DESIGN AND DEVELOPMENT OF A NEW SRF CAVITY CRYOMODULE FOR THE ATLAS INTENSITY UPGRADE

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ABSTRACT

The ATLAS heavy ion linac at Argonne National Laboratory is undergoing an intensity upgrade that includes the development and implementation of a new cryomodule containing four superconducting solenoids and seven quarter-wave drift-tube-loaded superconducting rf cavities. The rf cavities extend the state of the art for this class of structure and feature ASME code stamped stainless steel liquid helium containment vessels. The cryomodule design is a further evolution of techniques recently implemented in a previous upgrade [1]. We provide a status report on the construction effort and describe the vacuum vessel, thermal shield, cold mass support and alignment, and other subsystems including couplers and tuners. Cavity mechanical design is also reviewed.

KEYWORDS: ATLAS heavy ion linac, cryomodule, superconducting rf cavity.

INTRODUCTION

The Argonne Tandem Linac Accelerator System (ATLAS) is a national user facility supported by the U.S. Department of Energy Office of Nuclear Physics. As the world's first superconducting linear accelerator for heavy ions [2], ATLAS has operated since 1985 hosting several hundred users each year from around the world and providing heavy-ion beams to experimenters with a 95% availability.

In 2009 the accelerator received an upgrade of 30-40% in beam energy by replacing the last cryomodule of superconducting cavities with a new cryomodule containing seven beta = 0.15 quarter-wave cavities and one solenoid focusing magnet [3]. This upgrade implemented for the first time in ATLAS separate cavity and insulating vacuum spaces along with state-of-the-art surface processing and handling techniques to achieve record cryomodule performance for this class of cavity. Shortly after the successful implementation of this upgrade, a second upgrade of ATLAS was proposed which will increase the intensity of stable heavy-ion beams ten-fold and increase the transmission of short-lived low-intensity rare isotopes from the ATLAS Californium Rare Isotope Breeder Upgrade [4]. As part of this new upgrade, existing ATLAS cavities will again be replaced with new high-performance quarter-wave structures operating at beta = 0.08 and housed in a single cryomodule containing seven drift-tube-loaded (DTL) cavities and four solenoids. FIGURE 1 shows the ATLAS linac layout and FIGURE 2 shows a 3D model of the new “intensity upgrade” cryomodule.

This paper describes the mechanical design details of the cryomodule and the srf cavities themselves. The solid niobium cavities are bath cooled by liquid helium at 4.6 K and are housed in stainless steel vessels. These ASME code stamped vessels are described in detail along with the status of cavity and cryomodule construction. Subsystems including couplers, fast and slow tuners, cavity vacuum, thermal and magnetic shielding, cold mass support and alignment, and instrumentation are also described.

CAVITIES

Design and fabrication of the seven new DTL cavities for this upgrade follows the established practice within the Physics Division srf group at ANL [5]. Cavity geometry is created and optimized using CST Microwave Studio and mechanical design is performed using ANSYS, Pro/Engineer, and AutoCAD Inventor. Detailed structural analyses were performed by Advanced Energy Systems, Inc. to optimize cavity and vessel geometry and to model response to vibration as well as slow and fast tuning loads. FIGURE 3 shows a cutaway view of the cavity together with a sample ANSYS output.

