ATLAS UPGRADE*

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Abstract

The ongoing ATLAS (Argonne Tandem Linac Accelerator System) upgrade project requires several substantial developments in accelerator technologies: a CW heavy ion RFQ and a high-performance cryomodule with seven low-beta cavities. The upgrade project is well advanced. The physics and engineering design of the RFQ are complete and fabrication of OFE copper parts is in progress. High-temperature furnace brazing of the 5 strongly coupled segments which form the 3.9-meter long RFQ is planned for the summer of 2011. The RFQ design includes several innovative features such as trapezoidal vane tip modulation and a compact output radial matcher to form an axially symmetric beam. The upgrade project also includes the development and the construction of a cryomodule containing seven 72.75 MHz SC quarter wave cavities designed with a geometrical β_G=0.077 and four SC solenoids. The cavity design provides an accelerating voltage greater than 2.5 MV per cavity. The prototype cavity which includes a high-power capacitive coupler and piezoelectric tuner has been developed, fabricated and is being tested. This paper reports on the innovative design features incorporated into both the RFQ and the cryomodule and the current status of the project.

INTRODUCTION

The efficiency and intensity upgrade of ATLAS [1,2] is motivated by the need to increase intensities for both stable and exotic beams to address the most pressing scientific issues defined in the most recent NSAC Long Range Plan. A normal conducting 60.625 MHz CW RFQ will be installed in front of the SC linac to increase both transverse and longitudinal acceptance of ATLAS. A new high-performance cryomodule with 7 β_G=0.077 72.75 MHz resonators will replace three existing cryomodules with aging split-ring cavities.

Stable beams of 12C – 238U with intensities up to 5 pμA and energies up to ~20 MeV/u will be delivered for experiments. Using these intense beams, in-flight radioactive beams with intensities up to ~10^7 part/s and up to 20 MeV/u will become available. For lighter ions the available currents are limited by the available shielding and administrative regulations. The stable beam acceleration capabilities that will be available by the completion of the Phase I upgrade of ATLAS in FY2013 are illustrated in Fig. 1. The projections are based on the current ECR source performance and the assumption that beams up to 10 pμA can be transported through split-rings resonators and up to 1 pμA can be accelerated by these structures because of their beam steering properties. This leads to a drop in intensity with energy for some species. The highest beam energies are achieved by selecting charge states higher than the optimum delivered by the ECR ion source.

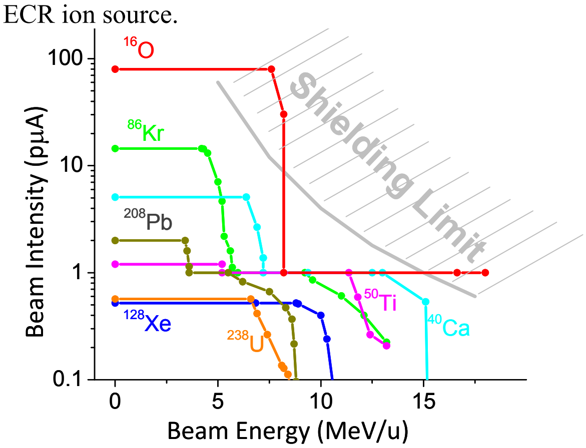

Figure 1: The maximum expected beam intensity is shown as a function of beam energy for selected ion species that will be available after the Phase I upgrade.

CW RFQ

The new CW RFQ will deliver 295 keV/u ion beams to the ATLAS Positive Ion Injector linac (PII). In our application, the RFQ must provide stable operation over a wide range of RF power levels to allow acceleration of ion species from protons up to uranium. The new design builds on the successful Rare Isotope Accelerator (RIA) RFQ prototype tested in 2006 [3]. The resonator is a pseudo split coaxial structure which reduces the maximum transverse dimension to 18 inches at an operating frequency of 60.625 MHz. The cavity is designed as a 100% OFE copper structure and the fabrication is based on a two-step furnace brazing process. The cavity consists of five nearly identical longitudinal segments as shown in Fig. 2. The main parameters of the RFQ are listed in Table 1. Several innovative features are being implemented in this RFQ:

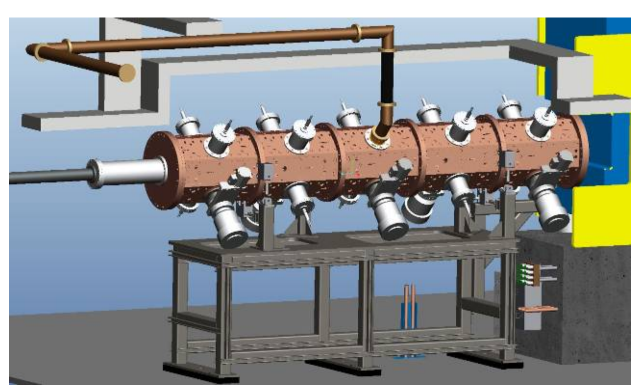

Figure 2: The RFQ is composed of five segments.

