THE APT SCRF CRYOMODULE: PRESENT STATUS AND POTENTIAL FUTURE PLANS

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*Abstract**

A prototype cryomodule for the $\beta = 0.64$ superconducting rf linac is being developed at Los Alamos National Laboratory (LANL) for the Accelerator Production of Tritium (APT) program. This design is aimed toward proof-of-principle testing and forms the starting point for the large-scale APT plant. Several alternate design options are also being explored to improve manufacturability and maintainability, reduce cost, increase reliability, and increase availability of qualified commercial suppliers. Progress to date on the prototype cryomodule is summarized in this paper, as are some interesting possible design improvements.

1 THE ENGINEERING DEVELOPMENT AND DEMONSTRATION PROGRAM

The APT high-energy proton linac uses superconducting radio frequency (SCRF) technology [1]. It has two sections of cryomodules designed to accelerate proton beams with betas of 0.64 in the first section and 0.82 in the second. Each cryomodule contains two, three or four solid niobium cavities. Each cavity has two rf power couplers.

The scope of work for the SCRF High Energy Linac Engineering Development and Demonstration (ED&D) program includes the design, fabrication, and testing of prototypes of the cavities, power couplers, and cryostats. The goal is to provide integrated design and performance data for very high rf power and beam currents.

The APT superconducting cavities, which will be fabricated by industry, are made of solid sheet niobium having a residual-resistance-ratio (RRR) value of ≥250. They are contoured five-cell cavities with elliptical irises, optimized to operate reliably at an accelerating field ranging between 4–6 MV/m. They will be housed in individual liquid helium vessels and operated at 2.15 K. Each power coupler is required to transmit 210 kW of rf power to the cavity. Each coupler has a dual room-temperature alumina RF window followed by a 50-ohm coaxial line. Because of the high power, it is important to optimize cooling and RF matching of the couplers.

The cavities, helium vessels and couplers are housed in a cryostat that supplies insulating vacuum and structural support, and provides the access required for a prototype. Fig. 1 shows a cutaway view of the cryomodule assembly.

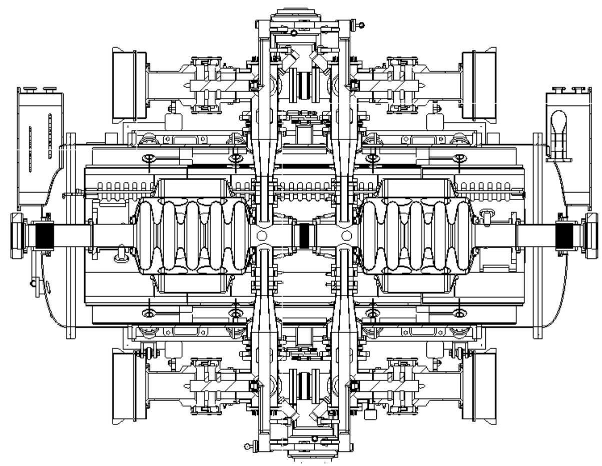

Figure 1: The assembled ED&D cryomodule seen from above with a section cut at the beamline. Clearly seen are the 5-cell cavities and the 4 power couplers.

2 CURRENT STATUS AND HIGHLIGHTS

In general, we plan to fabricate and test power couplers and cavities through March, 2000. They will be installed into the cryostat and be ready for integrated testing by October, 2000. Each item is briefly described below.

2.1 Five-Cell Cavity Fabrication

Four five-cell β=0.64 solid niobium cavities are being been fabricated at *Centre de Recherche en Calcul Appliqué* (CERCA). The cavities will be installed in titanium helium vessels. The vessel bulkhead assemblies with bellows have been completed and sent to CERCA. Edged-welded titanium bellows used in these assemblies are being lifetime tested at *Thomas Jefferson National Accelerator Facility*.

* Work supported by DOE contract DE-AC04-96AL89607
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2.2 Power Coupler

To evaluate the developing designs of the power coupler and rf windows, a room-temperature test bed (RTTB) has been completed including data acquisition programming and instrumentation [2]. Parameters to be tested are coupler matching, peak power levels, rf losses, window-coupler power matching, and coupler adjusting. Tests on the first coupler will begin in early April.

