ENGINEERING DESIGN OF THE APT CRYOMODULES*

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Abstract

The high energy section of the Accelerator Production of Tritium (APT) linac uses Superconducting Radio Frequency (SRF) cavities to accelerate a 100 mA proton beam from 211 MeV to 1700 MeV. Since these SRF cavities can accept protons over a wide velocity range, only 2 different β designs are required. However, 3 different length cryostats, or cryomodules, are required primarily to accommodate the changing magnet focussing lattice. The comparatively short development time span for these cryomodules has inclined us to adopt many design features from proven operating cryomodules. What sets the APT cryomodules apart is the comparatively high RF power; making design to minimize refrigerator work a high priority.

1 INTRODUCTION

A cryomodule containing 2 β=0.64 cavities (β=particle-velocity/speed-of-light) is under design at Los Alamos as part of the Engineering Development and Demostration (ED&D) program. The other types of cryomodules will be designed by General Atomics, one type for 3 β=0.64 cavities and another type for 4 β=0.82 cavities. A modular approach has been adopted that will reduce the total engineering and design effort required to produce these cryomodules.

2 THE β=0.64 ED&D CRYOMODULE

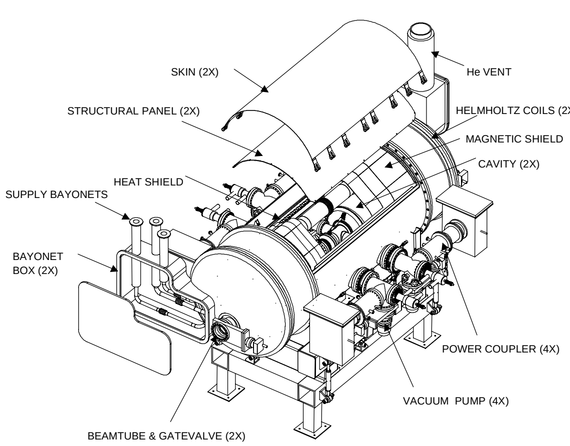

Figure 1: The β=0.64, 2 cavity, ED&D Cryomodule.

The β=0.64 ED&D cryomodule is pictured in Figure 1. The length is 4.9 m, width is 2.7 m, diameter is 1 m, and it weighs 3100 kg .

The extension sections, domed ends, and bayonet boxes are identical modules for all 3 types of cryomodules. Only the length of the RF Section, pictured in Figure 2, varies for the other types of cryomodules.

2.1 Vacuum Tank

The 120° [angle] top opening in the vacuum tank can be seen in Figure 1 with the structural panel and vacuum skin popped up. This design was adopted from the CERN-LEP cryomodule. A similarly large lower opening provides excellent access for assembly and laminar air flow in the clean room.

The center section of the vacuum tank is designed to be easily cleaned before going into the clean room. The side walls are formed from 310 stainless steel plate with a ground finish. No tapped or blind holes are used.

2.2 Heat Shield

The heat shield installed in the complete RF Section is pictured in Figure 2. The heat shield is assembled from top and bottom parts and two end parts. The parts are made from aluminum sheet with a tube trace attached by welding. Slots in the sheet relieve stresses during cool down as in the Tesla Test Facility (TTF) cryomodule.

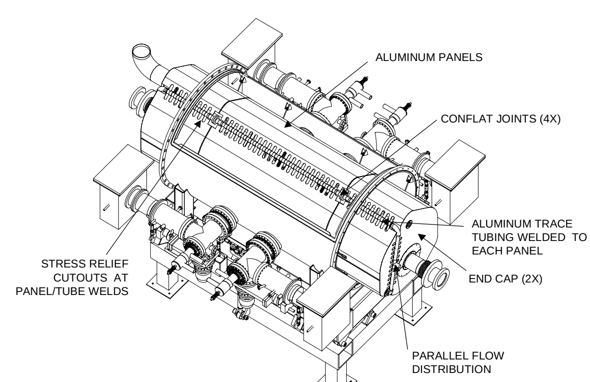

Figure 2: Complete RF Section with heat shield installed.

