UPGRADE OF ARGONNE'S CW SC HEAVY ION ACCELERATOR*

P.N. Ostroumov#, A. Barcikowski, Z. Conway, S. Gerbick, M. Kedzie, M.P. Kelly, S. Kim, S. Kutsaev, R. Murphy, B. Mustapha, R. Pardo, D. Paskvan, T. Reid, S. Sharamentov, G. Zinkann
ANL, Argonne, IL 60439, U.S.A.

Abstract

The ATLAS National User Facility at Argonne National Laboratory is the world's first CW superconducting ion linac. The accelerator is being continuously upgraded to extend its scientific reach. To increase the efficiency and intensity of both stable and radioactive beams [1], we have developed, built and installed a new normal conducting CW RFQ capable of providing a 295 keV/u for any ion from proton to uranium. The RFQ has been fully integrated into ATLAS and in routine operation since January 2013.

A new cryomodule containing 7 high-performance 72.75 MHz SC QWRs and 4 SC solenoids was completed this year and has been commissioned off-line. New design and fabrication techniques for these QWRs resulted in record voltages up to 4-5 MV per cavity and low residual resistances of 2-3 nΩ at 2K were demonstrated in individual cold tests of several QWRs. The primary purpose of the new cryomodule is to replace 3 old cryomodules and to increase the intensities of accelerated stable ion beams up to several hundred electrical micro amps. Beam commissioning is expected by the end of the year after significant modification of the accelerator tunnel for increased shielding and installation of a redesigned beam transport system.

CW RFQ

Last summer we commissioned a CW RFQ designed and built for the ATLAS Facility [2, 3]. Several innovative ideas were implemented in this CW RFQ. By selecting a multi-segment split-coaxial structure we have achieved moderate transverse dimensions for a 60.625 MHz resonator. For the design of the RFQ resonator and vane tip modulations we have developed a full 3D approach which includes MW-Studio and TRACK simulations of the entire structure [4]. A novel trapezoidal vane tip modulation is used in the acceleration section of the RFQ which resulted in increased shunt impedance. To form an axially symmetric beam exiting the RFQ, a very short output radial matcher, only 0.75βλ long, was developed. Figure 1 shows an internal view of the RFQ's last two segments. The openings in the vane and trapezoidal modulation of vane tips are clearly seen.

An advanced fabrication technology was applied for the construction of the RFQ which included precise machining and two-step high temperature brazing. Thanks to the high accuracy of the overall fabrication, the assembly of the 5-segment RFQ was straightforward and no additional alignment was required. The resonance frequency control system based on water temperature regulation showed excellent performance. The RF measurements show very good RF properties for the resonator, with a measured intrinsic Q equal to 94% of the simulated value for OFE copper. The multi-segment split-coaxial structure creates strong coupling between the quadrants and individual RFQ segments which reduces the effect of local frequency deviations on electromagnetic field distortions. Therefore, no bead-pull measurements were required to tune the accelerating field.

An O^{5+} ion beam extracted from an Electron Cyclotron Resonance (ECR) ion source was used for the RFQ commissioning. In off-line beam testing, we found excellent agreement of the measured beam parameters with the results of beam dynamics simulations [3]. The great success of this advanced design and fabrication technology is reflected in the measured beam parameters after the RFQ which are nearly identical to the simulated data.

After the successful off-line commissioning of the ATLAS CW RFQ accelerator with oxygen and helium beams, the device was moved, installed and integrated into the ATLAS system during the October-November 2012 period. Fig. 2 displays the current view of the ATLAS front end. The RFQ is directly attached to the first SC cryomodule. For the RFQ beam matching we have incorporated a MEBT which includes 3 SC solenoids and a SC cavity as a buncher [1]. Since January 2013, the RFQ is in routine operation. The beam parameters have been measured after the Positive Ion Injector (PII) of ATLAS which includes three SC cryomodules. The beam energy and time spectra have been measured using silicon barrier detectors (Fig. 3). The results of these measurements are consistent with the TRACK simulations. The efficiency of ATLAS beams on

