THE FIRST ASME CODE STAMPED CRYOMODULE AT SNS*

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Abstract

The first spare cryomodule for the Spallation Neutron Source (SNS) has been designed, fabricated, and tested by SNS personnel. The approach to the engineering design for this cryomodule was to maintain critical features of the original design such as bayonet positions, coupler positions, cold mass assembly, and overall footprint. However, this new cryomodule design was required to meet the pressure requirements put forth in 10 CFR 851: Worker Safety and Health Program. The most significant engineering change was applying Section VIII of the ASME Boiler and Pressure Vessel Code to the vacuum vessel of this cryomodule instead of the traditional designs where the helium circuit is the pressure boundary. Applying the pressure code to the helium circuit within the cryomodule was considered. However, it was determined to be schedule prohibitive because it required a code case for the niobium materials which are not currently covered by the code. Good engineering practice however, was applied to the internal components to verify the quality and integrity of the entire cryomodule. The design of the cryomodule, fabrication effort, cryogenic and high power RF test results will be reported in this paper.

INTRODUCTION

The Spallation Neutron Source (SNS) contains a superconducting linear accelerator (SCL) which consists of eleven medium beta and twelve high beta cryomodules. The linac tunnel has nine additional slots for high beta cryomodules for expansion and upgrades. Throughout the operating history of the SNS SCL, several operating scenarios have indicated that there is a necessity for a spare medium and high beta cryomodule to allow for repairs of existing cryomodules and mitigate risk in the event of a cryomodule failure. Damage to components and degradation of performance have been observed in several cavities which have resulted in multiple cryomodules requiring repair and rework [1-2]. This has served as a driver for SNS to initiate the spare cryomodule fabrication effort.

Because future expansions would consist of adding high beta cryomodules to the LINAC, the decision was made that the first spare cryomodule would be a high beta. This would enable the repair of any of the twelve high beta cryomodules and serve as a Power Upgrade Project prototype. This effort would not only serve to give SNS operating flexibility and reliability but enable SNS personnel to gain valuable experience prior to entering into an upgrade project.

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DESIGN CRITERIA

The SNS LINAC houses twenty-three successfully operating cryomodules designed and fabricated by Jefferson Laboratory. When possible, SNS would reproduce the same design as previously used. However in 2007, the Department of Energy enacted 10CFR851, the Worker Safety and Health Program. This law contained a section on pressure safety and made specific references to the cryogenic and vacuum industries. All vessels that could be defined as a pressure vessel according to Section VIII of the ASME Boiler and Pressure Vessel Code (B&PV) would be required to have a code stamp, an independent peer review, or a professional engineer review. The result of the reviews would have to determine and certify that the vessel was as safe as or better than what would be required by the code. The SNS approach was to enact section VIII of the ASME code to avoid any ambiguity that may arise from a review process.

To enact the code, two options were considered; applying the code to the vacuum vessel and applying the code to the helium vessel. The decision was made to define the vacuum vessel and end can envelope as the pressure boundary [3] due to the difficulty in applying the pressure code to the helium circuit materials. The niobium, titanium and niobium titanium alloy are not code listed at the operating temperature that is routinely maintained within the cryomodules. The approach to use the vacuum vessel as the pressure boundary made use of the interpretation of VIII-1-89-82 where it was deemed acceptable to stamp the exterior vessel of a heat exchanger if the tube side exceeded the rated operating pressure provided the shell and associated relief devices are designed to withstand the highest design pressure associated with the tube side. Moving the pressure boundary from the cavity helium circuit to the vacuum vessel has additional safety benefits. First, the vacuum shell material is 304 stainless steel which is one of the best materials for fracture toughness and ease of fabrication. Second, the vacuum shell will never reach the helium operating temperature even with a catastrophic failure of the helium lines due to the thermal mass of the vessel material which is at room temperature. Therefore the material properties at liquid nitrogen can be used. Third, the vacuum vessel envelope could be easily pressure tested without the SRF cavity string installed.

DESIGN APPROACH

To keep the cryomodule consistent with original cryomodules and make it a viable spare, several design

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criteria were held constant. The spare cryomodule must plug into any slot from which a high beta cryomodule requiring repair would come. Slot length, bayonet positions, warm region interface and vacuum interfaces were identical with the former design. The components that were fixed in location and those that were considered moveable are depicted in Fig. 1. The design and relief pressures of the helium circuits were also held constant.

