FIRST FRIB β=0.041 PRODUCTION COLDMASS BUILD*

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Abstract

Three β=0.041 cryomodules (CMs) are required for the Facility for Rare Isotope Beams (FRIB) accelerator. Cleanroom assembly of all three coldmasses for these cryomodules has been completed. The cleanroom assembly includes; the superconducting radio frequency (SRF) cavities, the superconducting solenoids, fundamental-mode power couplers (FPC), beam position monitors, alignment rail, and transport cart. This paper will provide an overview of the techniques and procedures used to assemble this cavity string to be put to practical use in the FRIB accelerator.

INTRODUCTION

The β=0.041 cryomodules (CMs) are the lowest β CMs, being the first superconducting accelerator components of the FRIB accelerator. There will be three of the β=0.041 CMs. The core of the CM is referred to as the coldmass. Generally speaking, the lowest β coldmass is the most difficult to manufacture and to assemble for its tight space. The coldmass assembly is done in an ISO 5 cleanroom. The coldmass is considered complete once the physical assembly matches the assembly drawing, and is under vacuum and leak checked.

COLDMASS COMPONENTS

The completed β = 0.041 coldmass is shown in Figure 1. It can be seen from the figure that four β = 0.041 superconducting RF (SRF) cavity vessels and two superconducting (SC) solenoid vessels are mounted on the alignment rail.

Figure 1: Completed β=0.041 coldmass.

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Alignment Rail and Cart

The alignment rail is a stainless steel structure on which the cavities are mounted and aligned along the beam axis. The cart is a simple assembly which the alignment rail is mounted on to allow easy transportation and manipulation of the entire coldmass. The alignment rail undergoes numerous inspections upon arriving from the vendor. The cooling lines, which are welded to the rail, are leak checked. A coordinate measurement machine (CMM) verifies that the alignment features of the rail are within tolerance. The alignment rail is measured for residual magnetic field. Once the rails are accepted they are cleaned with a high pressure solution of ultra-pure water and Micro90 detergent, then brought into the cleanroom. Surface particle counts are taken on the rails after they enter the cleanroom to confirm that the rails are adequately clean and will not risk contaminating the SRF cavities.

SRF Cavities

The SRF cavities are of quarter wave resonator (QWR) structure with a resonant frequency of 80.5 MHz. They undergo a similar battery of acceptance tests as the rails, with the notable addition of a cavity surface inspection by borescope, and frequency measurement. After the cavities are accepted they will receive a bulk etching of 120 μm by buffered chemical polish (BCP). Then they are heat treated in a vacuum furnace at 600°C for 10 hours, and precision machined for beam line alignment. The cavities can be fine-tuned by preferential etching [1]. After all of the aforementioned steps are completed the cavity proceeds through the final processing steps, including an ultrasonic cleaning, light etch of at least 30 μm, and high pressure rinse with ultrapure water (UPW) for 150 minutes at a pressure of 93 bar [2].

The cavity typically dries overnight following the high pressure rinse. It is then assembled and installed to the testing insert. The beam line space is evacuated to ultrahigh vacuum and leak checked, then the test insert is removed from the cleanroom and prepared for cryogenic testing.

The test insert provides a platform which mimics actual CM operation. Liquid helium is supplied to the cavity helium vessel to make the cavity superconducting. A friction mass damper is installed to the cavity's inner conductor, just as it would be in the CM. During the cryogenic testing numerous performance parameters are measured to confirm that they are within specification. The cavity should not have any leaks from the helium jacket. The cavity frequency should be within the tuneable range provided by the stepper motor. In particular, the cavity quality factor, Q, should meet or exceed FRIB specification of 1.4×10^9 at

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an accelerating gradient of 5.56 MV/m. It is seen from Figure 2 that all of the cavities installed to the CMs meet this requirement.

The tested cavity and insert are cleaned and moved back into the cleanroom for a post-test leak check. If the cavity passes the post-test leak check it will be removed from the test insert to await fundamental mode power coupler (FPC) installation.

It is important to note that, due to the nature of the bottom flange indium seal, the cavity is not re-rinsed after testing. Because of this, it is critical that the procedures used to remove the cavity from the test insert preserve the cleanliness of the cavity.