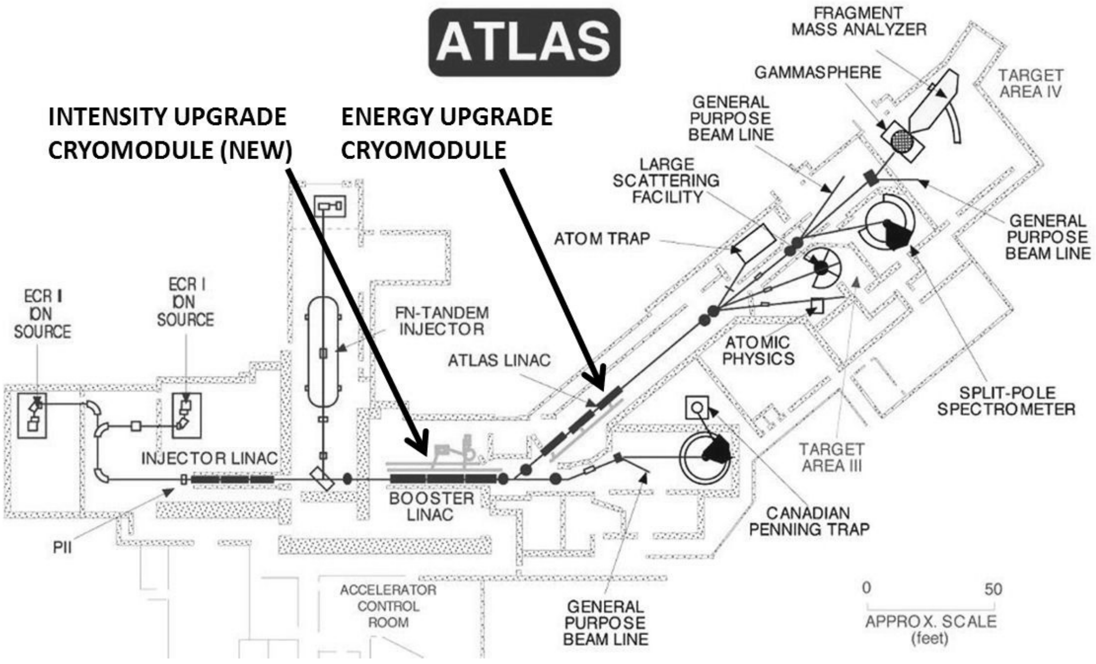

FIGURE 1. Layout of the ATLAS heavy ion linac showing the existing location of the energy upgrade cryomodule and the proposed location of the intensity upgrade cryomodule.