In applying the pressure code to the vacuum envelope, three separate pressure stamps were necessary; one for the vacuum vessel, one for the supply end can vacuum boundary and one for the return end can vacuum boundary.

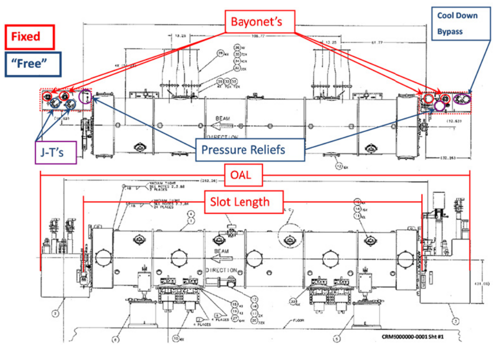

Figure 1: Reference interface locations.

This was done so that each of these could be pressure tested according to code requirements without the cavity string installed in the vacuum vessel. Once the internal components were installed, no pressure testing was permitted. Since this was a first of a kind approach, additional conservatism was applied to the design. The design pressure of the vacuum boundary was 3.0 atmospheres absolute while the maximum allowable working pressure was limited to 2.5 atmospheres absolute. Typically, these numbers are not different. However, additional safety margin was allowed by this approach. This design pressure was chosen because of two primary reasons. First with this design pressure, it was determined that reliefs could be sized to handle any worst case scenario that may occur within the vessel. Second, the original design materials were consistent with this pressure rating. However, there were required changes to the nozzles, the way the end cans were connected to the cryomodule and a 6" burst disk was added to the vacuum vessel in addition to the two existing lift plate reliefs.

DESIGN AND FABRICATION CHANGES

The primary changes to the cryomodule occurred in the end cans. Previously, these had not been designed or fabricated in a way that the vacuum boundary could withstand pressure. Therefore, the shape and thickness of the end cans were modified. Because of the three pressure stamps philosophy, the end cans had to be capable of being pressure tested individually and the same was true for the vacuum vessel. The end cans attached to the side of the vacuum vessel by a flanged connection. This allowed for easy pressure testing of all three vessels. However, it removed the bridging ring from the original design concept. This required that the main part of the vacuum vessel in the spare cryomodule be longer than the original cryomodules. Removal of the bridging ring complicated assembly in the warm to cold transition region necessitating design changes to this region of the cryomodule. This also affected the flexibility of alignment of the string to the warm beam line flange. Therefore modeling of the string within the vacuum vessel had to be very precise because the movement of the warm to cold transition in the old design was eliminated. The alignment was performed with a laser tracker and the modeling was successful such that the string aligned with the warm valve within the specification limit of 1 mm [4].

To simplify the supply end can as much as possible, the primary and secondary JT valves were moved from the end can to the vacuum vessel. This significantly reduced the piping within the supply end can. The new supply end design is compared to the original design in Fig. 2. Similar analysis was conducted to simplify the return end can by moving the heat exchanger into the vacuum vessel. To accomplish this, the heat exchanger would have had to change. However, the decision was made to keep all of the original equipment in the return end can since it was a proven reliable design. Because the new pressure rated end cans were connected differently to the vacuum vessel, they required new mechanical support brackets (Fig. 3).

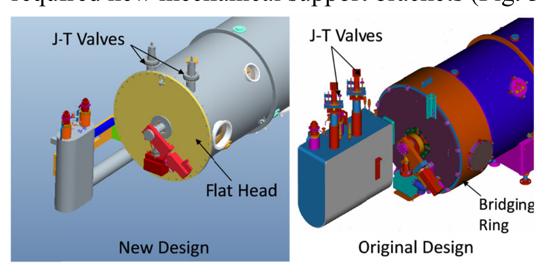

Figure 2: Comparison of the supply end design.

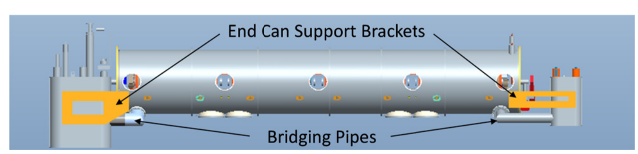

Figure 3: Interfaces between end cans and vacuum vessel.

