ENERGY UPGRADE OF THE ATLAS SC HEAVY-ION LINAC*

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Abstract

An energy upgrade project of the ATLAS heavy ion linac at ANL includes a new cryomodule containing seven 109 MHz β_G=0.15 quarter-wave superconducting cavities [1] to provide an additional 15 MV voltage to the existing linac. Several new features have been incorporated into both the cavity and cryomodule design. For example, the primary feature of the cryomodule is a separation of the cavity vacuum space from the insulating vacuum [2-4]. The cavities are designed to cancel the beam steering effect due to the RF field [5]. The cryomodule was designed and built as a prototype for the driver linac of the Facility for Rare Isotope Beams (FRIB). The design can be effectively used for other TEM-class superconducting cavities such as, for example, the SC proton linac for the Project X at FNAL. Currently, we have completed the cryomodule assembly and are performing the final off-line cold-tests prior to installation in the ATLAS linac. The initial commissioning results are presented.

INTRODUCTION

Basing on experience with the cryostats for the Positive Ion Injector at Argonne's ATLAS heavy ion linac, a rectangular cryomodule design has been developed [2-4] that is space efficient and consistent with the requirements for high performance superconducting rf surfaces. Features include separation of the cavity and the cryogenic vacuum systems, and top-loading of the cavity-string subassembly which enables hermetic isolation of the cavity string along with assembly in a clean room. The cryomodule assembly includes three stages: (1) clean-room subassembly of the cavity-string, (2) installation of cryogenics, RF and mechanical systems while cavity-string is suspended from the cryostat lid, (3) installation of the final assembly into the cryostat to form a completed module. The design of the cryomodule and cavities reflects the current state-of-the-art in SRF technology and incorporates several new features with respect to other recently commissioned SC ion linacs [6]. As a result, substantially higher accelerating fields and cavity voltages appear to be possible as compared to other new TEM cavity linacs around the world..

The off-line cryogenic and RF commissioning of the cryomodule is nearly complete and the cryomodule is scheduled to be installed in the ATLAS tunnel within the next month.

CRYOMODULE DESIGN

The ATLAS energy upgrade cryomodule (Table 1) consist of 7 β_G=0.15 QWRs operating at 109.125 MHz and one 9-Tesla SC solenoid. There is presently one empty slot that will accommodate an additional resonator. Primary design and fabrication technology of the cryomodules, cavities and sub-systems have been reported in several papers [8-10].

Table 1. Main Parameters of the Cryomodule

Parameter	Value	Units
Cryomodule dimensions	1.0×2.0×4.62	m
Average acc. gradient	8.4	MV/m
Cavity eff. length	25	cm
Total heat load (4.5K)	100	W

Cavities

The new cavities exhibit improved performance relative to existing ATLAS cavities due to a combination of optimized geometry and the implementation of clean handling and processing techniques. All cavities but one have been cold tested in the test cryostat before the assembly. The cold tests results, reported at LINAC-08 [10], exhibited an average accelerating gradient of 10.2 MV/m, providing more than 2.5MV of accelerating potential per cavity

RF Couplers

Six cavities are equipped with adjustable inductive couplers as reported in ref. [9, 10]. We have also developed an adjustable capacitive coupler which is installed on one of the cavities. This coupler was a simple modification of the other "loop" antennas.. In this application as a bottom mounted coupler on QWR cavities, the cold tests show that the capacitive coupler is less susceptible to the RF heating in overcoupled operation than the loop coupler. Figure 1 presents measurements of the external Q-factor as a function of the coupler position. The inductive coupling strongly depends from the loop orientation. The cold measurements were performed in the test cryostat for inductive coupler. The cavities will be operated at $Q_{EXT}=1\times10^8$ at average

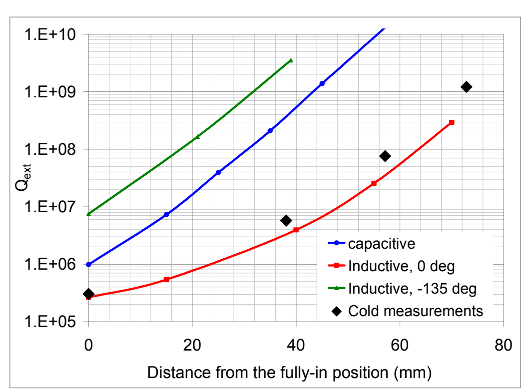

Figure 1: External Q as a function of the coupler position.