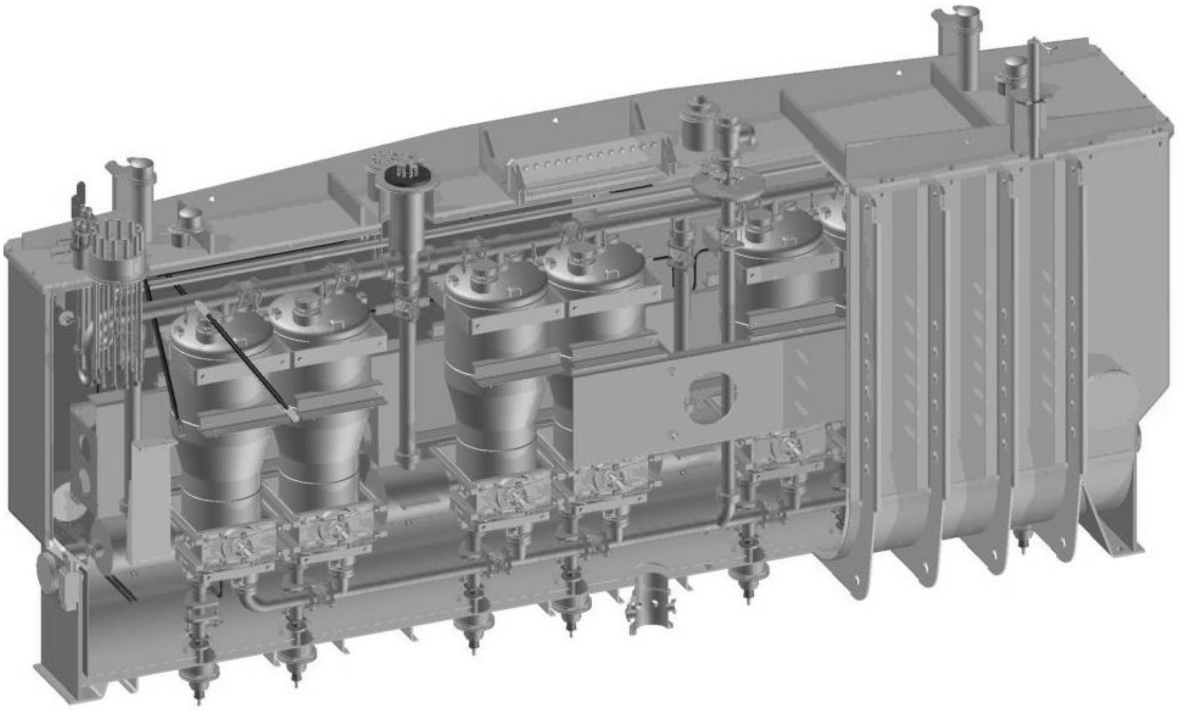

FIGURE 2. Cutaway 3D model of the intensity upgrade cryomodule showing cavities and solenoids suspended from the lid of the top-loading cryomodule.

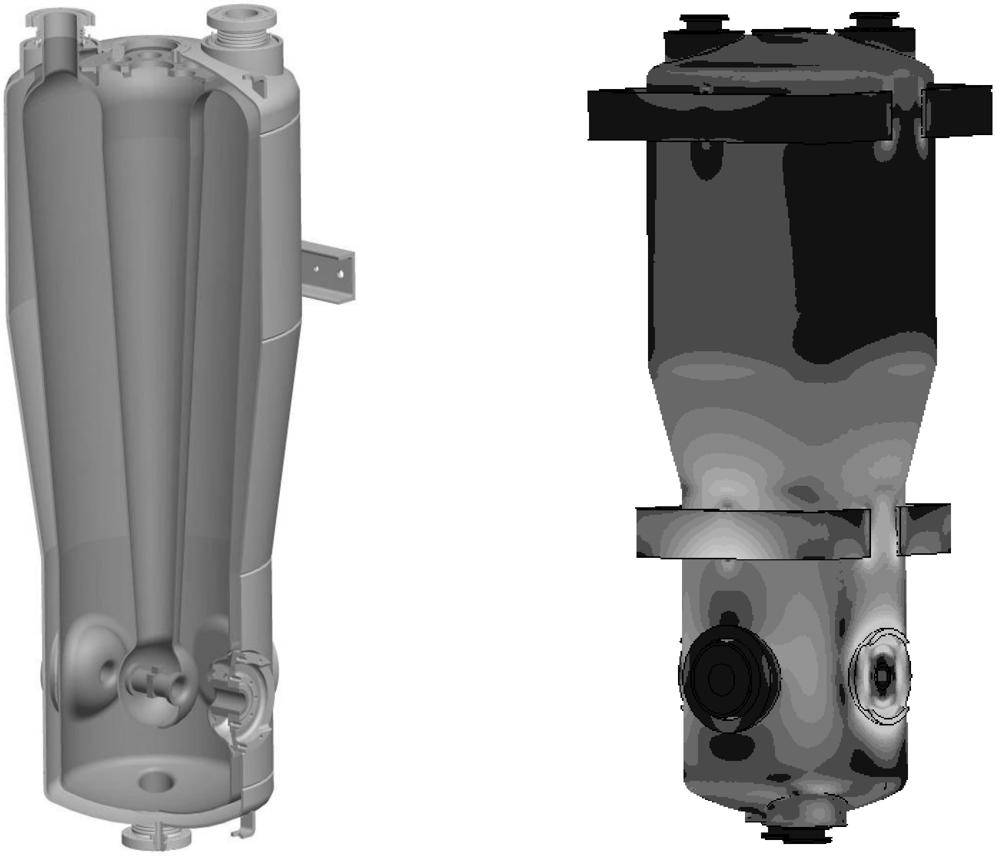

FIGURE 3. Cutaway 3D model of beta = 0.08 quarter-wave cavity (left), ANSYS multiphysics analysis of pressure load on complete cavity (right). The combined electromagnetic/structural analysis yields information on changes in cavity resonant frequency with changes in helium pressure.

