Medium Beta Cavity and Cryomodule Prototyping for RIA

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Abstract

ANL is prototyping a set of five different types of drift-tube-loaded cavity for use in both the RIA driver linac and the RIA RIB linac. All the cavities include integral stainless steel LHe tanks, using brazed niobium-to-stainless transitions, allowing us to test "fully dressed" cavities and qualify subsystems including input couplers and both slow and fast tuners. Our development effort is focused on the relatively unexplored velocity range $0.15 < \beta < 0.6$. We have designed and nearly completed construction of a $\beta_{GEOM} = 0.15$ quarter-wave and a $\beta_{GEOM} = 0.26$ half-wave loaded cavity. We have completed and successfully tested a $\beta_{GEOM} = 0.40$ double-spoke-loaded cavity. Finally, we have designed and have begun construction of two types of triple-spoke-loaded cavities at $\beta_{GEOM} = 0.50$ and 0.62 which can improve the cost and performance of the RIA driver by replacing the baseline-design elliptical-cell cavities, eliminating the need for 2.1K refrigeration.

In parallel with cavity development, we have built on our experience with the ATLAS Positive Ion Injector to design a box-style cryomodule suitable for all classes of RIA cavities. A primary feature is to separate cavity and cryogenic vacuum spaces while maintaining a convenient top-loading design. The cryomodule is designed to facilitate the clean handling and processing techniques required for maximum cavity performance. An innovative cold-to-warm beam line transition reduces the number of components involved in clean assembly and minimizes dead space between cryomodules. A prototype module is being constructed as an AIP-funded upgrade of the existing ATLAS linac and will be operated with quarter-wave cavities installed, enhancing performance of ATLAS while serving as a proving ground for RIA cryomodule technology.

Introduction

Drift-tube-loaded SRF cavities have a long history at Argonne National Laboratory, dating from the 1970's [1]. Present development efforts focus on the velocity range $0.15 < \beta < 0.6$ for the RIA driver and RIB linacs, making use of ANL's established fabrication techniques and processing facilities. We have extended the R&D beyond bare cavities to fully jacketed structures incorporating the liquid helium (LHe) containment. This allows detailed study of cavity performance under realistic operating conditions. External factors such as interaction with the cryogenic system are realistically evaluated with a dressed cavity. Subsystems such as input couplers and tuners are being designed, installed, and tested on these cavities as well. ANL is able to draw on its longstanding and extensive associations with industry to design and build pre-production prototype cavities using techniques suitable for mass production.

Figure 1: double spoke cavity CAD model (left) and during construction (right)

<u>Cavities</u>

The baseline RIA driver linac requires six different types of drift tube cavities, three of which are similar to existing heavy ion linac technology. The remaining three span the velocity range $0.15 < \beta < 0.6$ where little experience exists and development work is required. Positive results [2] on two prototype single-spoke cavities led to development of a double-spoke cavity which lowered peak fields by eliminating sharp corners and incorporated a realistic LHe containment vessel integral with the cavity (Figure 1). This two-cell spoke-loaded cavity with $\beta_{GEOM} = 0.40$ has performed well in test. It has also provided valuable information on subsystem performance and microphonic behavior [3]. The lower portion of this velocity range is served by a quarter-wave (QW) loaded cavity at $\beta_{GEOM} = 0.15$ and a half-wave (HW) loaded cavity at $\beta_{GEOM} = 0.26$, both of which are nearing completion (Figure 2).

ANL has proposed an update to the RIA driver linac baseline design which incorporates three-cell spoke loaded cavities operating efficiently at 345 MHz and 4.5 K instead of elliptical-cell SNS-type cavities for the high beta region of the driver. This will lower overall costs and eliminate the need for 2.1 K refrigeration. In support of this proposal we have designed and begun fabrication of triple spoke cavities at $\beta_{GEOM} = 0.50$ and 0.62 (Figure 3).

Figure 2: (l-r) QW CAD model, HW CAD model, QW center conductor, HW center conductor with toroidal ends, HW beam port re-entrant cup.

