High Intensity Neutrino Source Superconducting Spoke Resonator and Test Cryostat Design and Status

Thomas H. Nicol, Giobatta Lanfranco, and Leonardo Ristori

***Abstract*—Fermilab is in the process of constructing a 60 MeV linac as part of the High Intensity Neutrino Source (HINS) R&D program. Developments from this program could play a direct role in an upgraded injector for the existing Main Injector at Fermilab to support the ongoing neutrino physics program. In addition this same R&D could lead to breakthroughs in superconducting radio frequency (SRF) technology useful in any of several large-scale SRF accelerator projects being discussed around the world. The initial beam acceleration in the linac front end is achieved using room temperature spoke resonators combined with superconducting solenoids for focusing. At the end of the room temperature section, three cryomodules containing either 9 or 11 single spoke resonators operating at 4.5 K and 325 MHz, also with superconducting solenoids, accelerate the H- test beam to its final energy. Each spoke cavity will be tested individually in a cryostat that replicates conditions in the longer multi-cavity modules. This test cryostat has all the features of the longer cryomodules – magnetic shielding, 80 K thermal shield, multi-layer insulation, support post, and input coupler. The goal is that by using common features we will facilitate the eventual design of the longer cryomodules. This paper describes the design of the test cryostat, the mechanical design of the spoke cavities and their helium vessels, and includes a detailed status of the development work [1] [2].**

***Index Terms*—Neutrino source, Spoke resonators, Superconducting resonators, Test cryostat.**

I. Introduction

THE present configuration of the HINS front end linac has three cryomodules that contain combinations of superconducting single spoke resonators (SSR) and solenoids. The first two cryomodules, designated SSR1, each contain nine 325 MHz single spoke resonators and 9 superconducting solenoids. The third, designated SSR2, contains 11 resonators and 6 solenoids. Fig. 1 illustrates the layout of the linac front end from the ion source (IS) through the last single spoke resonator cryomodule. This figure also illustrates the position of the RF quad, medium energy beam transport (MEBT) and room temperature (RT) cavity sections. The overall length of the entire linac from the ion source to the end of the last cryomodule is approximately 53 meters and the maximum energy is 60 MeV.

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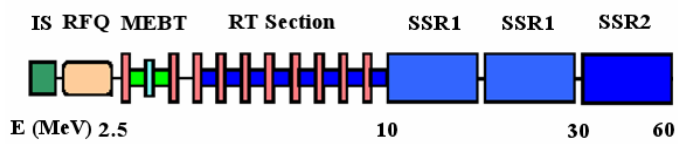

Fig.1. HINS front end linac layout.

The subject of this report is a standalone cryostat that will be used to individually test each superconducting spoke resonator immediately prior to its assembly into a cryomodule cavity string. It has been sized for all the cavities envisioned for use over the next several years either with or without the cavity's associated superconducting solenoid.

As a rule, many of the constraints facing the design of cryostats for superconducting components are at odds with one another. This design is no different. The final assembly must be structurally strong to resist static and dynamic loads imposed by operation and by shipping and handling. The suspension must be stiff enough to resist long term degradation in alignment and must be thermally efficient to minimize heat input to the helium system. Magnetic shielding is included to shield the cavity under test from the effect of the earth's magnetic field as well as any electronic equipment nearby. A thermal shield operating nominally at 80 K intercepts heat radiating from the room temperature vacuum vessel. Multi-layer insulation (MLI) further serves to reduce heat flux into the cavity structure. Fig. 2 illustrates the test articles, both the bare cavity and the cavity as installed in its helium vessel.

Fig.2. HINS cavity and cavity / helium vessel / solenoid assembly.

II. Cryostat Design and Assembly

The following sections provide detail about the design, manufacturing, and assembly of the main cryostat components and the overall assembly of the cryostat itself.

A. Vacuum Vessel

The vacuum vessel contains the insulating vacuum for the cryogenic system, serves as the base for the internal structural support, and provides the attachment to the floor of the test cave. The diameter was chosen to be the same as that envisioned for the final cryomodule design so that the test cryostat could serve, in a limited way, as a test vehicle for the final cryomodule design. The overall length was chosen to accommodate cavities ranging in size from the first single spoke resonators or SSR1, with an optional solenoid attached, through triple spoke resonators envisioned for potential future use. Cryogenic connections are made through a top hat assembly on the top of the vessel. The ends consist of hinged domes to facilitate access from both ends during installation of the cavity and solenoid, connection of instrumentation, and connection of internal piping. The material is type 304 stainless steel to minimize the presence of any residual magnetic fields that might be expected from a carbon steel vessel. Fig. 3 illustrates a solid model of the vacuum vessel showing the top hat and hinged end domes.