Although the helium circuit is not code stamped with this design philosophy, good engineering practice was applied to this portion of the cryomodule. The helium vessels were modified so that the stiffening in the heads of the vessels was increased. In addition, the design of the cylindrical portion of the helium vessel was modified so that all welds could be full penetration welds. The fabrication techniques used were consistent with ASME code practices and procedures. The inspection requirements were also consistent with those called out in the ASME B&PV code. All welds that would eventually be subjected to cryogenic temperatures were made using low ferrite filler material. Ferrite is known to reduce

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toughness in cryogenic applications and therefore filler material had a ferrite number below 5 [5].

The design changes were successfully incorporated into the fabrication and pressure test of the SNS spare cryomodule (Fig.4).

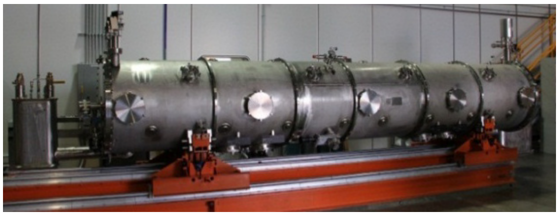

Figure 4: SNS spare high beta cryomodule.

TESTING

The first cryogenic and RF testing of the spare cryomodule took place in March 2012. The cryomodule was cooled down using the Central Helium Liquefier 4K Cold Box. Previously, this had only been accomplished during maintenance periods while the SNS Superconducting Linac was at 4K operation. This particular cool down was accomplished while operating the SCL at 2K. During the initial cool down of the transfer line to the test cave where the spare cryomodule testing takes place, there were multiple pressure spikes that communicated with the cold turbine discharge which required careful monitoring. Supercritical helium flowing to the liquid helium storage dewar was split with a portion going to the dewar JT valve and the other portion going to the test cave. The helium was supplied to the cryomodule primary path through a JT valve. The helium exited the primary return bayonet and was routed to the shield return bayonet where the helium flowed backwards through the shield passage which resulted in a shield operating temperature ranging between 6 and 12K. Helium was then routed back through the shield passage of the transfer line where it was directed to the purifier through an ambient heat exchanger. A diagram of the flow path is shown in Figure 5.

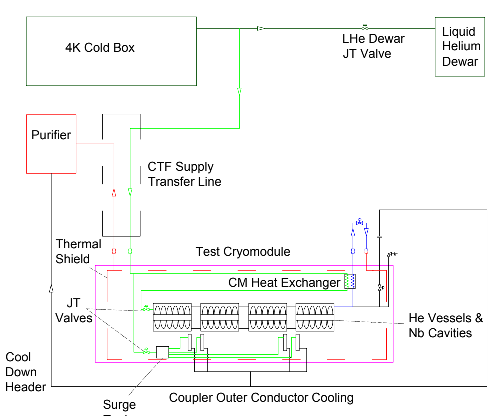

Figure 5: Test Process Flow Diagram

The cool down of the cryomodule was completed with no observed negative effects. There were no sign of leaks in the insulating vacuum or beam line vacuum boundaries. Although this operation was conducted with a unique flow path, operability of the system was controlled successfully. The shield passage varied from the normal shield operating temperature of 38K–50K. Despite the unusual flow path and shield operating temperature, helium liquid level and pressure were controlled within tolerance limits. By successfully conducting this cool down while the SNS SCL was at 2K operation, it enables more flexibility in conducting critical testing in the RF test cave when the risk is warranted.

After cool down was complete and the cryomodule was filled with liquid helium, each cavity was RF tested individually. The cryomodule test results are summarized with the VTA test results in Table 1. For cavity HB54, the limiting gradient was increased by RF processing and reducing the effects of multipacting. The cavity RF results are consistent with the initial VTA results. The limiting condition of all 4 cavities is the partial quench at the end groups that is also the prevalent limiting condition of the cavities in the SCL. Because the radiation onset of the cavities is close to the limiting gradients, it is likely that collective effects [2] will be manageable which gives good confidence to this being a viable spare cryomodule. In the summer of 2012, the spare cryomodule is scheduled to be installed in the SNS LINAC tunnel.

Table 1: Cavity RF Test Results

Cryomodule test in the test cave, Average limiting gradient $E_{lim,avg}$: 16.0 MV/m				Vertical test $E_{lim,avg}$:16.3 MV/m
Cavity	Limiting gradient (MV/m)	radiation onset (MV/m)	Limiting condition	Limiting gradient (MV/m)
HB54	14.0	12.0	End group quench	13.0
HB56	16.0	16.0	End group quench	17.5
HB58	17.5	16.0	End group quench	17.2
HB53	16.5	15.5	End group quench	17.6

ACKNOWLEDGMENT

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