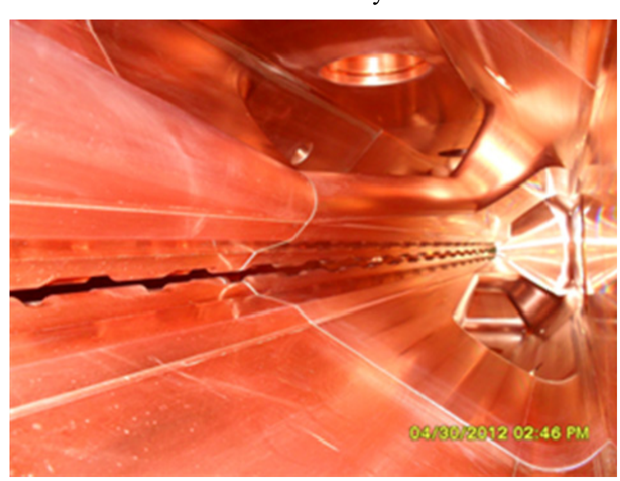

Figure 1: Internal view of the RFQ's high energy end.

* This work was supported by the U.S. Department of Energy, Office of High Energy Physics and Nuclear Physics, under Contract DE-AC02-06CH11357
#ostroumov@anl.gov

ISBN 978-3-95450-138-0

target has doubled as compared to the pre-RFQ operation.

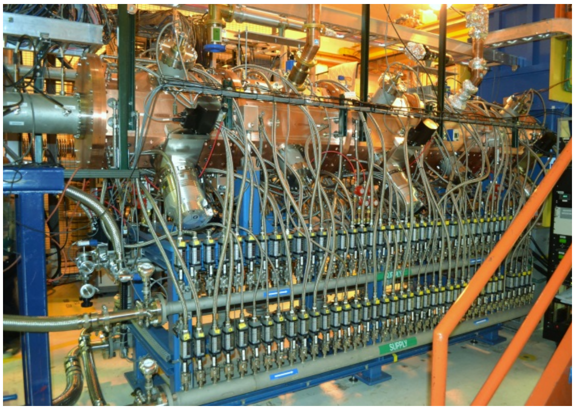

Figure 2: ATLAS front end with the RFQ in position.

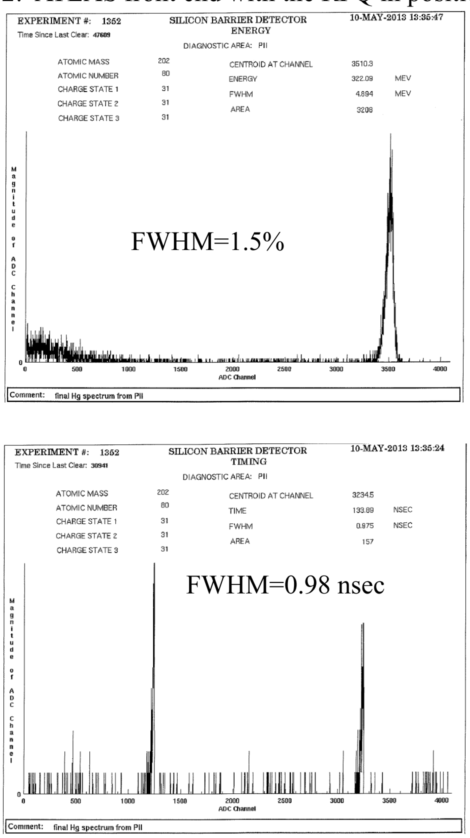

Figure 3: Mercury beam energy (top) and time spectra measured after the PII by elastic scattering at 7.5°.

QWR CRYOMODULE

While split-ring resonators are successfully operated at ATLAS with low-intensity ion beams, they exhibit a fundamental limit in the acceleration of high-intensity beams due to RF steering. Therefore we are replacing 16 ATLAS split-ring resonators with 7 QWRs. Four years ago we put into operation a new cryomodule containing seven 109 MHz β_{OPT}=0.15 QWRs to provide an additional 15 MV voltage to ATLAS. Now, we have developed and built a new cryomodule consisting of seven β_G=0.077 QWRs at 72.75 MHz SC cavities and four 9-Tesla SC solenoids. The new high-performance cryomodule will replace three existing ATLAS cryomodules of split-ring cavities to increase the intensities of accelerated ion beams.

