PROGRESS ON CAVITY FABRICATION FOR THE ATLAS ENERGY UPGRADE

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Abstract

An accelerator improvement project has been underway for several years to increase the energy of the ATLAS heavy ion linac at ANL. A new cryomodule containing drift-tube-loaded superconducting cavities is nearing the end of construction, with seven new cavities complete and ready for clean assembly into the cryostat. We describe the present status of the project, focusing particularly on cavity fabrication. Several cost saving techniques suitable for multi-unit production have been used, including electric discharge machining (EDM) part trimming and multi-part electron beam weld (EBW) fixturing. Subsystem fabrication including couplers, slow tuners, and VCX fast tuners is also described as are the clean processing techniques used for particle-free assembly.

INTRODUCTION

The Physics division at Argonne National Laboratory is working to extend its existing program in nuclear physics with rare isotopes. In support of this effort, the ATLAS accelerator will be upgraded in energy by 30%-50% depending on ion species. This will be achieved by adding additional accelerating structures to the end of the linac, housed in a single eight-cavity cryomodule [1] containing seven quarter-wave drift-tube-loaded (DTL) cavities and one half-wave DTL cavity [2]. 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.

FABRICATION METHODS

The lessons learned during fabrication of a variety of prototype DTL cavities [3] have been applied to the current effort, with several changes implemented to reduce cost in a multi-structure production environment. Of the eight cavities in the upgrade cryomodule, two were fabricated individually as prototypes (one quarter-wave, one half-wave) while the remaining six quarter-waves were fabricated as a group with associated cost savings relative to the prototypes. Techniques for welding, tuning, and processing were all modified to improve throughput and lower costs.

Electron Beam Welding

All niobium joints were were welded by electron beam (EB) at Sciaky, Inc., Chicago, IL, using techniques and weld parameters developed jointly by ANL and Sciaky. For multi-cavity production, greater investment was directed towards fixture design to facilitate multi-part setup (Figure 1). This reduced the number of chamber evacuation cycles and lowered per unit weld costs, even for a production run of six. The experience gained with this fixturing and tooling will apply directly to larger quantity cavity production associated with future projects.

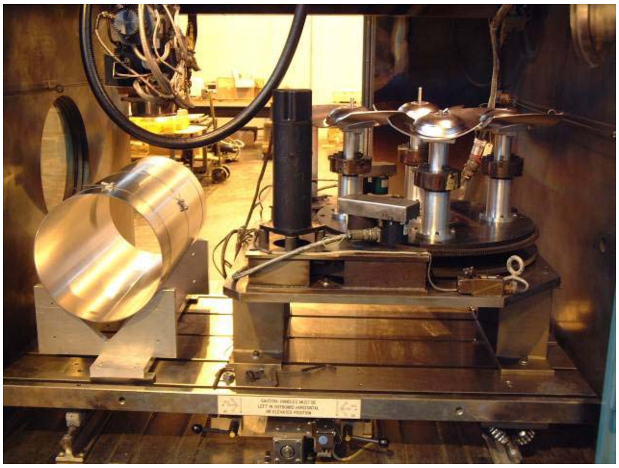

Figure 1: EB chamber loaded with a niobium cylinder and a cluster of four re-entrant nose groups.

Tuning

A tuning methodology has been developed to reliably produce structures with the correct resonant frequency. This technique involves periodic frequency checks during fabrication together with corresponding dimensional adjustment. Figure 2 shows a quarter-wave cavity clamped together with threaded rod to check resonant frequency. Offsets associated with thermal contraction, vented vs. evacuated rf space, chemical processing, and EB weld shrinkage are known or experimentally determined. Numerical analysis of the cavity geometry provides frequency sensitivity as a function of key cavity dimensions. Cavity subassemblies such as the cylinder, the center conductor, and toroidal and domed end caps are fabricated overlong to provide additional stock from which “tuning cuts” are made. An iterative process of clamping and measuring followed by subassembly trim cuts eventually yields completed cavities with frequencies within 0.1% of nominal.

Conventional machining was used on the prototype cavities to perform tuning cuts. The six production units were tuned by using electric discharge machining (EDM). This technique offers several advantages, including negligible tool forces and zero risk for tool bit inclusions.

Figure 2: Clamped-up cavity during frequency check.

The cuts performed for cavity tuning all involved shortening a cavity component by slicing off a section (Figure 3). This method is well suited to the wire EDM technique, where the cut is performed by spark erosion as a continuously spooling conducting wire travels through the workpiece. Part fixturing is very straightforward and inexpensive because little or no force is applied by the tool to the workpiece. Setup time is also reduced and part throughput was similar to that achieved using conventional machining, in spite of the relatively slow wire travel speed.

Past experience has shown that conventional machining can increase the risk of blowout during EB welding due to the presence of inclusions caused by tool bit breakage during joint machining. Wire EDM eliminates this possibility and provides machining accuracy comparable to conventional techniques.

Figure 3: Quarter-wave cavity cylinder and center conductor with "trim rings" produced by wire EDM.

Electropolish

The electropolish (EP) technique follows that developed at ANL in the 1970's and used for all srf cavities in ATLAS. EP capability has recently undergone a significant improvement with the installation of a new chemistry facility [4]. Cavity subassemblies were EB welded as far as possible prior to EP of the six production cavities, resulting in two polished final subassemblies (see Figure 4) which are joined with a final closure EB weld.

Figure 4: End domes (top) and cylinder/toroid/center conductor assemblies (bottom) following EP.

