DESIGN OF THE SNS CRYOMODULE*

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Abstract

The Spallation Neutron Source (SNS) has changed the high-energy end of its linac to a superconducting RF (SRF) system. The design uses medium and high beta cavities installed into cryomodules to span the energy region of 185 MeV up to 840-1300 MeV. This paper describes the design of these cryomodules that provide a significant portion of the total acceleration to the negative Hydrogen ion beam. The design minimizes the effect of losses on cavity performance by preserving cavity cleanliness, maintaining high vacuum and shielding the cavity from the earth's magnetic field. A modal analysis was performed to maintain the cavities on resonance by minimizing cavity microphonics and providing cavity tuning. The cryomodule design optimizes the cryostat heat load to the refrigerator on the primary (2 K), secondary (5 K) and shield (50 K) circuits and facilitates production of multiple modules (32 maximum) at a reasonable cost. The paper describes the two types of cavities, the helium vessel, the tuner, the magnetic shields, the thermal shield, the fundamental power couplers, the space frame, the vacuum tank and the end cans that make up the medium and high beta cryomodules.

1 INTRODUCTION

The SNS is a 1 GeV negative Hydrogen ion accelerator with up to 2 MW power producing a source of neutrons for materials research. The initial portion of the acceleration is achieved via a conventional negative proton injector, a drift tube linac (DTL) and a coupled cavity linac (CCL), that provide a nominal energy gain up to 185 MeV. The machine was changed in December 1999 from a warm temperature to a cold temperature linac to improve overall machine performance. The superconducting linac (SCL), discussed here, contains 11 medium beta cryomodules capable of 345 MeV and 12 to 21 high beta cryomodules capable of up to 1300 MeV. After passing through an accumulator ring the beam goes to a mercury target where a neutron beam of as much power as 2 MW is produced.

The cryomodule (CM) is based on the CEBAF CM with improvements borrowed from LHC, TESLA, and the JLab 12 GeV upgrade and uses the frequency scaled KEK fundamental power coupler (FPC). Figure 1 is the elevation view of the high beta CM, while Figure 2 is the flow schematic. The FPC requires a 4.5 K lead flow to cool the outer conductor; therefore the LHC concept of producing the 2 K in the CM rather than in the refrigerator is utilized.

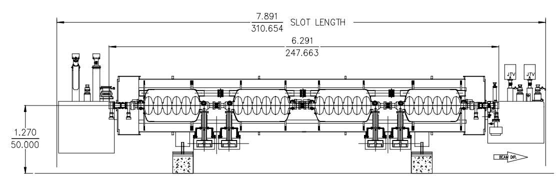

Figure 1: High Beta Cryomodule

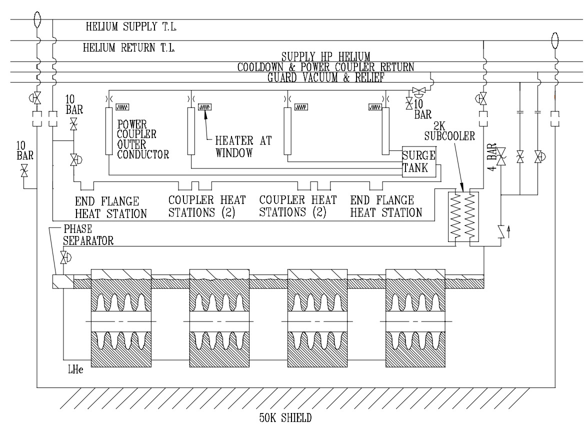

Figure 2: Flow Schematic

The refrigerator produces a 3 bar, 4.5 K stream, which feeds two Joule-Thompson (JT) valves in parallel. The first supplies a small sub-cooler in the CM and then cools the cavity. The second feeds the power coupler outer conductor. The CM shield is cooled by a 4 bar, 35 K stream, which first cools the supply transfer line (TL) shield, then the CM shield, and finally the return TL shield before returning to the refrigerator at 52 K. The bayonet design permits replacement of a CM in less than a day if needed without warming up the entire linac. In the nine years since the initial CEBAF cooldown, the linacs have never been warmed up and only four CMs have been replaced during scheduled accelerator shutdowns.