2.3 Cryostat

Fabrication drawings for the two-cavity cryostat are nearing completion. Shown in Fig. 1, it is based on the CERN design and provides the necessary access and flexibility needed for an experimental facility. A full-size cryostat mockup has been built complete with mockups of the cavity/helium vessel, thermal shields, and power couplers. Procurement packages are expected to be released in October.

3 OPTIONS BEING CONSIDERED FOR THE APT PLANT

The primary objective of the ED&D program is to test high-level rf power couplers and the associated cavity assemblies integrated into a cryostat. The objective of the APT plant is to build these SCRF systems at minimum cost and operate them at very high availability for 40 year lifetime. Consequently, there are incentives to improve upon the ED&D design to meet these more demanding goals of fabricability, inspectability, reliability, and maintainability. Design alternatives are therefore being considered for the cavity, helium vessel, cryostat, power coupler window material and shape, window changeout schemes, and power coupler vacuum system. Each are briefly discussed below. They will be explored contingent on funding.

3.1 Cavity Fabrication

The cavity represents a large cost item in the cryomodule and every effort must be made to reduce cost consistent with achieving the desired Q at the expected MV/m. The solid niobium option was chosen as the most conservative with the most predictable performance. The sputtered niobium coating on copper may be worth revisiting to explore recent technology advances.

However, another possibility is vacuum deposition on copper of niobium supplied by pulsed laser ablation of a high-purity articulating niobium source. This would provide a middle ground between low-energy thermal vapor deposition and high-energy magnetron sputtering. Niobium ion energy levels would be 1-2 eV. With normal losses, a 10 micron layer could be deposited on the inside of a 5-cell copper cavity in about four hours with a 5 J laser pulsed at 10 Hz. Use of high-expansivity copper rather than niobium for cavity structure eliminates the differential expansion issue if steel is used for the helium vessel.

3.2 Helium Vessel

An alternate, lower cost, helium vessel and cavity tuning structure is also being explored. Figure 2 shows the concept, which consists of 12-inch and 18-inch diameter pipes with elliptical heads and joined with two 8-inch pipe sections. The lower pipe contains the SCRF cavity. The liquid level is in the upper pipe, about 4-inches inches above the cavity.

The tuning structure consists of titanium rods and AISI 310S rings that connect the flange on the left with the tuner. The ED&D tuner design is used, which could be made from AISI 310S rather than titanium.

This vessel has about half the liquid helium and about one-third less metal volume than the ED&D design, but more ullage to allow helium expansion. The total weld length is reduced by about 20%, and all welds are simple pipe-to-pipe or pipe-to-head with no difficult weld intersections.

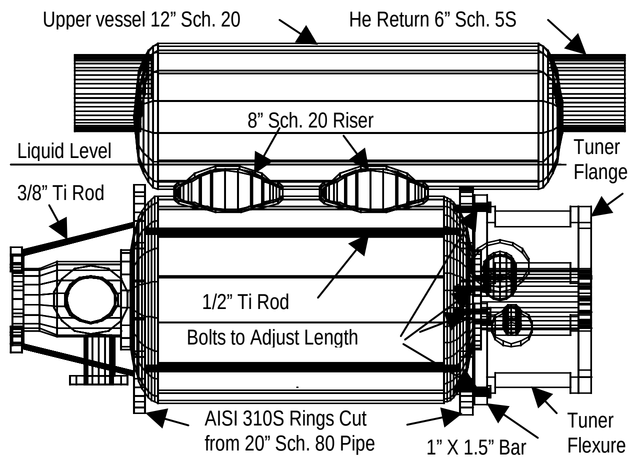

Figure 2: Alternate helium vessel that could be made of stainless steel pipe sections.

Rather than titanium, the vessel could be made of less expensive 310S austenitic stainless steel, which prevents martensite domains from forming due to cold-work, welding, or thermal cycling to liquid helium temperature. This alloy is much stronger than Grade 2 titanium used in the present vessel and eliminates titanium-to-stainless joints in the helium piping. An even stronger Inconel alloy could replace the titanium in the tuning bellows, allowing more flexibility and a greater fabrication base. The simpler shape and lower material and welding costs are expected to lead to significant cost reductions.

Thermal and fluid analyses, including the response to a sudden loss of beam tube vacuum, have shown the response of this vessel to be similar to that of the ED&D design. Stress analyses have shown acceptable stresses in the stainless-steel-to-niobium transition joint after cooling to 4 K, and low stresses due to a 45-psi helium pressure in the vessel.