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Figure 2: Slow tuners mounted on the cavities.

accelerating gradient of roughly 8.4 MV/m determined largely by the VCX switching power.

Slow and Fast Tuners

Large frequency excursions are corrected using a pneumatically actuated mechanical slow tuner (Figure 2) which compresses the cavity along the beam axis. Tuning range is 30 kHz at helium gas pressure variation from 0 to ~19 psi.

The VCX fast tuner is similar to those that is used on existing ATLAS cavities, and was modified slightly to support independent cavity and cryogenic vacuum spaces and to facilitate clean assembly. The VCX fast tuner provides a tuning window of about 40 Hz.

CRYOMODULE ASSEMBLY

A primary design goal was to minimize the number and complexity of the parts requiring clean assembly. This is achieved by limiting class-100 clean-room assembly to a minimum number of components. These include a pumping manifold to evacuate the cavity rf volume and the seven dressed cavities, each with coupler, VCX fast tuner and rf pickup installed. The cavity string is supported on an anodized aluminum strong-back. A pair of beam-line gate valves (one is visible in Figure 3) and a large right-angle valve are installed on the pumping manifold to seal the cavity vacuum system before it is removed from the clean room. Following the DESY developments, we have implemented low particulate pump down and venting scheme [11] for the cavity string. Final cavity frequency adjustment is made by squeezing the cavities near the drift tubes, and preliminary alignment of cavities is performed in the clean room prior moving the cavity string (Figure 3) out of the clean area for further assembly.

The cavity string is suspended from the box cryostat lid outside the clean room. Installation of liquid nitrogen and helium systems, complete assembly of couplers, local thermal shielding, RF pick-up cables, solenoid current leads, thermometry, etc have been performed outside the clean room. After leak checking of LHe and LN systems, the assembly (Figure 4) was loaded into the cryostat vacuum-box and sealed. Final leak checks of the insulating vacuum, LN and LHe systems were performed after cool down to LN and LHe temperatures respectively. The cryomodule was cooled down to 77K and warmed up twice due to a cold leak in the LN system, found to be in a

Figure 3: The cavity string assembly in the clean area is complete, including complete, sealed cavity vacuum system.

Figure 4: Cavity string suspended from the lid, with all cryogenic plumbing assembled and leak-checked, ready to drop into the box vacuum vessel.

commercial flexible metal hose in the cryostat thermal shield circuit.

OFF-LINE COMMISSIONING

We have installed 38 diodes to monitor temperatures in various locations during the cool down. The LHe cool down of the cavities is performed sequentially by manually opening valves in each LHe line of the cavity to provide fast transition through the "Q-disease" temperature range. Figure 5 shows cool down of the 7 cavities and solenoid as a function of time.

As soon as temperature stabilized at 4.5K, we have measured the resonant frequencies of all 7 cavities. Table 2 shows frequencies measured at room temperature and 4.5K. The operational frequency is 109.125 MHz. The target frequency before activation of the slow tuner is 109.135 MHz. As can be seen from Table 2 six production cavities have very similar frequencies and the warm-cold frequency shift is similar. Cavity #1 in Table 2 has slightly higher frequency and accordingly the warm-cold shift is also different. This is the prototype QWR cavity [1] with a slightly different geometry. The slightly higher cavity frequency can be easily reduced by plastic deformation of the cavity at room temperature using the