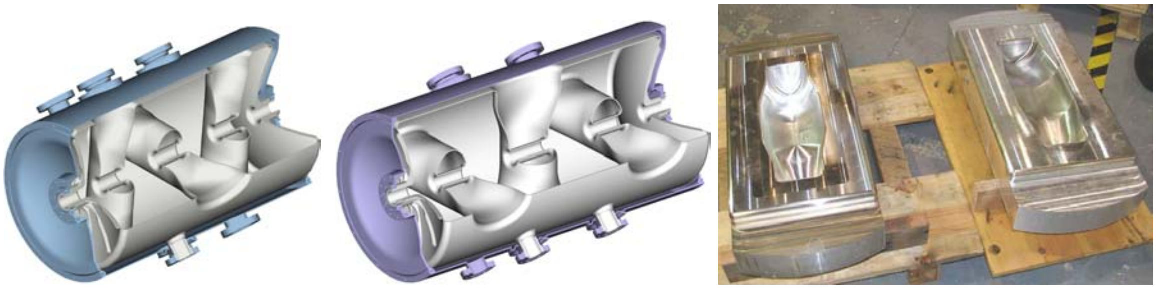

Figure 3: (l-r) β = 0.5 triple spoke, β = 0.62 triple spoke, and spoke tooling

Fabrication Techniques

ANL has partnered with several companies over the years to produce drift-tube-loaded SRF cavities. Our RIA R&D effort has benefited tremendously from these longstanding associations and in turn we have developed a strong base of skilled, competent vendors upon whom the RIA project may draw. High purity (RRR>250) niobium is purchased from Wah Chang, Albany OR in 1/8" thick sheets as well as square and round bar. The sophisticated contours associated with these high-performance structures are hydroformed and precision machined by Advanced Energy Systems, Inc. (AES), Medford NY. Electron beam welding (EBW) is performed at Sciaky, Inc., Chicago IL in close partnership with experienced ANL personnel. Fabrication of the stainless steel LHe tank is performed at Meyer Tool & Mfg., Inc., Oak Lawn IL. In particular the niobium hydroforming skill of AES and the extensive library of EBW parameters built up over the years by ANL and Sciaky enable us to create virtually any geometry required for drift-tube cavities. Figure 4 shows additional photos of cavity fabrication.

Our design requires a cold, vacuum leak-tight transition between the niobium cavity and the stainless steel LHe tank. After exploring several niobium-to-stainless transitions, a modified version of the CERN technique [4] based on a pure copper braze material was chosen for its simplicity and reliability. Figure 5 shows the braze assembly. Our modified design lowers cost and yields a void-free joint that has withstood repeated rapid thermal cycling from liquid nitrogen to room temperature as well as large mechanical loads. Five braze transition assemblies have been successfully welded into our double spoke cavity and are performing without incident in cryogenic cavity tests down to 2 K.

Cavities are designed for manufacturability. The geometry is created using MicroWave Studio, then exported in STEP file format to Pro/Engineer for complete part generation. Tooling can be machined directly from the solid models for maximum fidelity to the original design. All corners are rounded and coupling ports are located to facilitate chemical etching and ultra-pure high pressure water rinsing (HPWR). Electropolishing (EP) has proven key to our ability to achieve high performance without appreciable Q-slope. Our cavity assembly sequences permit final EP of major subassemblies prior to the final closure EBW steps.

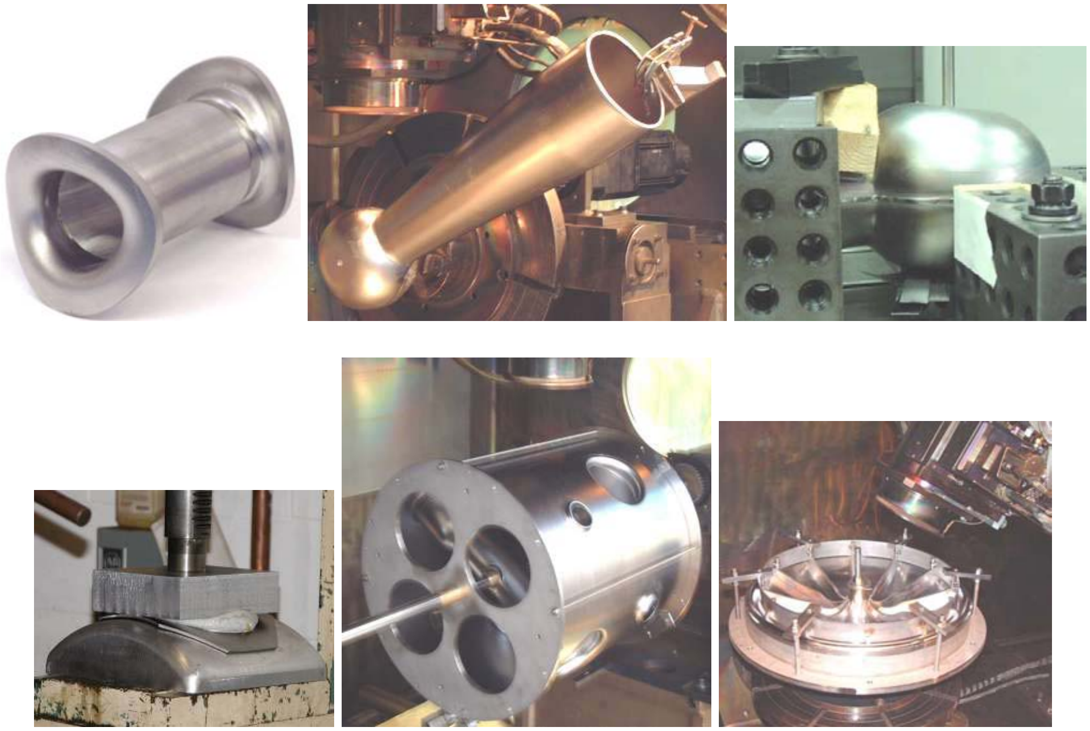

Figure 4: Cavity fabrication showing (clockwise from top left) beam spool for spoke, QW center conductor halves during EBW, boring the QW center conductor for the beam spool, EBW setup for double spoke end wall reinforcement, EBW of double spoke shell, and forming the HW beam port re-entrant cup.