Niobium Fabrication

The cavities are fabricated from RRR≥250 niobium. The outer shell, inner conductor, toroid and dome ends, re-entrant noses, and coupling port extension tubes were formed from 3 mm sheet while the beam tubes, beam ports, and coupling ports were machined from bar stock. Forming and machining were performed by Advanced Energy Systems, Inc., Medford NY. Additional machining was done by Numerical Precision, Inc., Wheeling IL.

Wire EDM (electric discharge machining) was used extensively to trim “flash” from the formed parts and to adjust part lengths for proper frequency. This work was performed both by Numerical Precision and by Adron, Tool Corp., Menomonee Falls WI. EDM was used successfully during production of the beta 0.15 cavities for the energy upgrade and this technique is being used wherever practicable for the current cavities. Benefits include easier fixturing of parts, low cost, and zero risk of inclusions. This last item is significant due to the risk of blowout during electron beam (EB) welding caused by the presence of foreign material such as a piece of broken toolbit in the weld joint. So far no blowouts or other EB weld defects have been encountered in any niobium weld joints that were machined using EDM. FIGURE 4 shows typical wire EDM and EB weld setups.

Helium Vessels

The helium vessels surrounding the niobium cavity are fabricated using 304L stainless steel (SS). They are built to the ASME boiler & pressure vessel code and carry an ASME code stamp. An established copper braze technique [6] is used to join the niobium to the SS at six locations: both beam ports, two upper coupling ports, and two lower coupling ports. The pressure boundary is defined to pass through the SS nozzles at the braze assemblies such that the niobium cavity is not included as part of the pressure vessel. FIGURE 5 shows a cross-section drawing of the cavity and helium vessel.

FIGURE 4. Wire EDM trim cuts are used to remove forming “flash” and to adjust part lengths for proper cavity frequency (left). Niobium parts are EB welded at Sciaky, Inc. using a library of weld parameters developed over the last decade by ANL in collaboration with Sciaky.

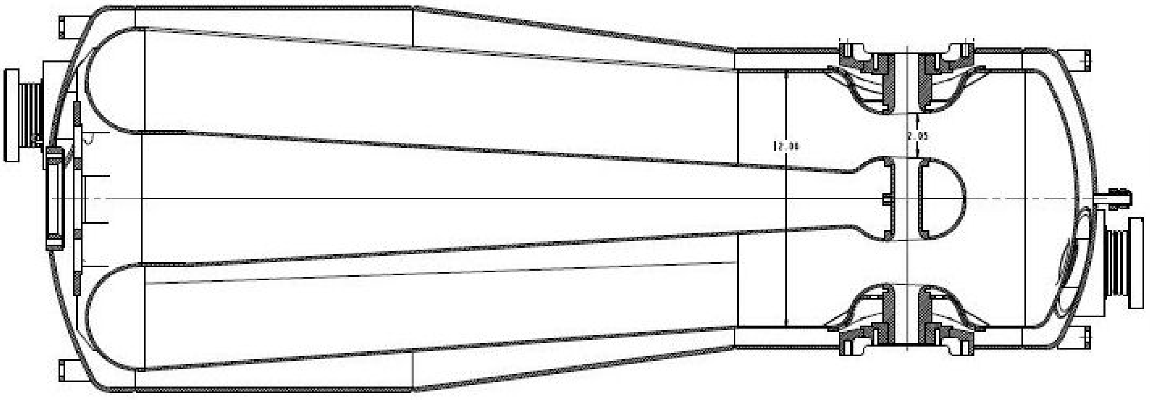

FIGURE 5. Cross-section drawing of the beta 0.08 quarter-wave cavity.

