PROGRESS OF APT SUPERCONDUCTING LINAC ENGINEERING DEVELOPMENT*

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Abstract

We have initiated a program to develop superconducting (SC) RF technology for high-power proton linacs. These linacs are useful in accelerator-driven transmutation applications and the Accelerator Production of Tritium (APT) Project. We are developing 5-cell niobium cavities with elliptical-cell shapes at 700 MHz. These cavities, unlike most elliptical cavities for electron accelerators, are designed to accelerate protons at β<1. Coaxial power couplers are being developed to transmit high (250 kW) CW RF power to the cavities. The couplers will be tested both at ambient temperature and at 2-K temperature, and power-handling and thermal properties measured. The cavities and power couplers will be integrated into a prototype cryomodule, which will be tested and characterized with RF under cryogenic conditions as required for a high-power proton linac.

1 INTRODUCTION

We have a program to develop SCRF technology for proton linacs in Los Alamos. Although this program has been initiated to support the APT SCRF linac [1], the technology development will be useful for all SC proton linacs with high CW power and current. The merit of using SCRF linacs for high-power applications, like accelerator-driven transmutation technology, has been described in Ref. 2. In this paper, we describe the issues encountered in the development of cavities, power couplers, and cryomodules. Design features of these components are given in Ref. 3 and will be repeated here only to the extents of explaining the issues.

2 CAVITY SHAPES

Figure 1 shows the cell-shape used for the APT 5-cell cavities, usually known as the elliptical cell shape which has been widely adopted in SCRF cavities that accelerate relativistic electrons. For proton linacs, the lengths of the cells are reduced to maintain synchronism with the slower proton beams (β=0.64 and 0.82). The shorter cell lengths lead to cell walls that have smaller slopes that could easily collapse under vacuum pressure and prone to multipacting. We have designed the APT cavities with a 10-degree slope for the cell wall. This is the optimum slope to minimize peak electric and magnetic peak fields and to maximize mechanical stability. With a slight increase in wall thickness (from 3 to 4 mm), we can eliminate the need of costly stiffeners that are otherwise needed to withstand the vacuum load. We have tested single-cell cavities [4]. Results (Fig. 2) show the APT cavity field can be achieved with more than a factor of two margin, and with no limitations due to multipacting, even in the case of β=0.48.

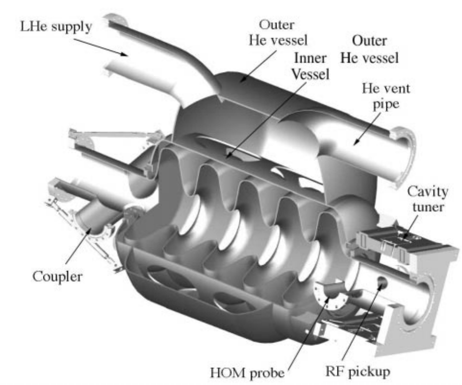

Figure 1: Illustration of β=0.64 cavity design.

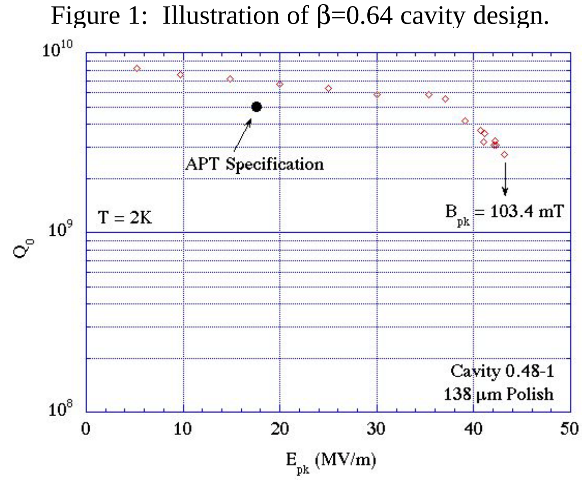

Figure 2: Typical test results of a β=0.48 cavity

3 POWER COUPLER ENGINEERING DESIGN

Figure 3 shows an illustration of the APT power coupler. Because of the high beam power, each coupler needs to deliver 210 kW of CW power to the beam. This

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power level was achieved only recently by a waveguide-type coupler; and it has not been achieved by coaxial-type couplers [5]. Additionally, since the APT-linac is required to produce tritium with high availability over 40 years, it is important that APT coupler operate reliably at high power.

