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# APPLICATION OF RF SUPERCONDUCTIVITY TO HIGH-CURRENT LINAC\*

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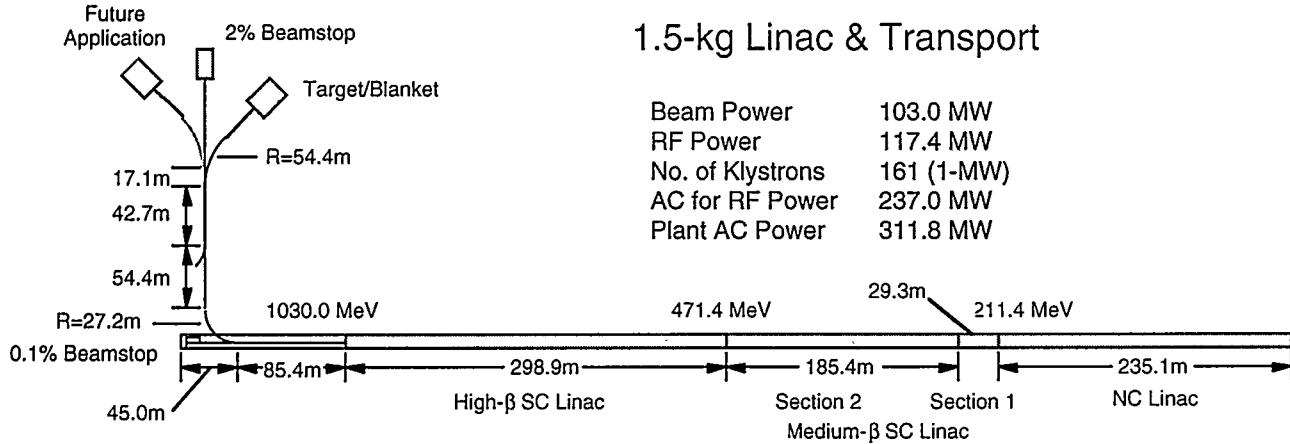


Fig. 1 Design of APT Linac

**Abstract** -- In 1997, we initiated a development program in Los Alamos for high-current superconducting proton-linac technology to build prototypes components of this linac to demonstrate the feasibility. We are building 700-MHz niobium cavities with elliptical shapes, as well as power couplers to transfer high RF power to these cavities. The cavities and power couplers will be integrated in cryostats as linac cryomodules. In this paper, we will describe the linac design and the status of the development program.

## I INTRODUCTION

High-current proton linacs, using a spallation process, can produce neutrons for research and transmutation applications. These linacs have multi-megawatts of beam power and are very power consuming.

A RF superconducting (SC) linac has been proposed for the Accelerator Production of Tritium (APT) Project sponsored by The US Department of Energy [1] [2]. Figure 1 shows the design of the APT linac that has a nominal production capacity of 1.5 kg of tritium per year. This design is upgradable to a capacity of 3.0 kg per year by increasing the proton beam energy to 1700 MeV. The linac consists of a normal-conducting (NC) Linac and a superconducting (SC) Linac. The NC Linac uses the usual room-temperature copper technology. It is chosen because of its capability to produce a proton beam with high quality for further acceleration. The SC Linac uses superconducting Nb technology. SC technology is

chosen for the high-energy efficiency and low beam loss. The use of RF superconducting cavities in these linacs has enhanced energy efficiency because of the absence of RF electrical resistance. The linac has reduced beam loss because of the large cavity apertures. The SC Linac has a Medium- $\beta$  ( $\beta=0.64$ ) SC Linac and a High- $\beta$  ( $\beta=0.82$ ) SC Linac. Each of them consists of identical cryomodules.

To insure our capability of building such a linac, we implemented an Engineering Development and Demonstration (ED&D) Program in Los Alamos [3]. The scope of the program is to build and test SC cavities and power couplers for the proposed linac and integrate them in a prototype cryomodule. The goal is to demonstrate the required performances. Similar development programs are now in place in Japan [4] and Italy [5]. Even though our program is designed for the APT Project, the development is useful for the application of SC to high-current proton linacs.

## II CAVITIES

Figure 2 shows the design of a  $\beta=0.64$  SC cavity. The cavity has five cells made of niobium sheet metal. It is surrounded by inner and outer He vessels. The cylindrical inner vessel provides the needed mechanical strength and the outer He vessel has a large volume to provide the required He liquid even at fault conditions. These He vessels are made of titanium to match the thermal expansion of the niobium. The inner He vessel is connected to the niobium cavity with titanium bellows.