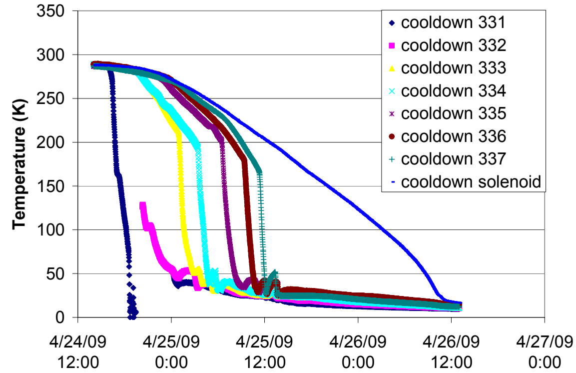

Figure 5: Temperature of the cavities and solenoid as a function of time.

Table 2: Cavity frequencies (kHz). Δf is the frequency warm-cold difference.

	293K	4.5K	Δf
1	109016.0	109165.9	-149.9
2	108953.1	109137.0	-183.9
3	108952.0	109137.7	-185.7
4	108952.5	109142.9	-190.4
5	108954.6	109137.2	-182.6
6	108952.0	109136.3	-184.3
7	108955.1	109140.8	-185.7

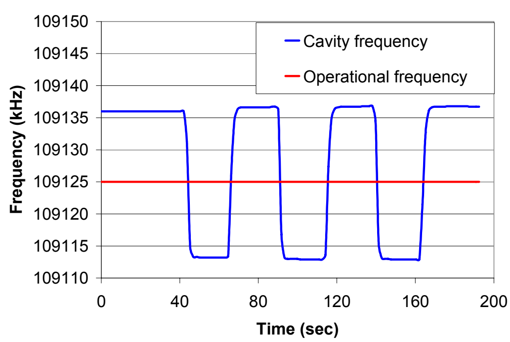

Figure 6: Cavity #3 frequency as a function of time during the cycling of the pressure in the slow tuner bellow from zero to 19 psi.

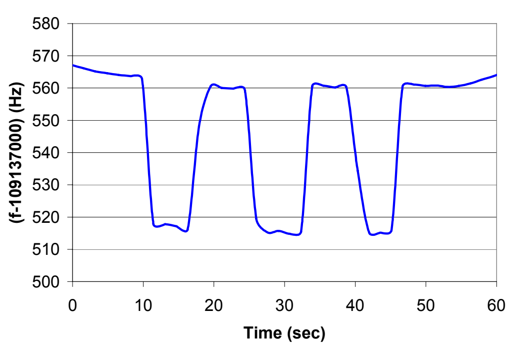

Figure 7: Cavity #5 frequency as a function of time during the cycling of the diode bias voltage.

slow tuner. All slow tuners were cold tested in the pressure range from 0 to 19 psi. As can be seen from Figure 6, the cavity frequency changes from 109.137 MHz (no pressure) to 109.113 MHz (19 psi). The tuning range is 45 kHz for the prototype cavity due to the geometry difference. The tuning range can be easily increased if necessary by increasing pressure to ~24 psi.

Fast tuners have been tested by manually switching bias voltage on the pin-diodes. Figure 7 shows typical cavity frequency dependence while the bias voltage is switched every ~8 seconds. The fast tuner frequency window is 35-45 Hz depending from the cavity number. So far, microphonics measurements have been made at low power and rms frequency shifts are ~1 Hz for all cavities.

INSTALLATION

After high-power RF conditioning of all cavities the box cryomodule will be moved into the ATLAS tunnel. Upstream of the cryomodule we are going to install a new SC 9-Tesla solenoid in an individual cryostat that is useful for maximizing the transmission of the heaviest ion beams (q/A=1/7). A cold trap with the total length of ~60 cm was built to install downstream of the Upgrade Cryomodule. Both the cold trap and the solenoid cryostat will help to isolate the cavity space in the Upgrade cryomodule from the rest of ATLAS vacuum space which is not maintained as a clean, low particle environment.

CONCLUSION

A new state-of-the-art cryomodule for TEM-class SC cavities has been successfully assembled and commissioned off-line. The installation of the cryomodule into the ATLAS beamline is planned for this month.

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