EXPERIENCES OF SUPERCONDUCTING RADIO FREQUENCY COLDMASS PRODUCTION FOR THE FRIB LINEAR ACCELERATOR

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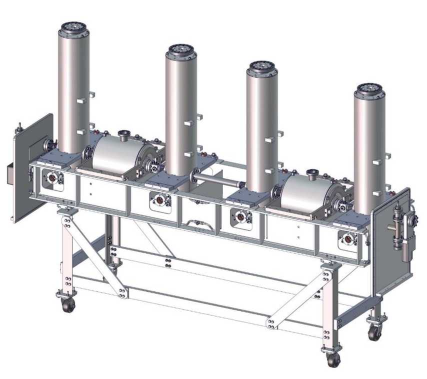


Figure 1: β=0.041 coldmass
- Quantity built: 4 (3 required for FRIB accelerator + 1 spare)
- 1 rail segment, 4 cavities, 2 superconducting solenoids


Figure 2: β=0.085 coldmass
- Quantity built: 12 (11 required for FRIB accelerator + 1 spare)
- 3 rail segments, 8 cavities, 3 superconducting solenoids


Figure 3: β=0.085 matching coldmass
- Quantity built: 2 (required for FRIB accelerator + 1 spare)
- 1 rail segment, 4 cavities, 0 superconducting solenoids
- Used for bunch shaping after beam is accelerated through β=0.085 cryomodules

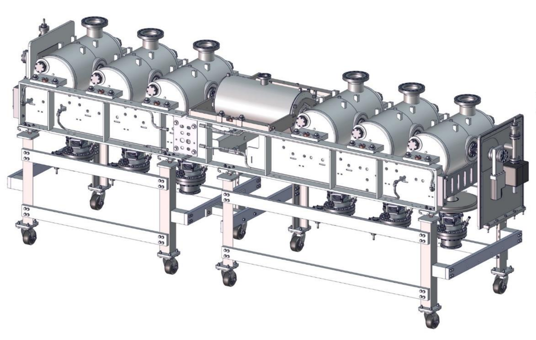
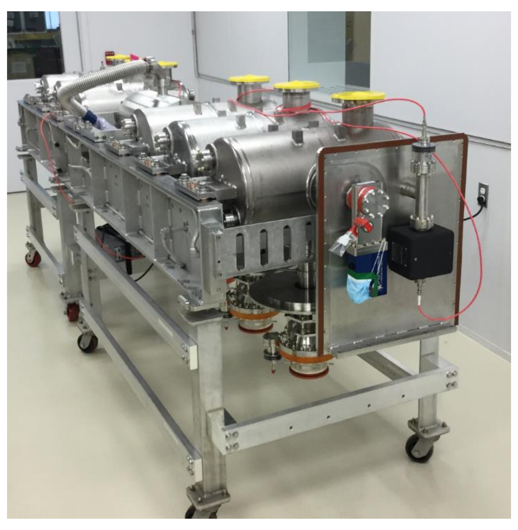

Figure 4: β=0.29 coldmass
- Quantity built: 12 (12 required for FRIB accelerator)
- 2 rail segments, 6 cavities, 1 superconducting solenoid

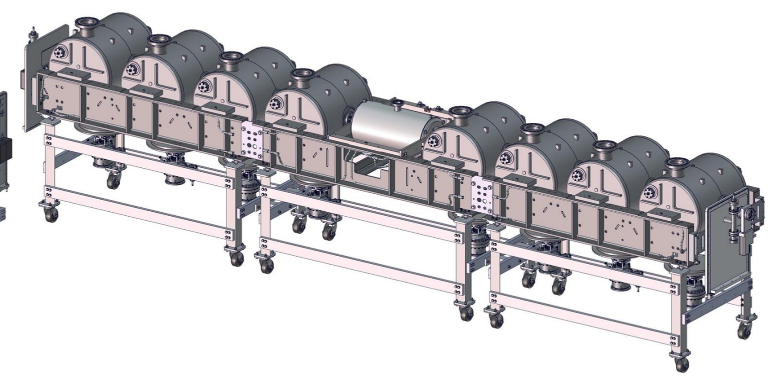


Figure 5: β=0.53 coldmass
- Quantity built: 16 to date (18 required for FRIB accelerator)
- 3 rail segments, 8 cavities, 1 superconducting solenoid

