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STANDARDIZATION AND FIRST LESSONS LEARNED OF THE PROTOTYPE HB650 CRYOMODULE FOR PIP-II AT FERMILAB*

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Abstract

The prototype High Beta 650 MHz cryomodule (pHB650 CM) has been designed by an integrated design team, consisting of Fermilab (USA), CEA (France), STFC UKRI (UK), and RRCAT (India). The manufacturing and assembly of this prototype cryomodule is being done at Fermilab, whereas the production cryomodules will be manufactured and assembled by STFC-UKRI. As the first PIP-II cryomodule for which standardization was applied, the design, manufacturing and assembly of this cryomodule led to significant lessons being learnt and experiences gathered. These were incorporated into the design of the pre-production Single Spoke Resonator Type 2 cryomodule (ppSSR2 CM) and the pre-production Low Beta 650 MHz cryomodule (ppLB650 CM). This paper presents the pHB650 CM lessons learned and experiences gathered from the design to the lower coldmass assembly and how this cryomodule has a positive impact on all the next Proton Improvement Plan-II (PIP-II) cryomodules due to the standardization set up among SSR and 650 cryomodules.

INTRODUCTION

After the completion of the PIP-II prototype [1] Single Spoke Resonator 1 (SSR1) cryomodule [2, 3], a design strategy was set up among the 650 and SSR cryomodules to reduce the cost, to increase the quality and performances, and to mitigate risks [4]. This design strategy led to the standardization of several components, tooling, assembly processes, and procurements.

STANDARDIZATION

The PIP-II SSR and 650 cryomodules are designed adopting the Fermilab style cryomodule that uses a room temperature strongback as foundation. Due to the design of the cavities and requirements being different for SSR and 650 cryomodules, the strongback design has been optimized for each cryomodule type. With the 650 cryomodules being transported overseas, rigid connections in between the vacuum vessel and the strongback as presented in Fig. 1 were required to meet the specifications. Thus, it was necessary to insert the strongback into the vacuum vessel, then to adjust it up to its nominal position before locking it down using 14 studs, set of screws and pins [5, 6]. The SSR cryomodules being assembled at Fermilab, thus not requiring overseas transportation, it was allowed to ease the interface strongback/vacuum vessel. Calculations have shown that bushing screwed to the vacuum vessel with rails connected to the strongback as presented in Fig. 2 met the requirements. The longitudinal position of the strongback is fixed using a central pin, and no lifting is needed [7].

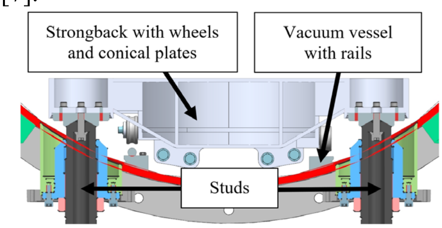

Figure 1: 650 vacuum vessel - strongback interface.

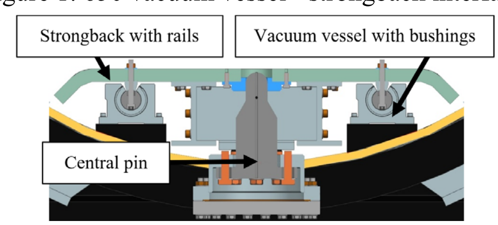

Figure 2: SSR vacuum vessel - strongback interface.

The 650 cavities are aligned using C-shape brackets [5, 8] at the interface with the cavity lugs, whereas SSR cavities use an alignment plate positioned at the bottom of the cavities. This concept was validated during the alignment of the prototype SSR1 string assembly [9].

All SSR and 650 cryomodules share the same cryogenic layout and the size of the cryogenic lines are identical for all cryomodules (Fig. 3). With the 650 production cryomodules manufactured in Europe and the SSR cryomodule assembled in the USA, it was decided to use ISO pipes which also match imperial pipe size to allow the procurement from the international market maintaining equivalency.

