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PROGRESS OF APT SUPERCONDUCTING LINAC ENGINEERING DEVELOPMENT*

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Abstract

We initiated a program to develop superconducting (SC) RF for high-power proton linacs. These linacs are useful in accelerator-driven transmutation technologies and the Accelerator Production of Tritium (APT) Project. We are developing multicell niobium cavities with elliptical-cell shapes at 700 MHz. These cavities, unlike most elliptical cavities for electron accelerators, are designed to accelerate protons at $\beta<1$. 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 cryogenic temperature (2K). Their power handling and thermal properties will be measured. The cavities and power couplers will be integrated into a prototype cryomodule. The cryomodule will be tested and characterized with RF under cryogenic conditions required for a high-power proton linac. This paper describes the status of this program.

1 INTRODUCTION

We have a program to develop SCRF proton linacs in Los Alamos. Although this program has been initiated to support the APT SCRF linac [1], the technology development can be useful for all SC proton linacs with high CW power and current.

The merit of using SCRF linac for high-power applications, like accelerator-driven transmutation technology application, has been described in Ref 2. To successfully build such a high-power proton linac, we need to develop $\beta<1$ SC multicell cavities and power couplers that can transfer high (250 kW) RF power to the cavities. We have to integrate the cavities and power couplers in cryomodules for the acceleration of beams. In this paper, we will describe the issues in the development of cavities, power couplers, and cryomodules. Details of the designs of these components can be found 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. It is usually known as the elliptical cell shape and has been widely adopted in SCRF cavities accelerating relativistic electrons. For proton linac, 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 be prompt to collapse under vacuum pressure and to multipacting. We have designed the APT cavities with a 10-degree slope for the cell wall. This is the optimum slope considering minimizing peak electric and magnetic peak fields and maximizing mechanical stability. This slope, with a slight increase of wall thickness from 3 to 4 mm, allows us to eliminate the need of costly stiffeners that will otherwise be needed to withstand the vacuum load. We have tested single-cell cavities [4]. Results (Fig 2) showed the APT cavity field can be achieved with more than a factor of two margin with no limitations due to multipacting, even in the case of β=0.48.

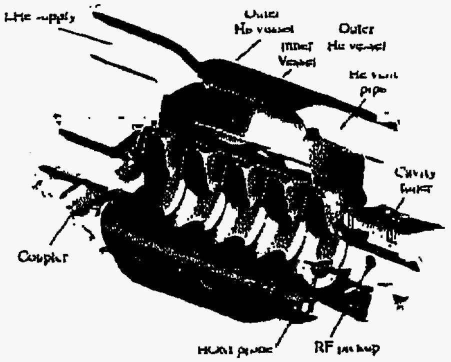

Figure 1: Illustration of β=0.64 cavity design.

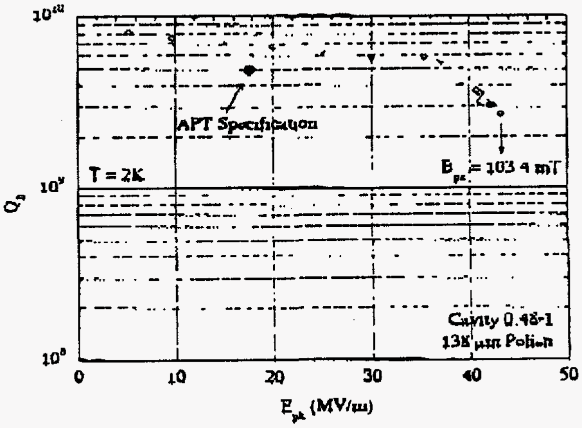

Figure 2· Typical test results of a β=0.48 cavity

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3 POWER COUPLER ENGINEERING DESIGN

Figure 3 shows an illustration of the APT power coupler. Because of the high beam power, each of this coupler needs to deliver 210 kW of CW power to the beam. This power level has been achieved only recently by a waveguide-type coupler and has not been achieved by coaxial-type coupler as chosen by APT coupler [5]. In addition, since the APT-linac is required to produce tritium with high availability over 40 years, it is important for the APT coupler to operate reliably at such a high power level.