3.3 All-Welded Cryostat

In order to obtain the required high availability for the APT plant, scheduled downtimes must be minimized. The elastomer seals used in the ED&D prototype are not expected to last the full plant life. Therefore, the option of welded, but accessible, seals is being explored for the cryostat and other joints. These seals, shown schematically in Fig. 3, are commonly used in vacuum applications. The seal material is only 1-2 mm thick and the seal weld can be cut and remade several times.

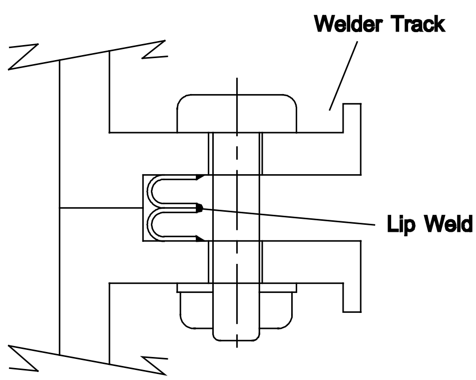

Figure 3: Typical lip-welded flange. This can be used on the cryostat covers and on cryogenic penetrations.

In the cryostat, these seals would be mounted on horizontal rigid flanges above and below the beamline, as seen in Fig. 4. Provision can also be made for elastomer seal grooves to be used during system checkout. Coated metal seal rings are also a possibility which, unlike elatomers, do not have to be removed prior to seal welding.

The upper and lower covers, which look like auto engine oil pans, can be removed allowing considerable access to the interior. Space must be allowed for the automatic welder/cutter, which results in a bowing out of the support structure. The rf waveguides are not in place when the lip seal is welded. The cryogenic bayonets can be placed on the upper cover in the middle of the cryomodule where there is space both inside and out. This facilitates disassembly and maintenance functions.

3.4 Power Coupler Components

Replacement of failed power coupler windows could severely reduce plant availability. Therefore a program has been established to explore windows with very long design life along with procedures for quickly replacing those that do fail. Being examined are other window materials, such as aluminum nitride, surface treatments and coatings, other shapes, e.g., planar, and waveguide valves that maintain cavity vacuum during replacement.

There are two other options for the power coupler vacuum pumps besides ion and turbo pumps: (1) cryogenic pumps with a specifically designed gettering arrays, or (2) a system of non-evaporating getters (NEG). The cryopumps would not use built-in compressors and expanders but would take a small portion of the main

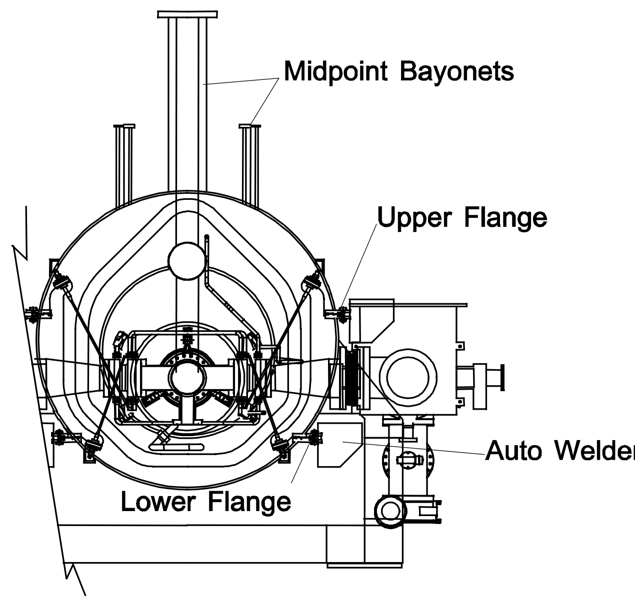

Figure 4. End view of optional cryomodule showing horizontal flanges containing lip welds.

cryomodule cryogen supply. Either option would consist of pumps capable of regeneration during operation. Since neither option has moving parts, they should meet the requirements of long life with low maintenance.

4 REFERENCES

[1] G.P. Lawrence, "High-Power Proton Linac for APT; Status of Design and Development", presented at the International Conference LINAC '98, Chicago, IL, August 23-28, 1998.

[2] J. Gioia *et al*, "A Room-Temperature test bed for Evaluating 700 MHz RF Windows and Power Couplers for the Superconducting Portion of the APT Linac", presented at this conference.