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The relevant parameters for both medium and high beta CMs are given in Table 1 and the relevant refrigeration capacities are given in Table 2.

Table 1. Cryomodule Parameters

	Medium	High
Slot length	5.839 m	7.891 m
CM length (bore tube)	4.239 m	6.291 m
CM diameter	1.22 m (~48 ")	
2K Heat load (static/dynamic)	25 / 14 W	28 / 20 W
Maximum coupler flow		0.075 g/s
Shield heat load including Transfer Line	170 W	200 W
Tunnel H x W		10 x 14 ft
Control valves per CM		5
Bayonets per CM		4
Radiation hardness		10^8 rads
Pressure rating	2K System Warm	3 atm
	Cold	5 atm
	Shield and 4.5 K systems	20 atm

Table 2. Refrigeration Capacities

	He Temp (K)	Capacity (W)	Pressure (atm)	Flow (g/sec)
Linac shields	35-52	8300	4.0	90
Linac cavities	2.1	2400	0.041	120
Secondary	4.5		3.0	0.15

2 CAVITY STRING

The design, manufacture, and performance of the SRF cavities are reported elsewhere[1]. The medium beta CM consists of three six-cell cavities while there are four six-cell cavities for the high beta CMs. The SNS cavities operate at 805 MHz. During initial tests, the cavities have met the design requirement for accelerating gradient, which is an E_{peak} of 27.5 MV/m at a design quality factor, Q_0, of 6x10^9 at 2.1 K. Power dissipation per cavity at 7% duty cycle is 2 W and 3.5 W for the medium and high beta cavities respectively. The relationship of Q_0 with temperature follows BCS theory. Accordingly, the Q_0 of 14x10^9 at 2 K decreases to 6.9x10^9 at 2.3 K. The two different beta cavities are elliptical in shape, manufactured from 4 mm thick niobium and have stiffening rings at 80 mm to minimize microphonics. The performance of the first prototype medium beta cavity, shown in Figure 3, has exceeded the required performance.

The cavities are housed in a titanium helium vessel, which matches the coefficient of thermal expansion of the cavity. The cavity is maintained at operating frequency through a TESLA-style tuner mounted on one end of the helium vessel, which operates through a bellows. The tuner, manufactured out of stainless steel, is actuated through a cold stepping motor through a harmonic drive. Power is brought into the cavity through the coaxial FPC[2] at one end of the cavity. Higher order mode extraction filters are attached at each end of the cavity to damp some potentially dangerous longitudinal modes. The string of cavities in the helium vessel with couplers, HOM damping filters and hermetic valves are assembled in JLab Class 100 clean room to minimize contamination. Figure 4 shows the arrangement of the cavity string including the cavity, coupler, helium vessel and tuner.