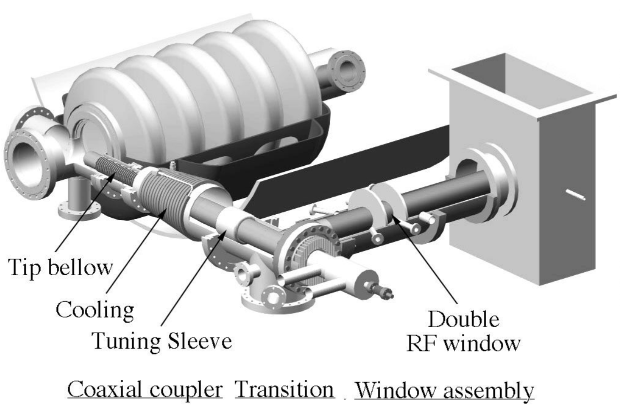

Figure 3: Illustration of the APT power coupler.

Based on experience from other laboratories, we have chosen a coupler design [3] with features that enhance reliability. Usually, RF windows are the primary source of coupler failure. In our design, we use warm RF windows with two ceramic pieces for redundancy, no direct line of sight to the beam, and window diagnostics to detect signs of the onset of failures. These windows, fabricated as complete assemblies by the klystron industry, have been designed, and will be tested to 1 MW.

The APT coupler consists of three sections: the RF-window assembly, the transition, and the coaxial coupler. To minimize reflected power during operation, extensive 3D electromagnetic modeling has been done to attain a good match between sections. The modeling procedure started with the design of separate components and benchmarking the simulations by building and measuring some of these components. Finally, a fully integrated study was performed. As a result, a coupler has been designed that has an excellent power transmission at and around the 700-MHz operation frequency. We have also minimized the electromagnetic interactions between the RF-window assembly with the transition and coaxial-coupler sections. The transmission of the coaxial-coupler section is maximized by adjusting the length of a quarter-wave stub and the shape of a tuning sleeve. The RF window as a complete assembly has also been simulated extensively with respect to thermal performance to minimize thermal stress.

There are two features in the coupler that can potentially reduce the reliability of the coupler: bellows and copper plating. First, two bellows will be used in a coupler, one to allow the joining between the RF-windows and the transition sections, and one (close to the tip of the inner conductor) for changing the length of the inner conductor and consequently the coupling to the cavities. These bellows could become work-hardened and yield after repeated elongation, compression and thermal cycling. Bellows made of BeCu are ideal for our application, but their availability is expected to be limited because of the toxicity of machining Be. We are studying options including copper alloys, electroformed copper bellows, and copper-plated or sputtered stainless-steel bellows. Second, copper plating will be used on the inside surface of the stainless-steel outer conductor. Stainless steel is chosen as structural material for the outer conductor because of its low thermal conductivity. Unfortunately, it also has high RF resistivity and RF heat loss. Copper has low electrical resistivity and RF heating. Copper-plated stainless steel will offer both low RF loss and low heat transfer at 2-K temperature. To maintain reliable performance, it is important that plating have a low outgassing rate and good adhesiveness to stainless steel. The plating process must produce these performance and thickness uniformity consistently. There are three ways to achieve copper plating: plating with UBEC (Ultra Bright Electroplated Copper), plating with OFE (oxygen-free electrolytic) copper, and plating with vacuum sputtering. We plan to perform outgassing and adhesive tests on plating samples produced using these three methods. We will also construct couplers with these plating methods and tests them at high RF power.

4 COUPLING COEFFICIENTS OF POWER COUPLER

For the amount of power needed to accelerate the beam, we need to obtain an external-Q (Q_L) of $2.5x10^5$. This Q_L will be provided by two couplers, each having a Q_L of $5x10^5$. We have investigated different coupler geometries to provide this Q_L. Results [6] show that we need to expand the beamtubes for the β=0.64 cavities from 6.5 cm to 8 cm. Lower coupling can further be achieved by slightly expanding the tip of the coupler center conductor. We have also extended the standard beam-loading theory for beam loading with multiple couplers [7]. Reflected powers resulting in failure scenarios and when the two couplers are not exactly identical were calculated.

