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DESIGN OF PRODUCTION PIP-II SSR1 CAVITIES *

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Abstract

The testing and manufacturing process of the PIP-II Single Spoke Resonators Type 1 (SSR1) prototype jacketed cavity presented opportunities for refinement of the production series. Experience from the prototype cavity and the design of other cavities at Fermilab were used. The mechanical design of the production jacketed cavity has been modified from the prototype design to allow for improvements in overall performance, structural behavior, and manufacturability of the weld joints.

OVERVIEW

The PIP-II project has the scope to upgrade the existing Fermilab's accelerator complex to deliver the most intense high-energy beam of neutrinos for the international Deep Underground Neutrino Experiment at LBNF. It is based on a proton driver superconducting linac that composes of five different Superconducting Radio Frequency (SRF) cavity types: half wave resonator (HWR), 325 MHz single spoke resonators type 1 and type 2 (SSR1, SSR2), low-beta and high-beta 650 MHz elliptical 5-cell cavities (LB650, HB650). Significant contributions from international research institutions in India, United Kingdom, Italy, France and Poland are planned to provide expertise and capabilities in accelerator technologies to the project.

The current PIP-II beam optics design requires that each SSR1 cryomodule contains four superconducting focusing lenses (solenoids) and eight identical SSR1 cavities, where each cavity is equipped with one high-power RF coupler and one tuner. Positioned as the second cryomodule type in the linac, the two SSR1 cryomodules operate at a frequency of 325 MHz with continuous wave (CW) RF power and peak currents of 5 mA to accelerate H- beam from 10 MeV to 32 MeV.

CAVITY STRUCTURAL DESIGN

The SR1 resonator is made of two pressure vessel components, an SRF cavity and a liquid helium containment vessel. The cross sectional view of the assembly can be seen in Figure 1.

Cavity

The inner vessel of the SSR1 resonator is a superconducting cavity. This vessel is subject to external pressure excerpted by the liquid helium while the inner surfaces see ultra-high vacuum. All cavity parts are formed and machined using bulk RRR (extra-pure) niobium and EB welded to each other. The system of stiffeners present on the cavities were investigated and optimized to maintain mechanical stability, acceptable response to microphonics and Helium pressure fluctuations and overall ease of tuning under operating conditions. To do this an internal niobium ring was EB welded to the cavity and flanges. The cavities are required to operate in CW regime in superfluid helium at a temperature within the range of 1.8 – 2.1K. The assembled cavity can be seen in Figure 2 and an explosion view with the components labeled can be seen in Figure 3.