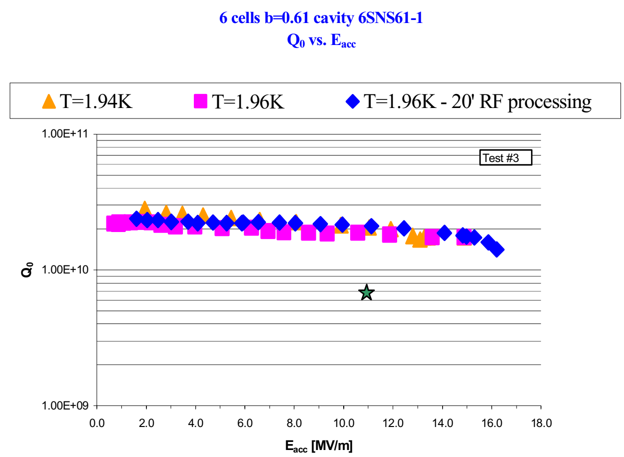

Figure 3: Medium Beta Cavity Performance

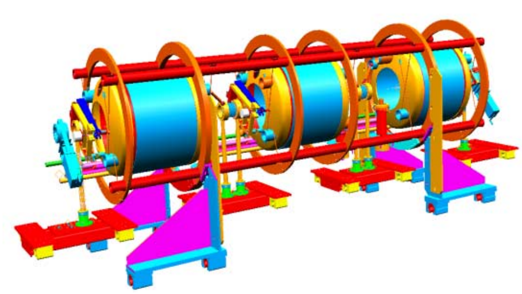

Figure 4: Cavity String Components Inside the Spaceframe Situated on Tooling

3 CRYOMODULE

A high beta CM consists of two end cans, a vacuum tank, a space frame, a thermal shield, two magnetic shields and a hermetically sealed string of four cavities in the helium vessel each with FPCs, a field probe, two HOM filters, bellows between cavities and seal valves. A medium beta CM is similar in construction but houses a string of three hermetically sealed cavities instead of four. The general arrangement of these components is shown in

Figures 5 and 6. The CMs used in CEBAF, the largest use of SRF in the US, employs a similar construction arrangement. What makes the SNS design unique is that the CMs are assembled at JLab and shipped to the SNS site at Oak Ridge National Laboratory (ORNL). This led to the development of a structure that can handle the over-the-road shipment of 500 miles while maintaining alignment of the cavities in a low loss cryostat[3]. The space frame was developed at JLab for the next generation JLab CM to facilitate installation of long strings of cavities efficiently at a relatively low cost. The space frame was adapted and strengthened to handle the relatively high transportation loads incurred during shipment to ORNL. The vacuum tank provides a support structure for the space frame and minimizes the gaseous conduction to the cold surfaces on the cavity string. The string is supported off of the space frame through nitronic rods, which limit the solid conduction between room temperature and the cryogenic surfaces. These rods are also able to take the shipping loads and maintain the cavities in alignment. A thermal shield, operating at 50 K, surrounded with multilayer insulation (MLI) provides a radiation barrier between the cavities and the outside world. There are two magnetic shields, one outside the

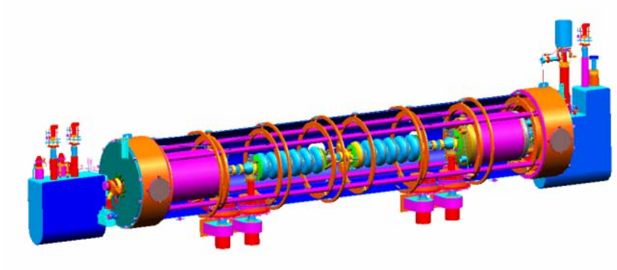

Figure 5: High Beta Cut-Away

space frame and the other at the helium vessel, which in concert reduce the earth's and stray magnetic fields by a factor of ~ 100 to minimize the effect on the cavity Q_0. L shaped end cans, a design developed for CEBAF to save space, close off the cavity string in the vacuum tank and provides the interface for the helium to cool the cavities, the couplers and the thermal shields. Between each CM is a 1.6 m warm space that contains quadrupole magnets and diagnostics including beam position monitors, current transformers and wire scanners.

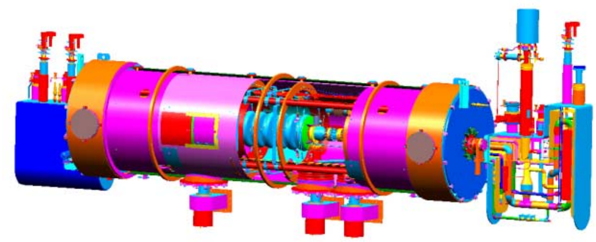

Figure 6: Medium Beta Cut-Away

4 STATUS

The designs of both cavities and cryomodules are complete and construction of the prototypical module has begun. Testing is expected to begin at the end of 2001. First articles of each of the components are in production. The production cavity order with HOM loads and the FPCs is expected to be awarded next month.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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