Compared to the previous generation of quarter-wave resonators, several innovations were implemented into the cavity design, fabrication and RF surface treatment. The cavity geometry is highly optimized to reduce both electric and magnetic peak fields: both outer and inner conductors are conical as shown in Fig. 4a. During the fabrication of the niobium components, a wire EDM technique instead of machining was used to maintain clean surfaces prior to electron-beam welding. Electropolishing of the cavities was performed for a completed cavity with the integral helium vessel installed. Each cavity is equipped with a newly-developed double-window 4-kW adjustable RF coupler with a nitrogen cooled cold window [5]. To minimize microphonics due to pendulum vibration of the central conductor, the central drift tube in each QWR has been electrically centred by tuning to the highest resonant frequency [6]. An additional reduction in microphonics is achieved by installing mechanical dampers inside the central conductor [7].

The new QWRs will create accelerating gradients a factor of three higher, on average, than the existing split-ring cavities, and are designed to provide an accelerating voltage of 2.5 MV per cavity which results in a 17.5 MV total voltage gain in this cryomodule. Four 72.75 MHz QWRs were cold tested prior to installation in the cryomodule and all of them provided more than 4 MV without quenching achieving E_{PEAK}>70 MV/m and B_{PEAK}>105 mT [7,8].

CRYOMODULE COMMISSIONING

After the completion of the assembly in a clean room (Fig. 4b), the cavity-solenoid string was pumped out, sealed and moved outside the clean room. The following assembly work included the attachment of the cavity string to the box cryostat lid, installation of slow tuners, installation of nitrogen and helium distribution systems, alignment of cavities and solenoids, and plumbing of nitrogen and helium cooling systems. The appropriate choice of alignment mechanisms resulted in an accuracy of solenoid end positioning within ±250 µm [9]. After a thorough leak check of the nitrogen and helium systems, the cavity assembly was loaded into the box cryostat (Fig. 4c).

Due to the much higher beam intensity in the upgraded ATLAS, the linac radiation shielding is being significantly enhanced by the installation of 1-meter thick concrete walls. Meanwhile, the cryomodule has been cooled down and RF tested off-line. The following major tasks have been accomplished during the off-line commissioning:

- Each cavity was cooled down quickly in the temperature range from 150K to 50K as shown in Fig. 5.

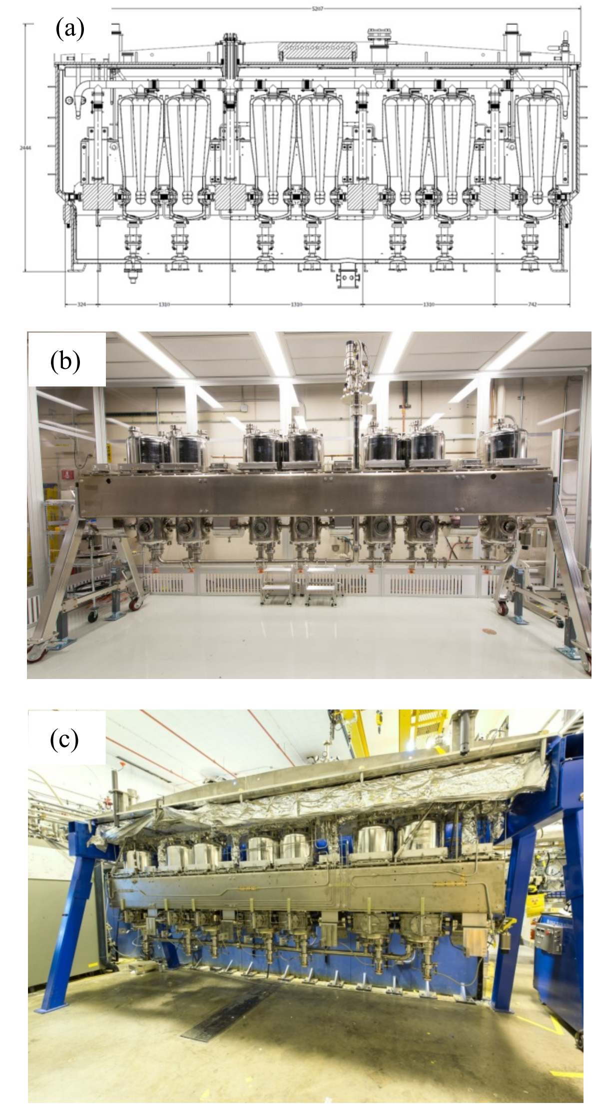

Figure 4: ATLAS intensity upgrade cryomodule. Side cross-sectional view (a), after completion of assembly in clean room (b) and after completion of full assembly prepared to load into the cryostat vacuum vessel (c).