Final Processing

After the final EB closure welds and leak checks, the cavities are fitted with integral stainless steel liquid helium vessels. The vessels are pieced together around the niobium cavities and TIG welded. Coupling ports are attached to each cavity in three locations (two at the upper end and one at the lower end). Each port consists of a niobium tube brazed to a stainless steel flange [5]. The connection procedure involves an internal EB weld at the niobium joint between cavity and coupling port followed by a TIG weld between the liquid helium vessel and a bellows welded to the stainless flange. Following a final leak check, each cavity receives a final chemical processing using a light (5 micron) BCP and a high pressure water rinse (HPWR). Figure 5 shows the BCP and HPWR setups.

SUBSYSTEM FABRICATION

Three primary subsystems support cavity operation: input coupler, mechanical slow tuner, and VCX fast tuner. The VCX (Figure 6a) has been described elsewhere [6] and is used on existing ATLAS cavities. The design was modified to support independent cavity and cryogenic insulating vacuum spaces and to facilitate clean assembly. The VCX fast tuner provides a tuning window of about 40 Hz. Together with a passive damper installed in the cavity center conductor [7], the VCX should control microphonics to an acceptable level. Slower, larger frequency excursions are corrected using a pneumatically actuated mechanical slow tuner (Figure 6b) which compresses the cavity along the beam axis. Tuning range is 40 kHz.

Figure 5: Final BCP following installation of liquid helium tank and coupling ports (left); high pressure water rinse (right).

Input coupler design has evolved from original inductively coupled, adjustable units built for the prototype quarter-wave and half-wave cavities to a more general purpose design appropriate for cavity frequencies up to 345 MHz [8]. The units built for the six production cavities (Figure 7) retain the high frequency capability but include larger antenna loops to improve coupling to the quarter-wave's magnetic field, which is weak at the lower end of the structure where the coupler is mounted.

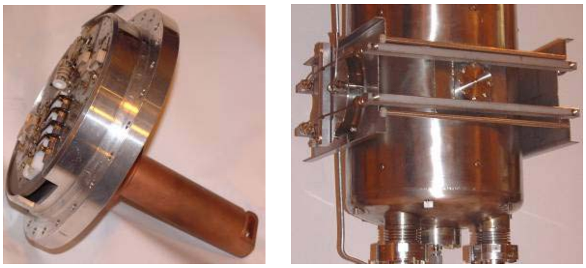

Figure 6a,b: VCX fast tuner (left); mechanical slow tuner (right).

CONCLUSION

A production run of six quarter-wave cavities has been completed. Earlier experience gained with prototype construction guided changes in production methods to lower costs and reduce risk. Investments in tooling for multi-part setups increased EB welding throughput. A tuning program efficiently produced cavities that were on frequency. Use of wire EDM for niobium trim cuts minimized fixturing costs and eliminated blowout risk due to toolbit inclusions during subsequent EB welding. The cavity assembly sequence (including electropolish, stainless steel helium vessel, coupling ports, and final processing) worked well and is suitable for larger scale cavity production. Cavities and subsystems are well integrated into a clean, easily assembled unit that avoids the introduction of any nonessential components into the particle-free assembly sequence.

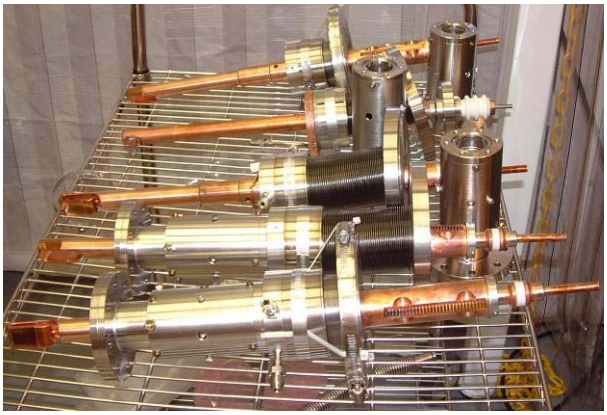

Figure 7: Group of five adjustable loop-type input couplers. The lower two are complete while the upper three have their bellows sections removed to show the antenna. Total coupler stroke is 7.6 cm.

REFERENCES

[1] Fuerst, J.D. et al, "Status of the ATLAS Upgrade Cryomodule," SRF 2005, Ithaca, NY, p. 548.

[2] Shepard, K.W. et al, "Superconducting Intermediate-Velocity Cavity Development for RIA," PAC 2003, Portland, OR, p. 1297.

[3] Shepard, K.W., "Development of Superconducting Intermediate-Velocity Cavities for the U.S. RIA Project," SRF 2003, Travemunde, Germany.

[4] Gerbick, S.M. et al, "A New Electropolishing System at ANL for Superconducting Quarter-Wave Resonators," SRF 2007, Beijing, China.

[5] Fuerst, J.D. et al, "Niobium to Stainless Steel Braze Transition Development," SRF 2003, Travemunde, Germany.

[6] Added, N. et al, "Upgraded Phase Control System for Superconducting Low Velocity Accelerating Structures," LINAC 1992, Ottawa, Ontario.

[7] Facco, A., "Mechanical Stabilisation of Super-conducting Quarter Wave Resonators," PAC1997, Vancouver, B.C., p. 3084.

[8] Shepard, K.W. et al, "Variable CW RF Power Coupler for 345 MHz Superconducting Cavities," PAC 2007, Albuquerque, NM, p. 2230.