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(1) the effective shunt impedance is increased by 40% by introducing a trapezoidal shape to the vane modulation in the accelerating section instead of a traditional sinusoidal modulation; (2) a very short exit radial matcher with the length of $0.8\beta\lambda$ forms an axially-symmetric beam for injection into the SC cryomodule with solenoidal focusing.

Table 1: Basic parameters of the RFQ.

	Parameter	Value
1	Input Energy	30 keV/u
2	Output Energy	295 keV/u
3	Average radius	7.2 mm
4	Vane Length	3.81 m
5	Inter-Vane Voltage	70 kV
6	RF power consumption	60 kW

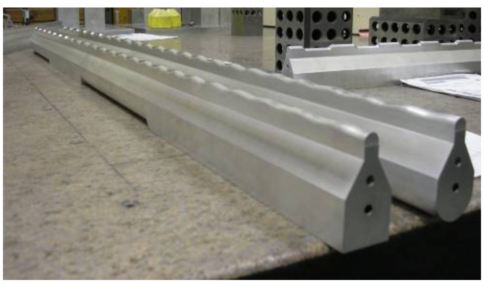

Figure 3: Mock-up vane tips.

We have fabricated aluminium mock-ups of the vane tips by using the same CNM programs that will be applied for the machining of copper blocks. Figure 3 shows several segments of the mock-up vane tips with sinusoidal and trapezoidal modulations. The physics design of the RFQ and beam dynamics simulations are reported elsewhere [4]. A comprehensive engineering analysis preceded the mechanical design of the RFQ as reported at this conference [5]. The fabrication procedure includes 8 main steps:

- Forging OFE copper to near-net-shape;
- Rough machining components;
- Drilling coolant passages;
- Brazing coolant passage plugs & SS inserts. Hydrotests of the cooling channels (150 atm.);
- Finish machining components. Modulation of vane tips;
- Pre-braze assembly to check fit and frequency;
- Brazing segment and vacuum test;
- Final machining.

Each fabrication step is followed by a CMM test. Figure 4 shows vane blocks after pre-brazed machining and prepared for the next fabrication step: brazing plugs and stainless steel inserts for water cooling system. The brazed segment assembly of the prototype RFQ cavity built several years ago is shown in Fig. 5. Currently, we

Figure 4: Vane blocks after pre-brazed machining.

Figure 5: Brazed segment of the prototype cavity.

just finished step 3 of the fabrication procedure and are aiming for the final brazing of all 5 segments by the end of this year.

The RFQ resonant frequency will be regulated by dynamically adjusting the water temperature in the body of the RFQ while the temperature of the vanes will be kept constant. The water temperature adjustment is provided by a mixer which mixes chilled water from the external cooling system and hot water circulating in the resonator body. The resonant control cooling system (RCCS) has been built and successfully tested on the prototype RFQ at the RF power level of 20 kW per segment.

Fabrication of the RFQ is well advanced and the completion is expected by the end of year. Prototyping of a frequency control system based on the adjustment of the cooling water temperature has already been developed and tested on the prototype RFQ.

CRYOMODULE

The new cryomodule takes advantage of the recent ATLAS Energy Upgrade (AEU) cryomodule developments [6]. In addition new innovative superconducting cavity fabrication and surface treatment technologies are being applied. The cryomodule consists of seven β_G=0.077 QWRs at 72.75 MHz SC cavities and four 9-Tesla SC solenoids [1]. The engineering 3D model of the cavity string suspended from the cryostat lid is shown in Fig. 6. New cryomodule features include the separation of the cavity and the cryogenic vacuum systems, and top-loading of the cleaned and sealed cavity-string subassembly. The new QWRs will create accelerating gradients a factor of three higher, on average, than in the existing ATLAS, and will provide a total voltage of 17.5 MV. Cavity design parameters were reported in [7]. Detailed engineering design and analysis resulted in excellent mechanical properties of the QWR despite large dimensions [8].