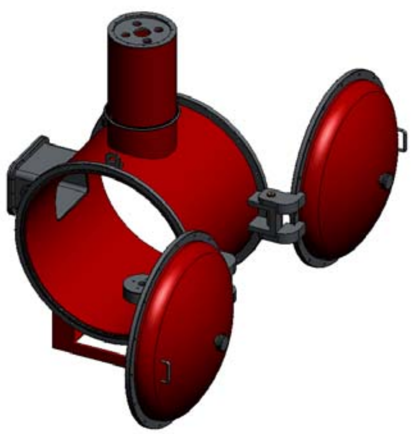

Fig. 3. HINS test cryostat vacuum vessel.

B. Magnetic Shield

The magnetic shield is the first installed layer inside the vacuum vessel wall and shields the cavity assembly from the effects of magnetic fields external to the cryostat. Shielding to isolate the cavity from stray fields originating in the solenoid is installed around the cavity, solenoid or both and is not part of the cryostat assembly itself. The shield consists of a shell of 1.5 mm-thick shielding material manufactured by Amuneal Manufacturing Corporation. Early in the development process we realized we weren't familiar with the special fabrication, fastening, and heat treating techniques necessary to design a reliable magnetic shield. As a result, the fabrication contract included developing the detailed design of the shield. The resulting process involved our providing an assembly drawing of the vacuum vessel into which the magnetic shield fits and iterating with the supplier's engineers to arrive at the completed design. Fig. 4 illustrates one of the graphics provided by Amuneal during the design process. The assembly mimics the inside surface of the vacuum vessel except that the ends are conical to reduce cost. The shield is permanently installed in the vacuum vessel during cryostat assembly. Only the ends are removable to facilitate access to the internal structure. Sitting just inside the vacuum vessel surface, the magnetic shield operates at or near room temperature.

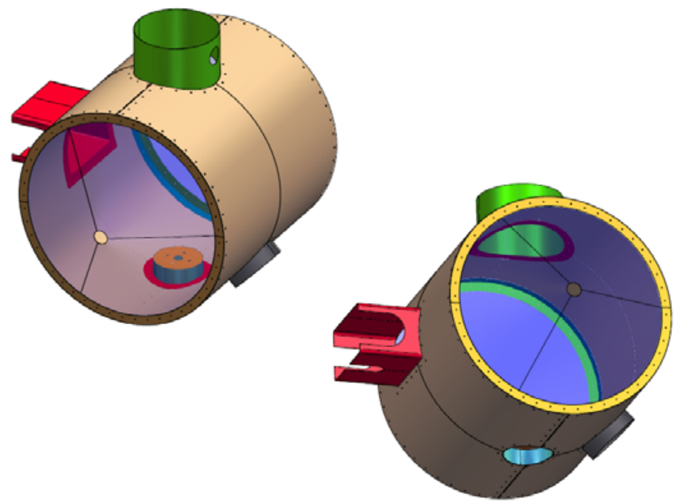

Fig. 4. Magnetic shield design as provided by Amuneal.

C. Thermal Shield

The next two layers inside the magnetic shield are the thermal shield and multi-layer insulation. The thermal shield is cooled by a single pass liquid nitrogen system and intercepts heat radiating from the vacuum vessel, nominally at room temperature. The shield is covered by a multi-layer insulation blanket consisting of 30 layers of reflective mylar with interleaved spacer material to facilitate vacuum pumpdown. The MLI reduces heat flux into the thermal shield to approximately 1 W/m^2 [3]. The shield is fabricated from 6061-T6 aluminum fed by stainless steel tubes connected to two aluminum extrusions through aluminum to stainless steel transition joints. The extrusions and transition joints were spare components originally purchased for our LHC interaction quadrupole program. Fig. 5 shows the thermal shield assembly. Like the magnetic shield, the thermal shield is permanently installed inside the vacuum vessel. Only the ends are removable for access to the assembly under test.

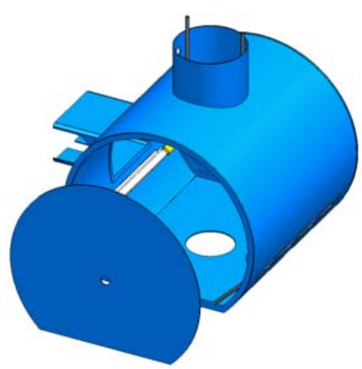

Fig. 5. Thermal shield assembly.