- Due to the variable RF couplers, the multipactor conditioning took less than a couple of hours per cavity.
- RF testing demonstrated that each cavity is capable of providing an accelerating voltage greater than 3 MV.
- Microphonics were measured to be below 5 Hz at the 5σ-level in all cavities. Each cavity is equipped with a 4-kW RF amplifier and variable coupler which provide up to a 30 Hz bandwidth for RF control.
- The pneumatic slow tuner range varies from cavity to cavity and was from 17 kHz to 26 kHz at 70 psi. If necessary, the tuning range can be increased by applying up to 90 psi pressure to the helium gas used to drive the tuners.
- The cavities and solenoids are equipped with crosshair alignment targets. The latter were used for optical measurements of the cavity and solenoid positions in the cold cryomodule. At 4 K the solenoid alignment error was measured to be 80 μm rms.
- The static 4 K heat load of the entire assembly was measured to be 11 Watts which is an extremely low number for such a complex cryomodule.

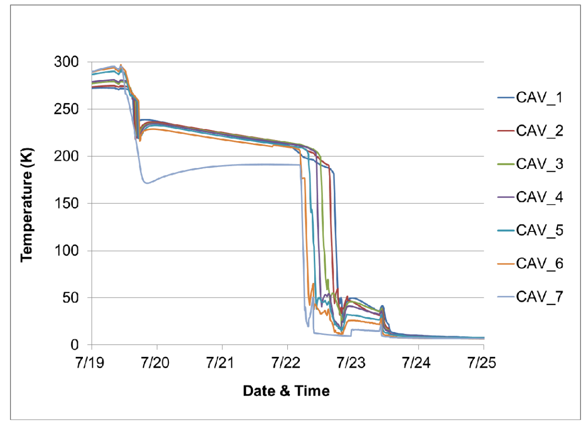

Figure 5: SC cavity temperatures vs time during the second cool down.

SUMMARY

A new CW RFQ with a suite of novel features has been developed, built and commissioned at ANL. The RFQ has doubled the ATLAS beam transport efficiency and demonstrated excellent performance since its integration into the accelerator in January 2013.

A new cryomodule with low-beta SC QWRs capable of providing 21 MV of accelerating voltage has been commissioned off-line and is being prepared for installation into the beamline. Beam commissioning through the new cryomodule is planned in December 2013.

REFERENCES

[1] P.N. Ostroumov, et al, PAC-11, March 28- April 1, New York, p. 2110.
[2] P. N. Ostroumov, et al., Phys. Rev. ST Accel. Beams 15, 110101 (2012).
[3] A. Perry, et al., “Beam Characterization of a New Continuous Wave RFQ Accelerator”, accepted for publication in NIM A, August 2013.
[4] B. Mustapha, A.A. Kolomiets and P. N. Ostroumov, “A Full 3D Approach to the Design and Simulation of a Radio-Frequency Quadrupole”, submitted for publication in PRST-AB.
[5] M. Kelly, et al, LINAC’10, Tsukuba, Japan, p. 884.
[6] Z. Conway et al., SRF’11, Chicago, USA, p. 943.
[7] M. Kelly, et al, Paper THIOC01 at SRF’13, Paris, France, September 23-27, 2013.
[8] Z. Conway, et al, Paper FRIOB01 at SRF’13, Paris, France, September 23-27, 2013.
[9] S. Kim, et al.,”4-Kelvin Alignment of the ATLAS Intensity Upgrade Cavities and Solenoids” In proc. of CEC/ICMC’13, Anchorage, Alaska, USA June 17-21, 2013.