<u>Cryomodule</u>

We have adopted the clean handling techniques pioneered on elliptical-cell cavities at DESY and JLab for use on drift-tube cavities and achieved substantial performance gains thereby. It is vital that the cavity interiors be isolated from the surroundings to protect the rf surfaces from particulate contamination. Our cryomodule design uses separate cavity and insulating vacuum spaces – a new feature for heavy ion linacs. We preserve popular features from the successful Positive Ion Injector (PII) at ANL's ATLAS heavy ion linac such as a space efficient, easy to assemble top-loading, rectangular box design (see Figure 6).

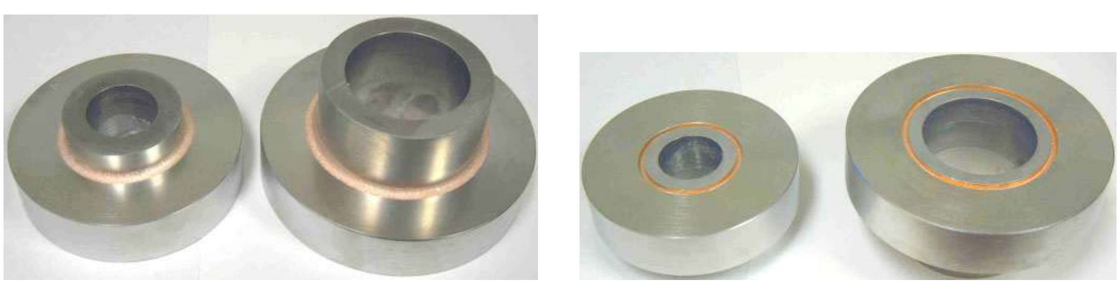

Figure 5: Braze assembly showing the underside of the joint (left) with copper fillet wetting both niobium and stainless steel and (right) the top side showing single groove for copper wire. The top surface with groove is later machined away.

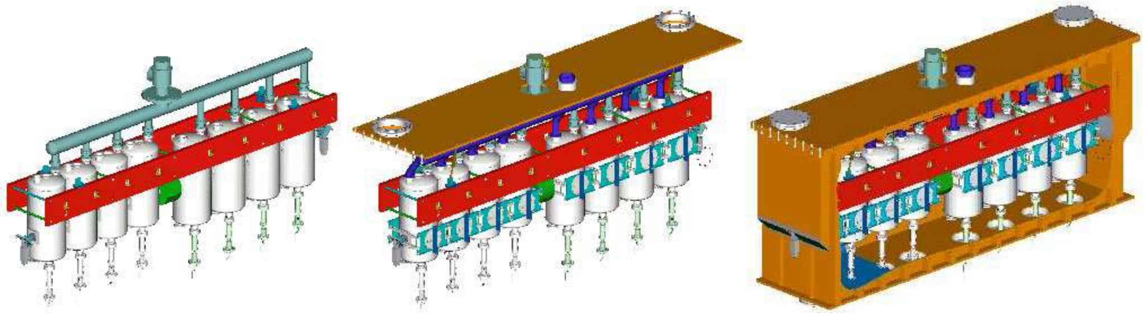

Figure 6: Box cryomodule assembly sequence showing (left to right) clean subassembly, sealed subassembly removed from clean area and suspended from top plate, and final assembly in vacuum vessel.

The flexible layout is suitable for all drift-tube cavities proposed for RIA, including the triple spoke structures. Module assembly is accomplished in stages, with the particulate-sensitive components (cavities, connecting spools, vacuum manifold, input couplers, beam valves) assembled together in a clean environment. Once this subassembly is complete, it is hermetically sealed, removed from the clean area and suspended from the cryomodule top plate. At this point various subsystems (tuners, cryogenic plumbing, instrumentation) are attached and the unit is lowered into the vacuum vessel. Beam valves pass through ports in the angled endwalls of the vacuum vessel. The prototype module will be installed in the ATLAS linac as part of an AIP-funded upgrade to both improve ATLAS performance and allow tests of RIA prototype components with beam.

Conclusions

ANL builds on its broad experience base and industry partnerships to design, build, and test prototype drift tube cavities and cryomodules. These devices are fully engineered pre-production prototypes, suitable for subsystem integration and testing. The fabrication techniques scale readily to production quantities. Placement of a prototype module in the ATLAS beam line will provide on-line operational experience.

References

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[4] Bacher, J.P., Chiaveri, E., and Trincat, B., "Brazing of Niobium to Stainless Steel for UHV Applications in Superconducting Cavities," CERN/EF/RF 87-7, December 1987.