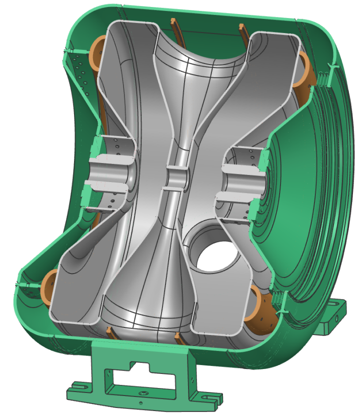

Figure 1: SSR1 Resonator Cross Sectional View

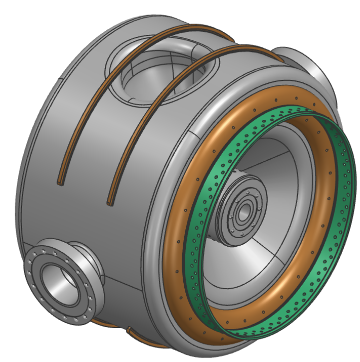

Figure 2: SSR1 Cavity

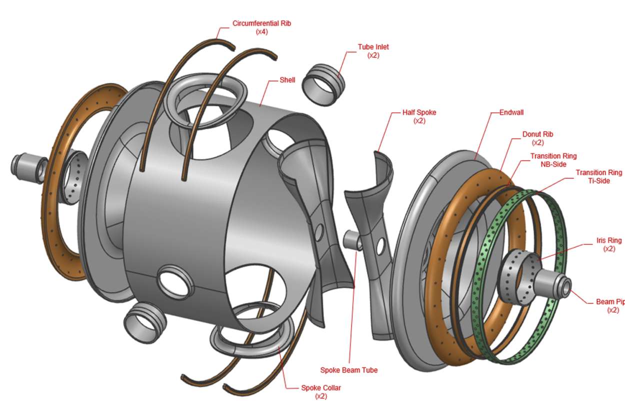

Figure 3: SSR1 Cavity Components

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Helium Vessel

The helium vessel is the outermost vessel of the SSR1 resonator and is constructed from titanium grade 2. The SSR1 helium vessel will be designed to hold liquid helium at a temperature of 2 K. It is subject to internal pressure. The main parts that comprise the helium vessel are two half-shells, two conical plates and two dome heads. Parts of the helium vessel are attached using a combination of EB, Fusion, and TIG welding. The helium vessel also includes the support base for securing the resonator inside the Cryomodule. Other features are included on the cylindrical shells: anchor points for the tuning system and threaded bosses that will accept hoist rings for handling operations. There are several openings in the helium vessel to allow the connection with the cryogenic, vacuum systems and beam line. The helium vessel is connected to the Nb cavity by the coupler flange, vacuum flange, the two beam pipe flanges, and the transition rings. The bellows facilitates the adjustment of the cavity frequency (tuning) acting on the beam pipe flange. The assembled helium vessel can be seen in Figure 4 and an explosion view with the components labeled can be seen in Figure 5.

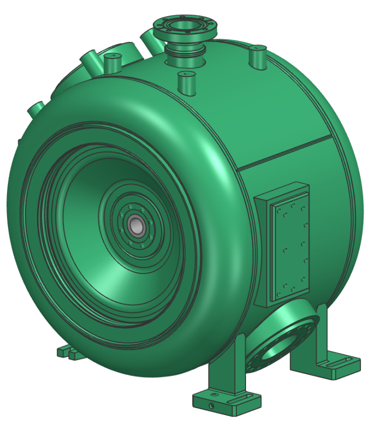

Figure 4: Assembled Helium Vessel

DESIGN VERIFICATION

The cavity is is required to have an external MAWP of 0.205 MPa. During operation at 2K, the external MAWP of the cavity increases to 0.41 MPa. The cavity has a tuning range of 0.26 mm that also needs to be considered when designing the components. During the warm up of the cavity, it is possible for helium to leak into the main volume of the cavity, applying an internal pressure load of up to 0.205 MPa.

The designs of components to withstand the required loads have been verified using the analysis methods provided by the Section VIII Division 1 of the ASME Boiler and Pressure Vessel Code (BPVC) [1]. Due to the non-standard geometry of the cavity, the additional guidance of section U-2(g) was followed to perform design by analysis of the assembly using the methods of Part 5 of Section VIII Division 2. To allow for the use of nonstandard materials, weld joints, and

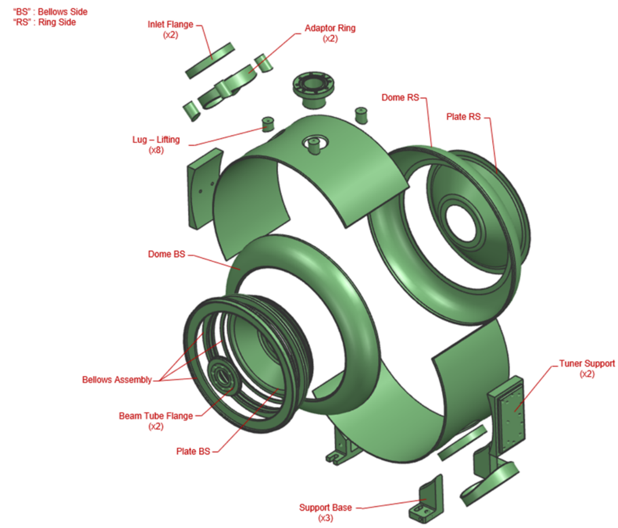

Figure 5: Helium Vessel Components

features, Fermilabs Environmental, Saftey, and Health Manual (FESHM) provides additional design guidelines [2, 3]. While additional verification will be needed for industry provided components, such as the bellows, components have been able to be shown to meet both to meet the FESHM and BPVC analysis requirements.

PRODUCTION CAVITY DESIGN CHANGES

Three significant changes have been made to the helium vessel design between the prototype and production models; the iris ring was modified, the bellows and slip joint were re-positioned, and the external flange was expanded. Additional minor changes to the helium vessel have been made to the helium vessel to bridge the connections between these components. The development of the weld joints between the helium vessel and cavity components have also been improved based on previous experience with the Niobium to Titanium joints [4].

Iris Support

The uris supports on the SSR1 cavitiy is designed to stiffen the assembly at the connection between the helium vessel cavity. The prototype design used an array of 6.25mm thick stiffeners to connect the cavity membrane to the beam tube of the assembly.

During the analysis of the prototype SSR1 cavities, the results showed that the MAWP of the assembly was lower than the required MAWP limit as per the FESHM guidelines [2], but higher than the ASME BPVC limit. Because all of the requirements of the FESHM guidelines were not met, the cavity was classified as an exceptional vessel and required additional internal reviews and documentation to be performed before it was shown to be safe for use in the cryomodules.