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Each cavity will be supplied with RF power using two power couplers throughout the RF drive ports. The diameter of the beam tube at the end with the RF drive port is larger to provide the required coupling between the cavity and power couplers. The tuner is mechanical in nature and has all the drive gears at ambient temperature to enhance reliability. It is a proven design used successfully at Cornell University.

Each cell has an elliptical shape similar to that used for electron accelerators with the exception that the length is shorter to maintain synchronism for the  $\beta=0.64$  beam. The slope of the sidewall is optimized to maintain mechanical stability under vacuum load without the use of costly stiffeners. It is required to operate at an accelerating field of 4-6 MV/m with a  $Q_0$  of  $5 \times 10^9$ . This performance requirement, peak surface field below 16 MV/m, is conservative. It should be readily achievable with readily available niobium with an RRR of 250 and standard processing techniques, viz., e-beam welding, buffered chemical polish, and high-pressure rinsing. We have tested single-cell cavities with  $\beta=0.48$  and  $\beta=0.64$  [6]. We achieved the required performance without observing multipacting. Figure 3 shows the measured performance of a  $\beta=0.48$  single-cell cavity. The cavity attained our required field with a factor-of-two margin.

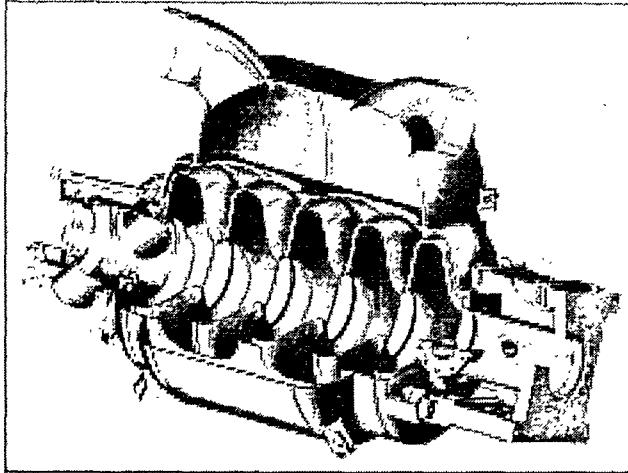


Fig.2  $\beta=0.64$  5-cell cavity

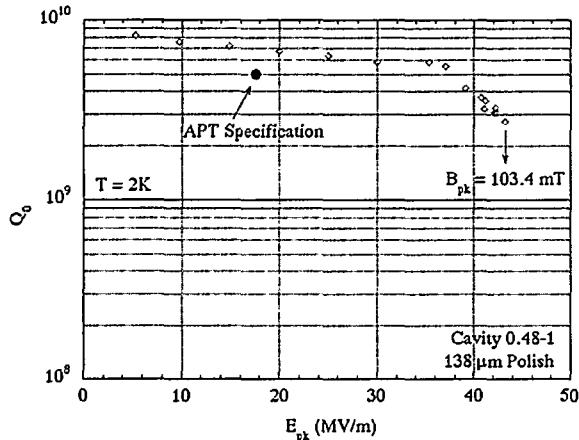


Figure 3: Typical test results of a  $\beta=0.48$  cavity

We completed the design of the  $\beta=64$  5-cell cavities. Four cavities have been ordered from industry. We completed the fabrication of one "prototype cavity" at Los Alamos (Figure 4), i.e., a niobium cavity without He vessels. This cavity is undergoing testing.

We completed a cost analysis, including both capital and operating costs. The cost analysis shows that the optimum temperature is at 2.4 K and the optimum is broad. The cost changes only by 10% with changes in temperature of  $\pm 0.2$  K. In addition, we would prefer to operate in the superfluid regime of to take advantage of the high thermal conductivity of superfluid He. Therefore we want to operate the cavity at the highest temperature, but with a controllable margin below the critical temperature so that the critical temperature will not be exceeded. Presently, we have nominally fixed the cavity operating temperature at 2.15 K.