Compared to the previous generation of quarter-wave resonators, the following innovations were implemented into the cavity design:

- The cavity geometry is highly optimized to reduce both electric and magnetic peak fields;
- A piezoelectric tuner is directly attached to the cavity niobium surface on the beam axis plane, 90° apart from the beam aperture;
- The cavity is equipped with a double-window 4-kW adjustable RF coupler with a nitrogen cooled cold window;
- Electropolishing of the cavity is performed for a completed cavity with the integral helium vessel installed.

Currently, the cryostat vessel and remaining 6 cavities are in production. Machining of niobium parts, electron beam welding and construction of the SS helium vessel are being performed in local shops under supervision of ANL experts. Four 9-Tesla SC solenoids for the cryomodule have been purchased from industry and installed in a helium vessel. The cryostat vessel will be moved to ANL in June to start engineering cold tests. Fabrication of production cavities will be completed by the end of the calendar year.

Prototype Cavity

The design and fabrication of the prototype cavity took 17 months and was completed in December 2010. Since then, the cavity has undergone RF surface processing, been installed in the test cryostat, and cooled down to 4.6K. Figure 7 shows the cavity in the chemistry room set up for electropolishing in the beginning of March. The RF conditioning and testing were started last week. Details of the cavity fabrication, RF surface processing and initial tests are reported elsewhere [9]. During the first 3 days of the prototype cavity cold tests we were able to measure the quality factor as a function of the accelerating gradient as shown in Fig. 8. Very high peak surface fields up to 70 MV/m and 105 mT were measured. The excellent performance of the cavity validates the state-of-the-art of the design approach, fabrication and RF-surface processing techniques.

CONCLUSION

The ATLAS upgrade includes the development of a CW normal conducting RFQ and a SC cryomodule with low-beta QWRs. The design of the system was developed for the acceleration of up to ~2 mA of beam current even though such high current is not required for ATLAS. This is a significant step towards high-power driver accelerators for protons and ions such as FNAL's Project X, FRIB and Accelerator Driven System (ADS).

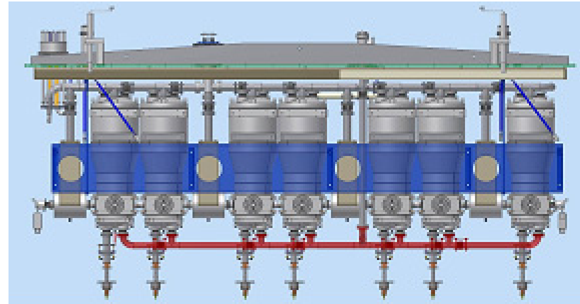

Figure 6: Cryomodule engineering model.

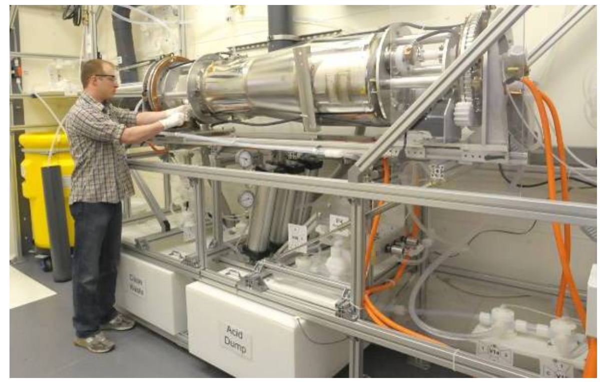

Figure 7: Prototype cavity is ready for electropolishing in chemistry room.

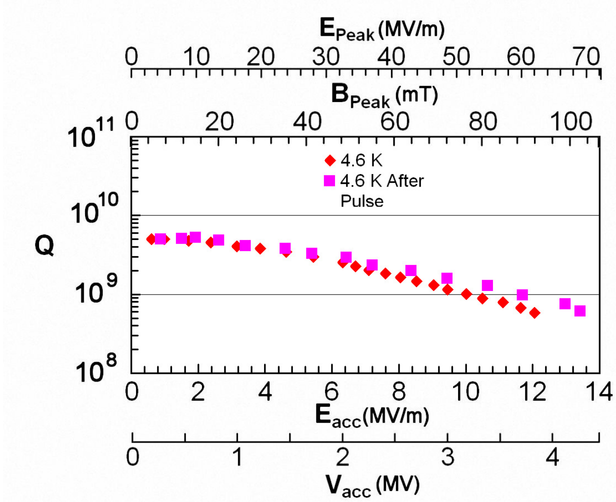

Figure 8: Cavity intrinsic Q_0 as a function of the accelerating field.

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