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2.3 Magnetic Shield

The magnetic shielding is designed to attenuate the earth's magnetic field reaching the cavity to about 10 mGauss. Two passive shields will be used to attenuate the radial fields and Helmholtz coils used for the axial fields.

2.4 Helium Venting for Fault Conditions

With a loss of vacuum, the liquid helium in the helium vessels will boil and rapidly evolve helium vapor that is vented to prevent over pressurizing the helium vessels and cavities. Four separate vent systems are required to handle the various fault conditions. The worst case is a breach in the beam tube outside the cryomodule that allows air to rush into the 2-K cavity. The air condenses on the cavity wall and deposits a heat flux of 3.8 W/cm^2 into the helium bath. The helium vessels vent through the 15-cm duct to pressure relief devices that discharge the helium directly into the tunnel.

2.5 Vacuum System

Separate vacuum systems provide the insulating vacuum and the power coupler and cavity vacuum. Turbo molecular pumps were selected over ion pumps because design advances have improved reliability and there is less risk of contamination from back streaming.

2.6 Cryomodule Heat Loads

Table 1: β = 0.82 Component Heat Loads

	β = 0.82 Cryomodule	
	2-K (W)	45-K (W)
Cavity (each)	24.1	0
Power Coupler (each)	5	22
HOMs (per cavity)	1.7	0
End Beam Tubes (2)	1.84	24
Radiation - MLI	2.2	19.4
Other	4	47.5

Table2: β = 0.64 Component Heat Loads

	β = 0.64 Cryomodule	
	2-K (W)	45-K (W)
Cavity (each)	15.4	0
Power Coupler (each)	3.5	15
HOMs (per cavity)	1.2	0
End Beam Tubes (2)	1.64	24
Radiation - MLI	0.92	9.1
Other	3	47.5

Tables 1 & 2 summarize the various heat loads, both static and dynamic, that the cryomodule components place on the refrigeration.

2.7 Cryomodule Assembly

The couplers and cavities are assembled and hermetically sealed in a class 100 clean room. The center section of the vacuum vessel goes into the clean room for assembly because the power coupler windows are located outside the vacuum vessel. This approach follows the procedure at CERN. The thermal intercept, cryogenic plumbing, and remaining components are installed outside the clean room with the cryomodule rotated 90°.

3 CAVITIES

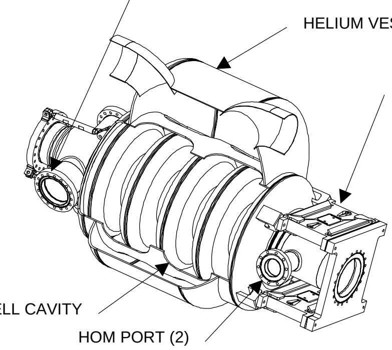

Figure 3: A β=0.64 Cavity and Helium Vessel

3.1 Cavity Design

A cavity and helium vessel, with ¼ of the wall cut away, is pictured in Figure 3. Table 1 gives a summary of the cavity design. The cavities are made from RRR 250 niobium that is formed and e-beam welded following well established cavity fabrication methods. The thickness of the niobium sheet is 3-mm for the β=0.82 cavity and 4-mm for the β=0.64 cavity.

Table 1: Cavity Design Summary

	β=0.64	β=0.82
Aperture Radius	65 mm	80 mm
Cavity Radius	194 mm	200 mm
Wall slope	10°	10°
Number of cells	5	5
Length	685 mm	878 mm
Frequency	700 MHz	700 MHz
Peak surface field	15 to 17 MV/m	14 to 17 MV/m
Accelerating gradient	4.7 to 5.0 MV/m	Constant 5.5 MV/m
RF losses @ $Q_0 = 5 \times 10^9$	15.4 W	24.1 W

After fabrication the cavities are chemically etched and high pressure water rinsed using state-of-the art procedures.