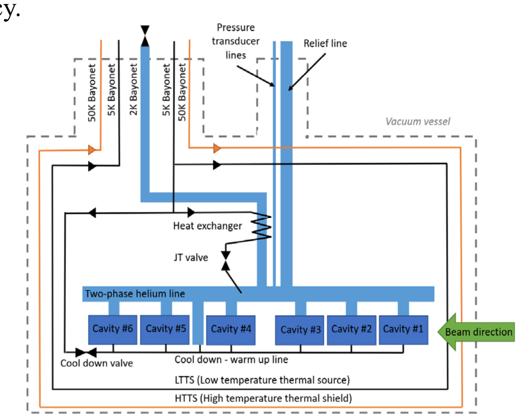

Figure 3: Schematic of the cryogenic lines.

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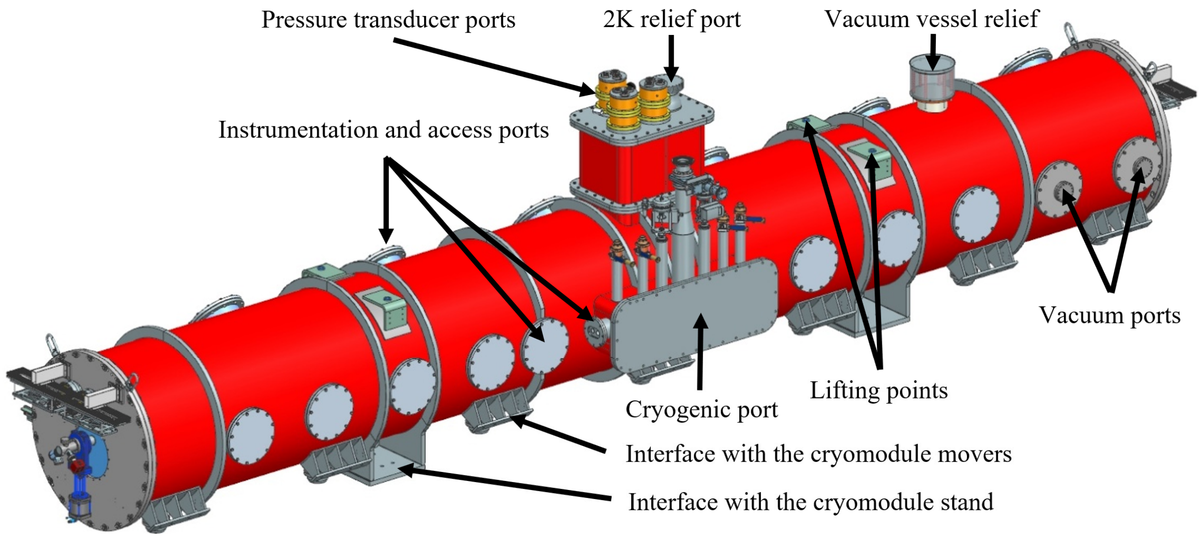

Figure 4: Standardized interfaces on the SSR and 650 cryomodules.

The external interfaces of the cryomodules have been standardized to simplify the design of the Cryogenic Distribution System (CDS) and to share tooling among SSR and 650 cryomodules (Fig. 4). Identical or similar components or features:

- Cryogenic port
- Vacuum vessel relief valve
- 2K relief port
- Interface with the cryomodule stand
- Interface with the cryomodule movers
- Pressure transducer port
- Instrumentation and access ports
- Vacuum port
- Cryomodule lifting points

Thanks to this standardization many components can be re-used from one cryomodule to another, and the lessons learned applied through design, procurement and assembly phases can be shared across cryomodule types and partners. In addition, the standardization will have a positive impact on the operation by providing:

- Similar ways to cool down the cryomodule
- Similar ways to regulate helium in the two-phase helium pipe
- Easier maintenance (tooling and spare parts can be used for different cryomodule types)

LESSONS LEARNED OF THE PROTOTYPE HB650 CRYOMODULE

Many lessons learned have been gathered during the design and assembly of the pHB650 CM. The main lessons learned applied to the design are listed below.