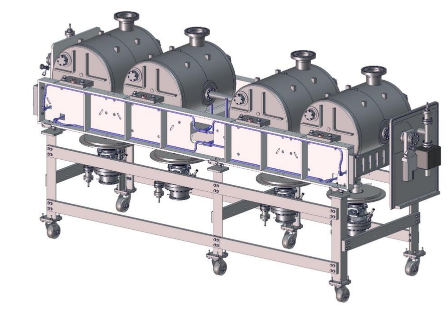


Figure 6: β=0.53 matching coldmass
- Quantity built: 1 (1 required for FRIB accelerator)
- 1 rail segment, 4 cavities, 0 superconducting solenoid
- Used for bunch shaping after a 180° beam turn in the middle of the β=0.53 portion of the accelerator

Abstract

The superconducting radio frequency (SRF) portion of the Facility for Rare Isotope Beams (FRIB) linear accelerator consists of 46 cryomodules of 6 different types. Each cryomodule contains a coldmass consisting of a string of SRF resonators. There are four different types of resonators; a Beta=0.041 quarter wavelength resonator (QWR), a Beta=0.085 QWR, a Beta=0.29 half wavelength resonator (HWR), and a Beta=0.53 HWR. In total there are 324 SRF resonators in the FRIB linear accelerator. This paper provides a summary of experiences from the assembly of all FRIB coldmass types in a clean room environment.

Summary of Coldmass Production

The first FRIB coldmass completed was a β=0.085 coldmass, which was finished in September of 2015. In the subsequent four years coldmass production has progressed steadily toward completing all 46 coldmasses required for the FRIB linear accelerator.

Cavities used for the FRIB coldmasses were manufactured by outside suppliers. A single supplier manufactured all of the β=0.041 cavities for FRIB. Two suppliers combined to manufacture all of the β=0.085 cavities for FRIB. One supplier produced nearly all of the β=0.29 and β=0.53 cavities. During the early stages of coldmass assembly, cavities were arriving simultaneously from multiple suppliers. Availability of necessary coldmass components, coupled with a desire to complete a full systems test for each cryomodule type early in production, led to numerous different coldmass types being assembled early in the production run.

After completing all of the β=0.041 coldmasses, primary focus shifted to completing the next higher beta coldmasses, the β=0.085s. During the assembly of β=0.085 coldmasses a significant number of β=0.29 cavities were tested [1] and certified for coldmass use. Since so many β=0.29 cavities were certified before they could be assembled into coldmasses, they were cleanly sealed and then stored outside of the cleanroom for later use. At one time nearly half of all β=0.29 cavities required for FRIB were certified and stored awaiting coldmass assembly.

Once the β=0.085 coldmasses were complete, certified, and stored, β=0.29 cavities were brought back into the cleanroom and assembled into coldmasses. The presence of prior certified cavities allowed for very quick coldmass assembly. This is seen in Fig. 8 when six β=0.29 coldmasses were completed in a three month period in early 2017.

As β=0.29 coldmasses were completed, a backlog of certified β=0.53 cavities developed. Though this backlog did grow to nearly 20 cavities, it was never enough to warrant storing certified cavities outside of the cleanroom. β=0.53 coldmass assembly progressed quickly through the backlog of certified cavities, and has only trailed off recently as cavities are now arriving from only one supplier.