To improve the design, the iris ring from the SSR2 cavity were modified to fit the SSR1 cavity. Instead of using mul-

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tiple rib stiffeners, one ring stiffener was used to attach the cavity membrane to the flange of the helium vessel. Performing the analysis on the updated version of the cavity, it was shown that analysis requirements of the FESHM guidelines were met, allowing for the potential for the SSR1 cavities to be non-exceptional (Fig. 6).

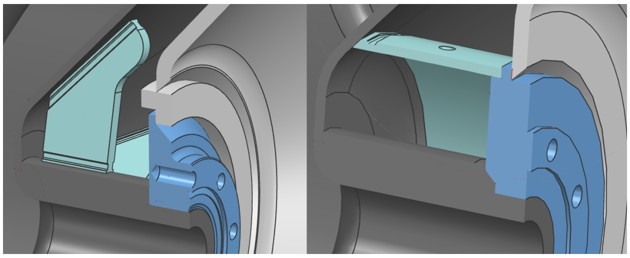

Figure 6: SSR1 Iris Support, Prototype Design (left), Production Design (right)

Bellows and Slip Joint

During the manufacturing of the SSR1 Prototype cavities, issues occurred due to the location of the slip joints in the connection between the helium vessel and cavity. In the prototype design, the slip joint was located near center of the cavity. When attempting to weld the connection after attaching the bellows, due to the distance from the bellows and the slip joint, it became difficult to control the spacing of components (Fig. 7).

To improve this feature, the slip joint was moved to be right next to the bellows assembly. Instead of attempting to align multiple parts simultaneously, with the design change, the bellows and end of the helium vessel can first be welded into the flanges of the cavity, then the bellows can be adjusted with the slip joint and attached to the helium vessel.

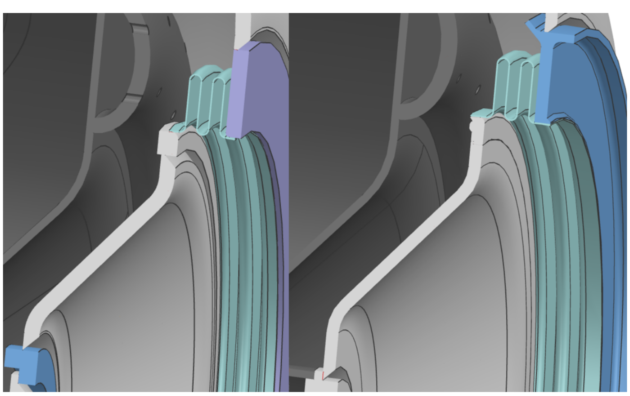

Figure 7: SSR1 Slip Joint, Prototype Design (left), Production Design (right).

Helium Vessel Adaptor Ring

The prototype design of the flange of the SSR1 helium vessel spoke flange was done such that the flange was attached to the helium vessel using an adaptor ring. The prototype design required the precise alignment of the helium vessel and cavity flange. The flange would then be attached to the helium vessel through using a EB butt weld. In addition to difficulties in alignment, the welded connection also created a risk of weld sputtering through the joint directly onto the cavity.

To correct for the alignment and welding risks, the spoke flange will be attached to the helium vessel through the use of an adaptor ring. The flange will be welded to an adaptor ring which will be TIG welded to the outside of the helium vessel. The change in the design can be seen in Figure 8.

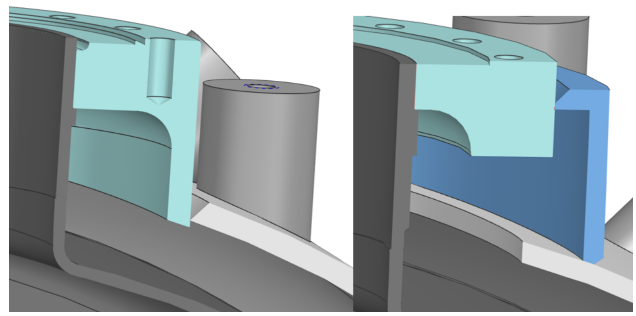

Figure 8: SSR1 Spoke Flange, Prototype Design (left), Production Design (right)

CONCLUSIONS

Addressing some of the issues seen during the manufacturing the prototype SSR1 cavities have lead to improvements in the design. The design changes have reduced the need for additional documentation to be collected, thereby reducing lead times on the vessels while also reducing the risk to critical components. The changes also improved the ability of partner organizations to assemble components reducing project risks.

ACKNOWLEDGEMENTS

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