Vacuum Vessel

The overall quality of the vacuum vessel is excellent with some minor non-conformances which could have been avoided if trips to the manufacturer would have been possible during the pandemic. To reduce the quality controls time and make sure that the quality of production vacuum vessels will be equivalent or better than the prototype vessel, we are requesting the manufacturer to prepare a detailed Manufacturing and Inspection Plan (MIP) that will list the sequence of manufacturing steps including hold points as well as the associated inspections:

- Visual inspections
- Dimensional inspections
- Leak checks
- Magnetic permeability measurements

Room Temperature Global Magnetic Shield

The HB650 room temperature magnetic shield has been designed based on the lessons learned of the prototype SSR1 cryomodule. To ease the assembly process of this shield on the vacuum vessel an inner skeleton with thread holes has been welded on the inside of the vacuum vessel [4]. However, the bending radius of the plates were significantly off, and a gap was visible in between this skeleton and the vacuum vessel (Fig. 5). This led to some of threaded holes on this skeleton being off by more than 15 mm. To avoid similar issues during production, very long slots and large clearance holes have been added to the design of the production room temperature magnetic shield.

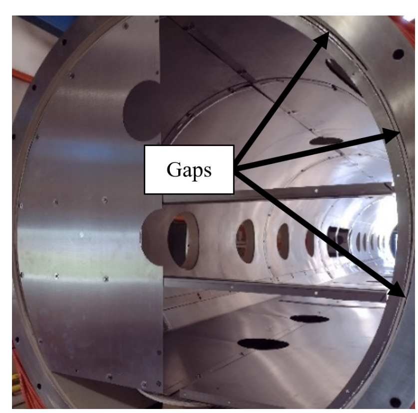

Figure 5: Gaps in between the skeleton and the vacuum vessel.

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In addition, it has been noticed during the assembly process that some magnetic shield plates had been bent in the wrong direction. These issues could have been detected by utilizing a simple inspection performed by the manufacturer or Fermilab using sheet templates. This quality control step will be set for the production units.

Vented Screws

During the assembly of this prototype, we realised that some small volumes were not vented which could introduce virtual leaks into the insulating vacuum. Vented screws have been added to increase the insulating vacuum quality.

Brazing

The Low Temperature Thermal Source (LTTS) is used to provide thermal intercepts to minimize the heat loads to the 2 K source from the following items: couplers, tuners, beam pipe end assemblies, and relief line. To ensure the efficiency those intercepts, copper blocks are brazed to the stainless-steel cryogenic pipe. To allow the quality controls (i.e. visual inspection) of the brazed joint in terms of continuity and uniformity of the braze material, holes will be added as show in Fig. 6.

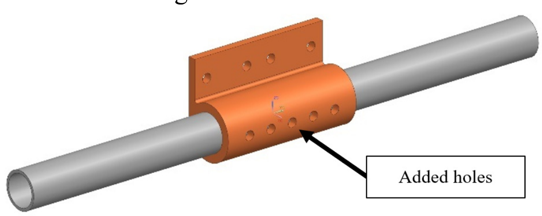

Figure 6: Holes added on the copper block to check the quality of the brazed joint.

Alignment Strategy

Laser trackers are employed throughout the different phases of the assembly process to align and check that beam line components are within the project requirements. Even if at first it seemed a good plan since this will improve the alignment quality of the beam line, it comes with a cost as well. The assembly process takes more time, and the laser tracker work cannot always be done in parallel with assembly work.

For the production cryomodule, and after a full review of the alignment of this prototype cryomodule, the plan is to minimize the number of alignment checks.

Procurement Strategy

Our procurement plan did not as planned due to the restrictions and supply chain issues that followed the pandemic. It has been necessary to manufacture several assemblies on-site at Fermilab to mitigate schedule delays and costs increase.

For the production cryomodules, the cryomodule will be divided in bigger assemblies in order to minimize the number of procurements and quality controls. This approach has been already adopted for the ongoing procurement of parts and sub-assemblies for the pre-production SSR2 cryomodule. The main procurement sub-assemblies will be:

- The vacuum vessel assembly
- The room temperature magnetic shield
- The strongback, G11 support posts and cavity supports
- The thermal shield with all the piping
- The targets frame assemblies
- The thermal straps

CONCLUSION

As the first “standardized” cryomodule, the pHB650 CM has a very big impact on the ppLB650 CM and SSR CMs. Lessons learned shared between cryomodule types and Partners are key elements of the design strategy. In the past months, the design of the ppSSR2 CM and ppLB650 CM already profited from the design of the pHB650 CM. In the coming years, we expect to continue benefiting from the standardization of the several types of cryomodules needed for PIP-II at Fermilab.

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