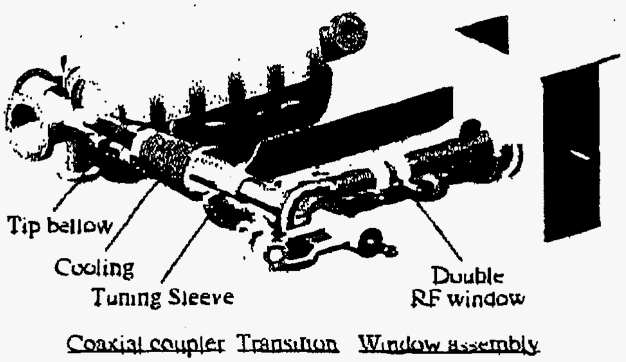

Figure 3: Illustration of APT power coupler.

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

The APT coupler consists of three sections: RF window assembly, transition, and 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 has been 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 can work hardened and yield after repeated elongation and compression and thermal cycling. Bellows made of BeCu is 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 has low outgassing rate and good adhesiveness to stainless steel. The plating process is needed to 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 do outgassing and adhesive tests on plating samples produced using these plating methods. We also will 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 2.5×10^5. This Q_L will be provided by two couplers, each having a Q_L of 5×10^5. We have investigated different coupler geometry 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 resulted in different failure scenarios and when the two couplers are not exactly identical were calculated.

5 OPERATING TEMPERATURE

The cavity operating temperature is chosen to be 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% operating at 2.15 K. Second, we decide to operate at the temperature regime of superfluid for better helium heat-transfer property and better margins against quench. An operating temperature of 2.15 K is the highest temperature that we can confidently control the LHe temperature so that the LHe remains superfluid.

6 HEAT LOADS AND POWER COUPLER COOLING

We are designing our components and cryomodules to maximize cryogenic efficiency and to minimize cryogenic power required. Table 1 shows a typical summary of itemized heat loads presented to the cryogenic system for a β=0.82 cryomodule. Such a cryomodule will have four cavities and eight power couplers. In this case, heats are removed by LHe and 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	61.6	0
Power Couplers	28	120
HOM	6.8	0
Others	6	65

The major heat loads are from the RF losses in the cavities. The Qo used to calculate this load is 5×10^{9}. The second major heat load is the power coupler. Power couplers are primary thermal connections between room temperature and 2.15-K temperature. They are also major heat sources because of the RF loss in the couplers. Depending on cooling scheme, the RF loss per coupler can amount to 200 W. It is important to prevent this loss 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 16-W at 2.15 K using counter-flow heat exchanger. 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 coupler, 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 the cleanroom (Class-100) environment. Figure 4 shows the assembly that will be assembled in the cleanroom. After the cleanroom, we will rotate the assembly through the axis by 90-degree 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.

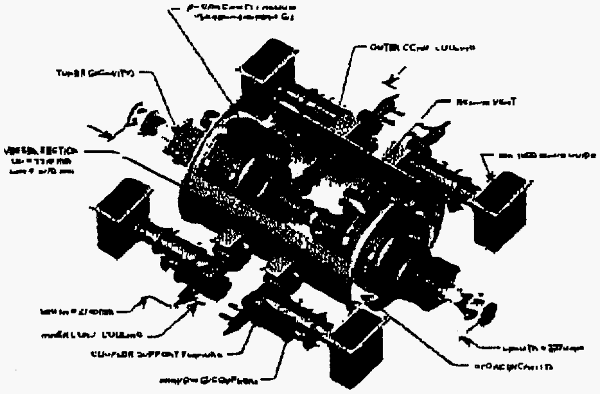

Figure 4. Part of cryomodule assembled in a Class-100 cleanroom

8 SUMMARY

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

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