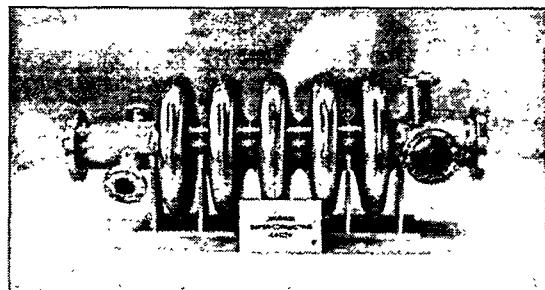


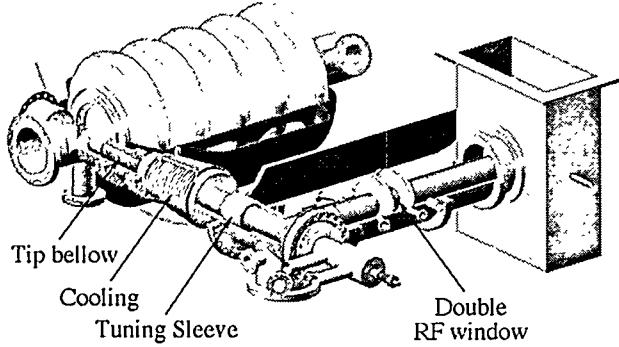
Fig. 4 Prototype  $\beta=0.64$  5-cell Nb cavity

### III POWER COUPLER

We need to develop a power coupler that can transmit 210 kW of CW power. The highest rated coupler presently is 188 kW to the beam. Figure 5 illustrates the design of the APT coupler. It has three sections: coaxial coupler, transition, and RF-window assembly. We have chosen the coaxial design because it has a better-understood geometry and was the highest rated design at the time our design was conceived. The RF window is usually the point of failure for couplers. We choose to use double warm windows for increased reliability. The window assembly is being fabricated by the klystron industry as one complete unit. We have done extensive modeling using 3-D electromagnetic codes to design the transition section. Using the tuning sleeve, we have minimized reflection and interactions between components.

The design was reviewed in May 1998. The review committee underscored the importance of thermal design and testing of the coupler. Because of the high power transmitted, the RF loss in each coupler is as high as 200 W. It is important to prevent this energy from reaching the LHe for good cryogenic efficiency. Presently, we are considering options of cooling the coupler outer conductors [7]. The options include the use of a double-

temperature thermal intercept and an heat exchanger. The selection will be made in consideration with the cryomodule and cryoplant designs. We are now fabricating the power coupler components. We have planned a detailed test program to test the coupler for its power-carrying capability and multipacting characteristics. We will also test the bellows and copper plating used in the present design.



Coaxial coupler Transition Window assembly

Fig. 5 Illustration of power coupler

#### IV CRYOMODULE

We held a review of the Conceptual Design in September 1997 and have since been developing this design. A final design review is planned for November 1998. Figure 6 shows the cryomodule design for  $\beta=0.64$  [8]. The cryostat will contain two 5-cell cavities and four power couplers. The cryostat has a center section and two end domes. It has removable panels for the center section for easy access. This design is based on the LEP-II cryomodule design. The thermal shield consists of two aluminum halves and is pipe cooled. The magnetic shield will reduce the magnetic fields at cavities to 10 mGauss to enhance cavity performance. The vacuum pumping is provided by oil-free turbopumps. The pumps are arranged to have redundancy to increase availability.

We have also developed the assembly process of the cryomodule. Because we are not using cold windows, the installation of the cavities and couplers is required to be done in a cleanroom. The assembly after the cleanroom will be rotated 90 degrees to facilitate the installation of magnetic and thermal shields.

#### V SUMMARY

The Engineering Development and Demonstration Program for the APT superconducting linac is progressing well. We are finishing our design phase and are entering the fabrication phase.

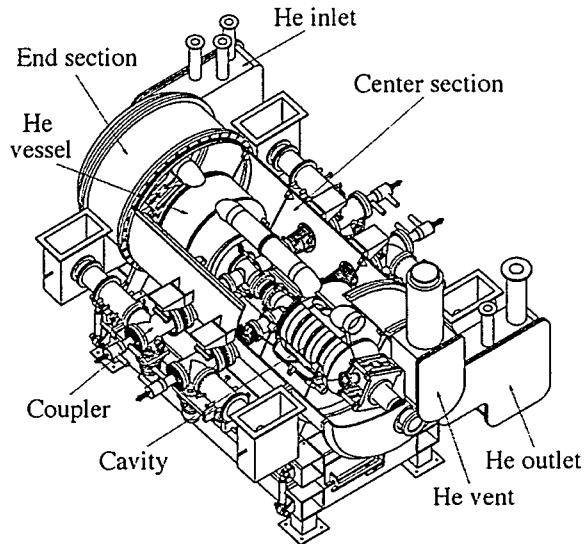


Fig. 6 Illustration of cryomodule

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