D. Support Post

The original design concept for mechanical support inside the cryomodule was for each cavity and solenoid pair to be attached to the vacuum vessel by its own support post to mitigate concerns about axial shrinkage affecting the input coupler. Subsequent concern about alignment of the solenoid with respect to the cavity has resulted in our separating the two, but still, each will have its own support post. The support post design is similar to those developed for other magnet projects at Fermilab and consists of a fiber reinforced composite attached to metal rings and disk by shrink fit techniques [4]. Fig. 6 shows the support post for the test cryostat and cryomodules. The bottom end is bolted to the vacuum vessel. The center ring attaches to the thermal shield and serves as both the mechanical attachment and thermal intercept. The top ring attaches to the cavity. Disks of multi-layer insulation minimize radiation heat transfer through the inside volume of the support.

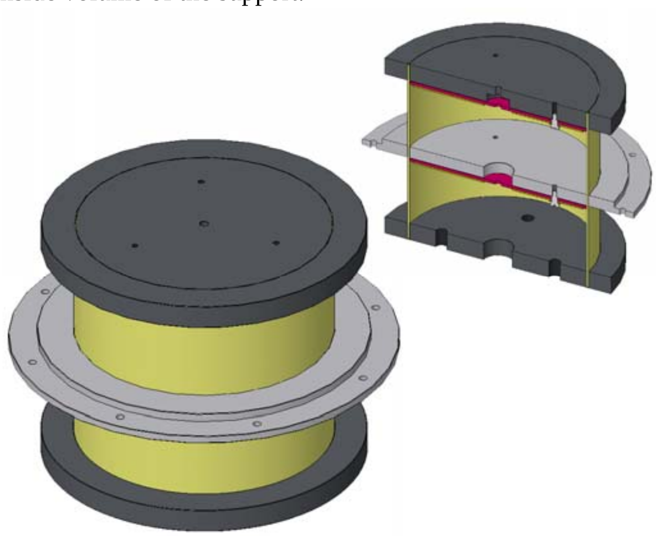

Fig. 6. Support post assembly and cross sectional view.

A few of the design and performance parameters for this support post design are shown in Table 1.

TABLE 1 SUPPORT POST DESIGN PARAMETERS

Parameter	Value
Tube material	G-11 CR
Tube OD	203 mm
Tube thickness	2.4 mm
Nominal shrink fit interference	0.25 mm on the diameter
Heat load to 80 K	2.2 W
Heat load to 4.5 K	0.3 W
Lateral bending stiffness (at cavity cg)	2,600 N/mm
Proof test load	23,600 N

E. Internal Piping

Cryogenics are fed to the cryostat from a bayonet can connected to a transfer line from the main refrigerator in the Meson Detector Building – the building at Fermilab where the linac will be housed. The helium returns to the refrigerator, but the LN_2 that cools the thermal shield vents to atmosphere outside the building. In the event of an insulating vacuum failure or failure of the cavity itself, any relief gas is also vented outside the building. Fig. 7 shows the flow diagram for the internal piping. Valves marked MV are manual valves on the bayonet connections. SV is the main safety relief valve. CV is an internal check valve to prevent thermo-acoustic oscillations inside the vent line. The phase separator helps to ensure that only single phase liquid enters the cavity and also provides a means of measuring the liquid level in the system. Lines connecting the cavity and solenoid are shown in phantom to depict their intermittent use.

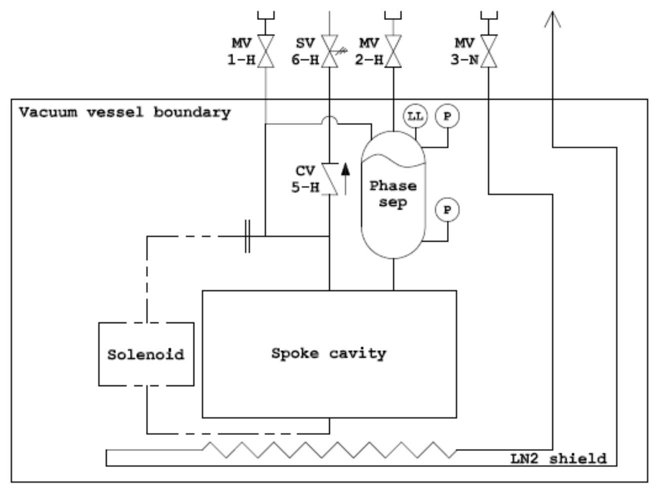

Fig. 7. Internal piping flow diagram.