Figure 7: Members of the cryomodules department with the final β=0.29 coldmass

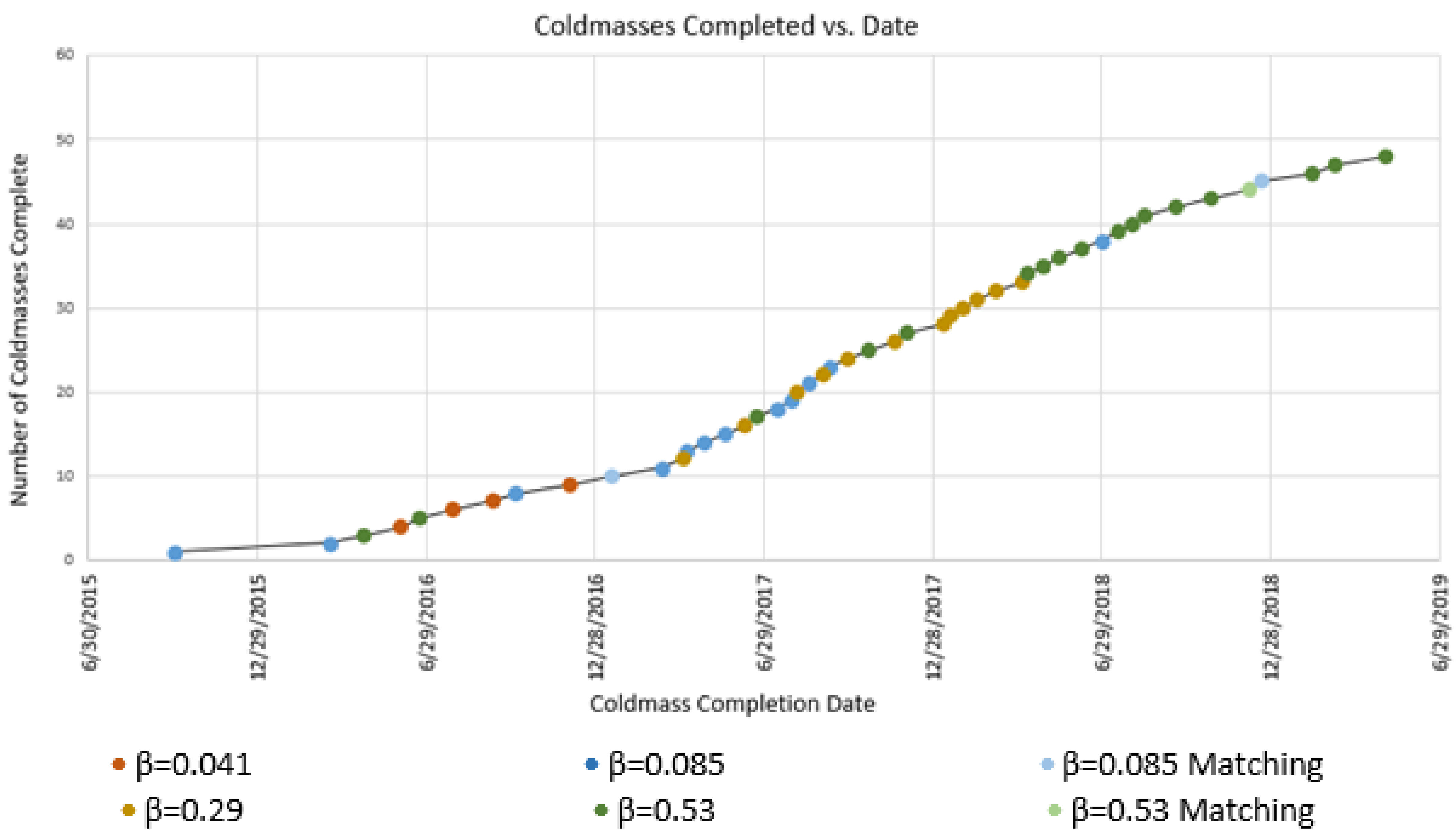

Figure 8: A timeline of coldmass completions from the first coldmass completed in September 2015 until current.

Bunker Testing of Completed Cryomodules

After each coldmass is assembled into a cryomodule it undergoes a full system test before it is approved for installation into the FRIB linear accelerator [2]. These tests are done inside a radiation shielding test bunker. The systems verified during this test include; the cavities, the FPCs, the solenoids, cryogenic instrumentation and valves, alignment, and vacuum systems.

To date 37 of the 46 cryomodules needed for FRIB have completed their bunker test. Contained within those 37 cryomodules are a total of 252 superconducting cavities. Of these 252 cavities only 12.3% (31 cavities) had any measured field emission during their bunker test. Figure 9 (below) plots the field emission level, at operating gradient during bunker testing, for all cavities currently tested in FRIB coldmasses. Note that the operating gradient of each cavity type is different. β=0.041 cavities have a specified operating gradient of 5.1 MV/m. β=0.085, β=0.29, and β=0.53 cavities have operating gradients of 5.6, 7.7, and 7.4 MV/m, respectively.