3.2 Helium Vessel Design

The helium vessels are made from grade 2 titanium that nearly matches the expansion rate of niobium and avoids possible residual magnetic fields inside the shielding. In the cryomodule the helium vessels are connected by an upper 15-cm vapor return duct and a lower 2-cm liquid transfer line. The liquid helium level at 2.15-K is 7-cm above the cavity. Sufficient ullage is provided in the helium vessel to allow the helium to expand in the event sub-atmospheric pumping is interrupted causing the helium to warm to 4.5-K. The purpose is to keep the return duct free of liquid to reduce recovery time after pumping resumes.

3.3 Cavity Frequency Tuner

Each cavity can be tuned to its 700 MHz resonant frequency by a magnetostrictive linear actuator that either compresses or lengthens the 5 cells. The actuator acts through a flexure device that provides parallel action and 4:1 leverage. The tuning range is ±324 KHz and the resolution is 10 Hz. The actuator travel of 2-cm is obtained by alternately clamping each end of the magnetostrictive rod. The tuner can also be used to de-tune the cavity 20 KHz to take it off line so that proton bunches do not excite cavity fields.

3.4 Cavity Microphonics

Cavity vibration and its effect on the RF frequency will be measured on the prototype 5-cell β=0.64 cavity that is currently being fabricated. The cavity will be installed in its inner perforated shell, shown in Figure 3, but without the outer helium vessel. This permits access to the cavity for installing accelerometers and also for adding cavity supports if needed. The RF control system has been extensively modeled [1] and this measured data will be used with the model to assess microphonic instability.

The next phase will be testing the cavity in the ED&D cryomodule at 2-K. A wire position monitor will be used to measure helium vessel vibration.

4 POWER COUPLERS

Each cavity is powered by 2 coaxial couplers [2], each rated at 210 kW for the β=0.82 and 140 kW for the β=0.64 cavities. A power coupler is pictured in Figure 4. Dual RF windows are warm and located outside the vacuum tank.

The losses from the high RF power transmitted by the couplers can result in large heat loads on the refrigeration plant. The power coupler cooling must be carefully designed to minimize these loads.

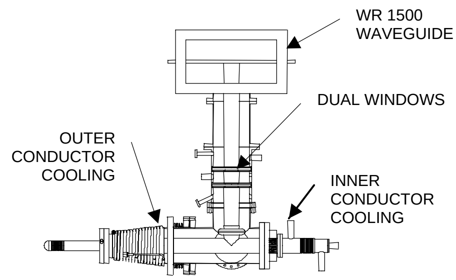

Figure 4: Coaxial Power Coupler

The power coupler cooling naturally divides into two separate considerations: maintaining thermal stability of the inner conductor under various operating scenarios, such as traveling and standing wave RF; and, outer conductor cooling to reduce the heat conducted to the low temperature superconducting cavities. Analysis has shown that the inner conductor is adequately cooled with 3 g/s of helium gas at 3 atm and 300 K. The maximum temperature rise of the inner conductor is limited to 50 K under 210 kW standing wave condition.

Two basic approaches have been considered for cooling the outer conductor: one or two localized thermal intercepts, and distributed cooling from counterflow heat exchange [3]. Independent of the cooling approach, the 2 K heat load is about 2 W, if the niobium is maintained in the superconducting state. The total room temperature refrigeration input power will depend on the details of the cooling approach, but a trade-off study considering additional factors such as manufacturability, reliability, and controllability will ultimately determine which cooling approach is used.

5 STATUS

We are currently in the final design phase and planning a design review for November. Testing is scheduled to begin in April of year 2000.

6 REFERENCES

[1] A. Regan, "APT LLRF Control System Model Results", 1997 Particle Accelerator Conference, Vancouver, May 1997.
[2] B. Rusnak, et al., "Power Coupler Design for the APT Linear Accelerator", Proc. Eighth Workshop on RF Superconductivity, Abano Terme (Padova), Italy, October 1997.
[3] J.A. Waynert et al., "A Thermal Analysis and Optimization of the APT 210 kW Power Coupler," Proceedings of LINAC98, Chicago, Aug 24-28, 1998, to be published.