CAVITY SUBSYSTEMS

Many subsystems must be integrated not only into each srf cavity but also into the overall cavity string. These systems include input couplers, slow and fast tuners, vacuum systems, support and alignment systems, and focusing elements (solenoids).

The input coupler and pneumatic slow tuner are evolutions of previous designs used successfully on the energy upgrade. The input coupler design was revised to include both room temperature and 80 K ceramic windows and is designed for greater power handling capability (up to 5 kW). The coupler is adjustable and retains the earlier design's +/-0.04 m (1.5 in) stroke. While the older design couples to the cavity magnetic field, the present design uses electric field coupling. The slow tuner is very similar to the energy upgrade design, with one significant change. The pressure range of the pneumatic bellows actuator is now 1-5 bar whereas the previous design operated between vacuum and 1.5 bar. This simplifies the tuner gas management system, avoids the possibility of air contamination, and improves the response time of the tuner.

A piezoelectric tuner has been developed [7] in order to provide fast mechanical frequency adjustment in addition to the slower, larger-scale adjustments provided by the pneumatic tuner. The piezoelectric device operates independently of the slow tuner mechanism by pressing directly on a high-field region of the niobium cavity. The reaction force is taken by vessel ring welded to the niobium and coaxial with the piezoelectric actuator. A tuning range of 30 Hz is available at frequencies up to 200 Hz. This tuner has been successfully prototyped on an existing 72 MHz quarter-wave cavity.

The cavity vacuum space is evacuated via a manifold that connects each cavity to a dedicated pump-out line. The system is designed for particle-free operation and is cleaned according to the same protocols as the cavities and couplers. This system is mounted below the cavities and connects to each unit at one of the lower coupling ports to prevent particulates from falling into and contaminating the cavities during assembly. This system allows the cavity string to be leak checked and isolated while still in the clean room and ensures that the clean string will remain hermetically sealed once removed from the clean room for assembly into the cryomodule.

The cavity support and alignment system provides a rigid platform for cavity and solenoid mounting and permits independent alignment of each string element. Alignment sensitivity is more than sufficient to meet the tolerance requirement of +/-0.001 m for cavities and +/-0.00025 m for solenoids. Adjustment is made using a kinematic mounting system.

CRYOMODULE

The intensity upgrade cryomodule design is an evolution of the top-loaded box cryomodule design used successfully for the energy upgrade. Several improvements have been implemented including an optimized vacuum vessel design, improved endwall geometry, simpler thermal shield design, and reconfigured internal plumbing. Elements carried over from the previous design include the magnetic shield design, separate cavity and insulating vacuum spaces, and the lid support/jacking system. Finally, the new cryomodule is designed specifically for the intensity upgrade unlike the energy upgrade cryomodule, which was designed both for ATLAS and as a technology test bed for the RIA/FRIB project. This single-purpose focus has simplified several subsystem integration issues, notably the input coupler/vacuum vessel interfaces.

Magnetic & Thermal Shielding

The magnetic shield consists of a single 0.001 m (0.040 in) thick layer of AD-MU-80 shielding material provided by Ad-Vance Magnetics, Inc. As with the energy upgrade cryomodule design, the shield material is attached to the inside surface of the vacuum vessel by a system of threaded studs and SS “batten strips” which ensure intimate contact between overlapping sheets of material.

The thermal shield differs in concept from that used previously. Instead of hanging copper panels from rectangular liquid nitrogen (LN2) manifolds mounted to the sidewalls of the vacuum vessel as in the energy upgrade, the current design uses an aluminum “bathtub” design that nests inside the vacuum vessel with LN2 trace tubing attached at intervals to the shield. This should be easier to install and remove if necessary in the future. FIGURE 6 shows magnetic and thermal shield assemblies.