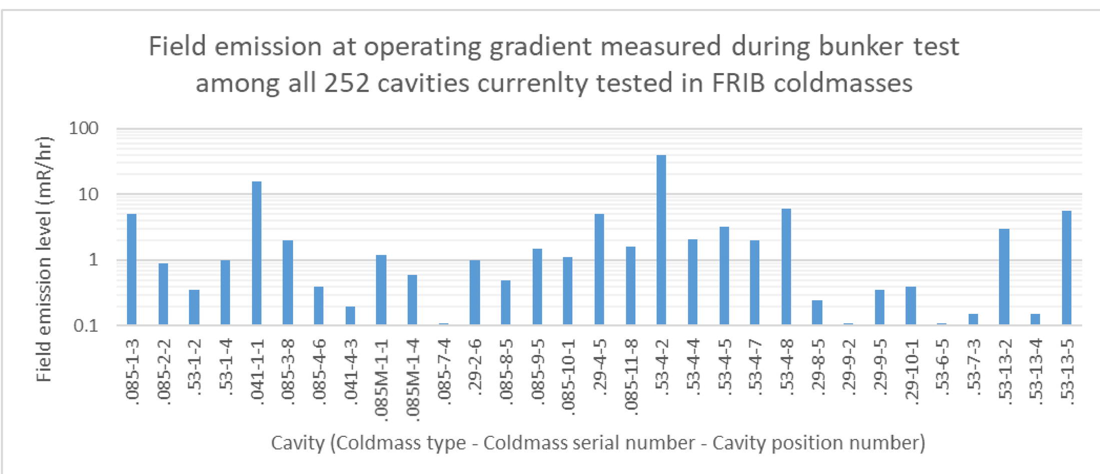

Figure 9: field emission data for all currently tested cavities in FRIB coldmasses

Challenges and Lessons Learned

Leak detection

During FRIB coldmass production great effort was put into leak checking coldmass components before they were assembled into a complete coldmass. There is certainly a tradeoff to leak checking each sub-component, but a high level of care can be beneficial towards limiting rework on highly sensitive finished coldmasses. Many different components, including "off-the-shelf" commercially available parts, have been found to have leaks.

Beamline gate valves

FRIB beamline gate valves were challenging for several reasons. The gate valves arrived from a supplier in several batch shipments. After several of the gate valves had been installed to coldmasses it was noticed that some of the valves had a tendency to slip, or drop, open.

After much communication, and a visit to the supplier, it was determined that one of the linkages in the gate assembly was not tailored to the variation in each valve appropriately. Around the same time it was determined that the EPDM o-rings used in the gate valve should be replaced by a specific grade of o-ring which would be vacuum degassed at FRIB. To fix these problems many gate valves were sent back to the supplier for linkage and o-ring replacement. Additionally seven tested cryomodules needed to be purged from ultra-high vacuum so that their gate valves could be replaced.

Information availability

During coldmass production emphasis was placed on ensuring that assembly information was readily available to assemblers. The two most valuable pieces of assembly information were the coldmass mechanical assembly drawing, and the coldmass assembly work instruction. The mechanical assembly drawing is a single sheet print depicting the coldmass and all of its subcomponents and their quantities. A laminated copy of this drawing was brought into the cleanroom and posted in the coldmass assembly bay. The work instruction defines the tools, process, and order of operations required to properly build the coldmass. Tablets were used in the cleanroom so that assemblers could always have a copy of the work instructions at their fingertips.

Conclusion

FRIB coldmass production began in mid-2015 with the completion of the first β=0.085 production coldmass. Since that time coldmass production has proceeded steadily for four years towards completion of all FRIB coldmasses.

Acknowledgement

Many thanks to the FRIB team, specifically the cryomodule department, both present and past, without whose effort and dedication this work would not have been possible.

References

[1] W. Hartung et al., "Performance of FRIB Production Quarter-Wave and Half-Wave Resonators in Dewar Certification Tests" presented at the 19th International Conference on RF Superconductivity (SRF'19), Dresden, Germany, July 2019, paper THP061, this conference.

[2] C. Wei et al., "Progress in FRIB Cryomodule Bunker Tests" presented at the 19th International Conference on RF Superconductivity (SRF'19), Dresden, Germany, July 2019, paper THP062, this conference.

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