5 OPERATING TEMPERATURE

The cavity operating temperature has been set at 2.15 K [8]. This temperature was chosen for two reasons. First, we evaluated the total cryoplant cost, including the capital cost and operating cost, as a function of the operating temperature. The total cost has a minimum around 2.4 K caused by a tradeoff between higher cryogenic efficiency at higher temperature and lower surface resistance at lower temperature. The minimum is broad, with the total cost increased by 3% by operating at 2.15 K. Second, we decided to operate in the temperature regime of superfluid for better helium heat-transfer properties and better margins against quench. An operating temperature of 2.15-K is the highest temperature for which that we presently feel confident to control the LHe temperature so that LHe remains superfluid. It may be lowered in the future.

6 HEAT LOADS AND POWER COUPLER COOLING

We are designing our components and cryomodules to maximize cryogenic efficiency and to minimize the required cryogenic power. Table 1 shows a summary of the baseline heat loads for a β = 0.82 cryomodule. Such a cryomodule will have 4 cavities and 8 power couplers. For this case, heat is removed by LHe boiloff and at an intermediate temperature of 45 K.

Table 1: Typical heat loads of a β=0.82 cryomodule

	2.15-K (W)	45-K (W)
Cavities	96.4	0
Power Couplers	40.0	176
HOM	6.8	0
Others	8.0	90.9

The major heat loads are from the RF losses in the cavities. The Qo used to calculate this load is $5x10^9$. The second major heat load is the power coupler. The power couplers are the primary thermal connections between room temperature and the 2.15-K temperature. They are also major heat sources because the RF losses in the couplers. Typically, the RF losses are 230 and 50 W, respectively, for inner and outer conductor. It is important to prevent these losses from reaching the 2.15-K temperature. We have developed a thermal model to explore a wide range of cooling schemes and operating conditions. This model includes heat-transfer mechanisms like conduction, radiation, RF heating, and cooling by forced convection. We considered cooling of the outer conductor with single- and two-temperature thermal intercepts and with a counter-flow heat exchanger. Results [9] showed that the power-coupler heat loads could be reduced to 16W at 2.15 K using counter-flow heat exchangers. Results from the model also showed that the inner conductor could be cooled using room-temperature gaseous helium.

7 CRYOMODULE ASSEMBLY

For high-performance of SC cavities and power couplers, it is important to maintain clean assembly of the cryomodule. For our power coupler design [10], with the absence of a cold RF window to seal off the cavity, we are required to assemble the power couplers with the cavities in a cleanroom (Class-100) environment. Figure 4 shows the assembly that will be assembled in the cleanroom. After cleanroom operation, we will rotate the assembly through the axis by 90-degrees to facilitate the installation of superinsulations, magnetic shields, LHe tubings, and instrumentation. After that, we will install all the LHe and vacuum connections and the two endcaps and test for vacuum.

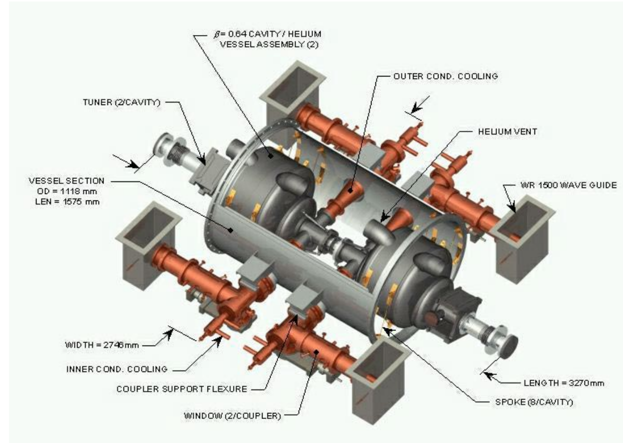

Figure 4: Part of cryomodule assembled in a Class-100 cleanroom

8 SUMMARY

We are developing SC RF cavities, couplers, and cryomodules to accelerate high-intensity proton beams. Issues identified during this development have been described in this paper.

9 REFERENCES

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