Cryomodule Clean Assembly

The cryomodule is designed for clean assembly of the cavities, couplers, solenoids, interconnecting spools, beam-line gate valves, and vacuum manifold. These subsystems along with the titanium support frame encompass the low-particulate clean elements of the cryomodule. These components are all cleaned, assembled, and hermetically sealed in a class 100 assembly area prior to suspending from the cryomodule top plate (FIGURE 7). Once the clearn string assembly is suspended from the cryomodule top plate, subsystems such as cryogenic connections, mechanical tuners, and instrumentation are added.

FIGURE 6. Example of magnetic shield installed on the inside surface of a vacuum vessel using batten strips (left). Aluminum thermal shield parts ready for assembly (right).

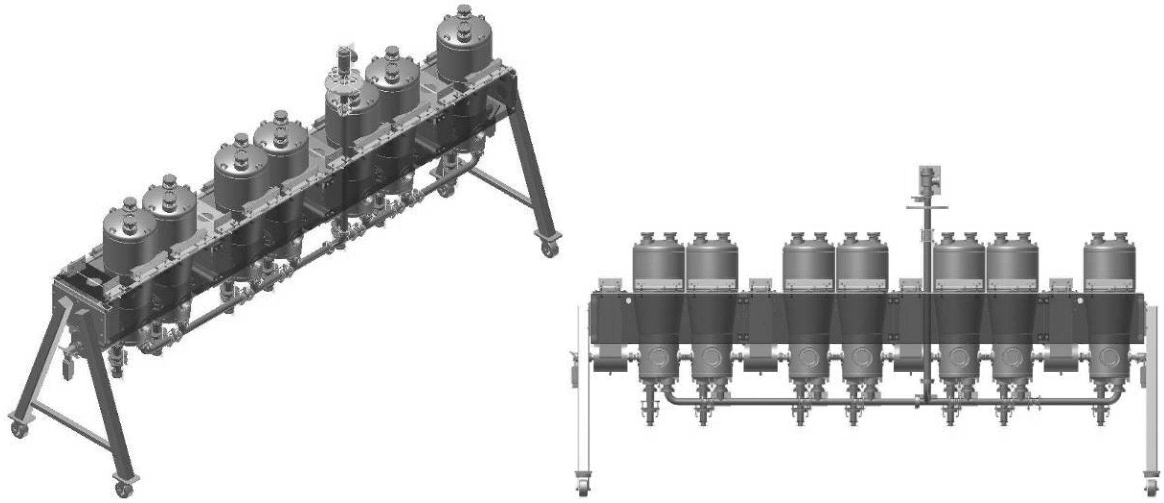

FIGURE 7. Cold mass clean assembly.

The cryomodule clean assembly incorporates several novel features which were not incorporated into previous box cryomodule designs. These features reduce the total number of flange assembly/disassembly cycles required. Most notable is that no connection need be made on the top of the cavity after final cavity cleaning cycle. The cavity can be cleaned and assembled with both the fundamental power coupler and field probes attached prior to mounting on the strongback. All remaining ports are capped with blank flanges. This seals the cavity minimizing particulate contamination. This is new to this design. Prior designs required the power coupler to be installed after mounting on the strongback. Once the cavities and solenoids are mounted on the strongback the beam ports are uncovered and the spool pieces and gate valves are installed.

Finally the vacuum manifold is hung from the strong back and attached to the bottom ports of the cavity. Previously the vacuum manifold was attached to the top of the cavity. Attaching the manifold to the bottom of the cavity prevents particulates from falling down into the cavity during assembly.

CONCLUSION

The ATLAS intensity upgrade cryomodule is an evolution of the successful box cryomodule design developed for a previous successful energy upgrade. We have kept the design features which aided the previous work while modifying many cumbersome and undesirable parts to facilitate a faster, cleaner, and cheaper cryomodule assembly. This cryomodule is expected to be finished and running with beam by December 2012.

ACKNOWLEDGEMENTS

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