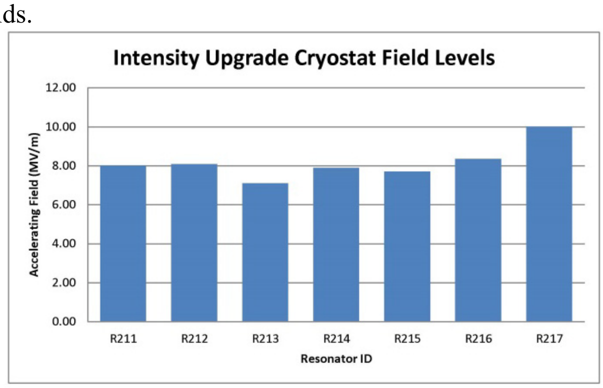

Figure 3: Performance of the ATLAS β=0.077 resonators during the first year of operation. The average field performance of these resonators has been 7.3 MV/m compared to the initial commissioning average of 8.2 MV/m.

Intensity Upgrade Cryostat

In February 2013 an additional new cryostat containing seven newly designed β=0.077 resonators was installed and commissioned. These resonators are described and their initial performance documented in [5]. The design choices made for these resonators and for the associated RF control system grew from the success achieved in the β=0.14 resonator developments of 2009. A major step was taken in this project by retiring the phase control system for all previous installations at ATLAS, the Voltage Controlled Reactance (VCX) PIN diode system and adopting a driven RF system for these resonators. They have now been operating for over one year and their online performance is shown in Figure 3.Compared to the field levels achieved in commissioning, the year over average is only reduce by 11%. This reduction is due to some difficulties with the new driven RF electronics and handling some vibrational situations with the cryogenics system. We see no degradation of resonator performance as seen by individual Q-curves for each resonator.

SUMMARY

The ATLAS upgrades implemented over the past 6 years have performed at or above the expected performance levels. We see no degradation in resonator field performance nor in the RFQ performance. The success of these projects has restored the original energy profile of the facility and sets the stage for the delivery of much higher beam currents than have been previously achieved.

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