Two potential failure scenarios determine the venting requirements for the system. The first is the potential loss of insulating vacuum which generates a heat flux of approximately 0.6 W/cm^2 on the outer surface of the helium vessel assuming a nominal amount of multi-layer insulation covers the surface. The second is the potential loss of cavity vacuum which generates approximately 4 W/cm^2 on the inner surface of the cavity (there's no insulation on the inner cavity surface). This second case determines the size of the vent system piping and the external relief valve, SV 6-H in the above figure. Using the triple spoke resonator which has an inner surface area of 2.71 m^2, the heat generated in the event of a cavity vacuum failure is 108,500 W. Given a relief valve setting of 0.3 MPa the resulting mass flow required through the vent system is 6062 g/s and the required external relief valve orifice size is 22.1 cm^2.

F. Input Coupler

The last major component of the test cryostat is the input power coupler which feeds RF power into the cavity being tested. The input coupler to be installed in this cryostat is the same one planned for use in all of the SSR1 and SSR2 cryomodules. The input coupler is a 50-ohm coaxial design with inner and outer conductor diameters of 33.4 and 78.4 mm respectively and supplies 250 kW peak and 750 W average pulsed power to a single 325 MHz superconducting cavity. The coupler contains two ceramic windows, one warm, one cold, which protect the integrity of the interior of the cavity and which enable us to break the coupler into warm and cold sections. During cryomodule fabrication, the cold section can be installed on the cavity in the cleanroom prior to assembly of the string. The warm section can then be installed from outside the vacuum vessel during cryomodule final assembly. The inner conductor is solid copper. The outer conductor is 304-stainless steel. A short section of hydro-formed bellows in the cold section of the outer conductor allows a small amount of tuning – 1 to 2 mm – to be performed from outside the vacuum vessel. Initial heat load estimates don't suggest a significant penalty for not copper plating the outer conductor so to preclude potential problems with copper plating the bellows, the prototype will not include plating. Fig. 8 shows the most recent coupler design. The copper elbow connects to the RF distribution system. The small stainless steel elbow and tube visible in the cross section view is the vacuum pumpout for the section between the two ceramic windows. Instrumentation ports are included for vacuum monitoring and multipacting detection.

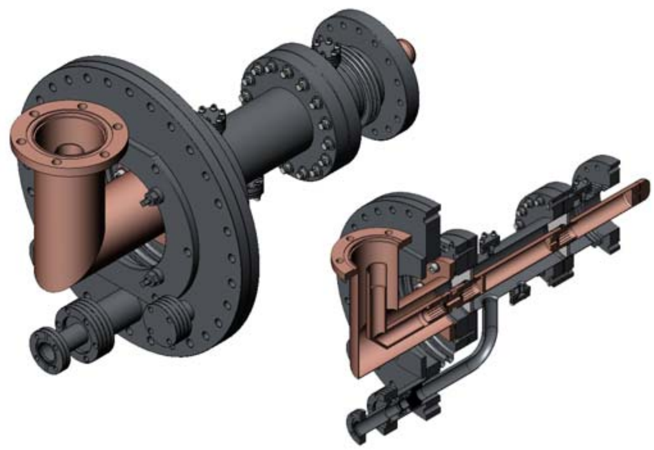

Fig. 8. Input coupler assembly and cross sectional view.

III. Design and Fabrication Status

At the time of this writing, the vacuum vessel, magnetic and thermal shields, and the multi-layer insulation have been fabricated and received from outside suppliers. Two support posts have been fabricated in-house, one for testing and one for installation into this test cryostat. Other long lead items like the cryogenic check valve and insulating vacuum pumping system are on order. The internal piping system is in the last stages of design and will be released to procurement within a few weeks. Two cavities have been delivered from outside sources so far, one of which is shown in Fig. 9, but the helium vessel design is still in-process. Also, two bayonet cans and a cryogenic transfer line need to be fabricated and installed in the Meson Detector Building. That work is planned for the end of calendar year 2008.

Fig. 9. One of the first two spoke resonators delivered from industry and the first test article for this cryostat.

IV. Summary

The design and construction of the HINS front end linac is moving forward. The ion source, RF quad, and much of the room temperature section are either complete or in-process. The medium energy beam transport section cavities are being provided by LBNL and are being negotiated. The SSR1 and SSR2 cryomodules are in the conceptual design phase and will see a more focused effort following completion and installation of this test cryostat.

Acknowledgment

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