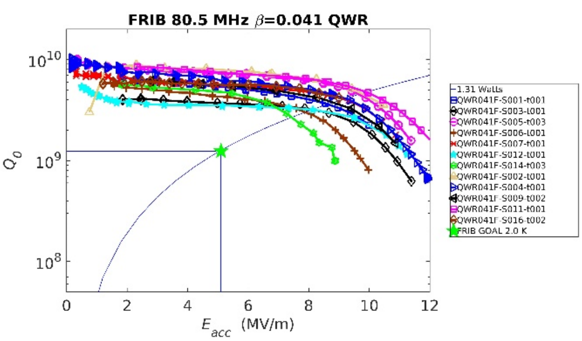

Figure 2: Cavity performance plots of Q vs. E_{acc} obtained during certification testing [3].

Fundamental Mode Power Couplers (FPCs)

The FPCs consist of two primary subassemblies. The first is the ceramic cold window, which is provided in a finished state by a vendor. The second is the copper plated bellows and adjustment mechanism. The cold window, copper plated bellows, and all adjustment mechanism are cleaned as parts both outside and inside the cleanroom. After the adjustment mechanism has been assembled to the copper plated bellows the entire assembly will be rinsed with ultrapure water and set on a shelf to dry.

Once the cold window and adjustment bellows have dried, they will be assembled together by a conflat seal. Surface particle counts are performed after the assembly to verify the FPC's cleanliness. The FPC is then installed to a certified cavity using a supporting fixture to align the flanges.

Superconducting (SC) Solenoids

The SC solenoids are provided from the vendor in a finished state. A matched armature is provided with each solenoid to align its magnetic axis with the beam axis. To produce the armature the vendor maps the magnetic field of the solenoid and then custom machines the pieces of the armature so that the magnetic axis and beam axis are properly aligned when the solenoid is installed to the rail.

When the solenoids are received they are validated against the acceptance criteria list including an overall visual inspection, demagnetization of the residual magnetic field, leak check, and leads and polarity checks of the coils. The solenoid and armature are ultrasonic cleaned as parts and then assembled after drying.

COLDMASS ASSEMBLY TECHNIQUES

Vertical Conflat Seals with Recessed Flanges

The beam port flange design used on all FRIB cavities necessitated the use of a new technique for making beam line vacuum connections.

When a cavity is installed to the rail its beamline flange is in the vertical orientation. Because the FRIB beamline flanges are recessed into the helium vessel, commonly used gasket holding tools cannot be applied. We have found that it is acceptable to carefully tape the gasket in place on the vertical flange with a very thin Kapton tape. This technique has been used on all FRIB cavity types without showing an increased likelihood of cavity leaks or performance issues.

Clean Flange Assembly and Disassembly

Three flanges must be removed from each β=0.041 cavity to properly install it to the coldmass. The first is the input antenna which is used only for the cavity certification test. The input antenna must be removed, and replaced with the FPC. Both of the beamline flanges must be also disassembled so that they can be connected to the other components of the coldmass string.

To disassemble these flanges cleanly all but two fasteners, on opposite sides of the flange, are removed. The two remaining fasteners provide a seal against particle migration into the clean cavity space. With the flange still in place, the open holes are cleaned with a cleanroom vacuum cleaner. The flange is then held in place by hand while the remaining two fasteners are removed.

A similar strategy to that described above is used for clean flange assembly. Two fasteners are installed and tightened to make a seal against particle migration. All flanges in the working vicinity are sealed in this way before they are populated with fasteners and torqued to ultra-high vacuum seal.

ISSUES FACED AND THEIR MITIGATIONS

Tuning Range Variations

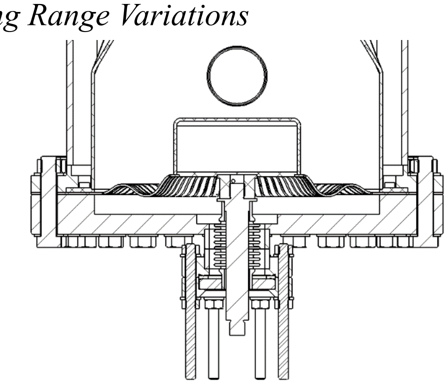

Figure 3: a mechanical drawing of the bottom of a β=0.041 cavity.

After a cavity is tested its tuner is exercised to verify that the cavity can be tuned to the operating frequency. It was noticed that some of the cavities had a smaller tuning range than others. It turned out that the tuner bellows assembly varied depending on which vendor made the part. The tuner bellows assembly is a post which couples the flexible cavity tuning plate to the actuator (see the drawings of Figure 3). Stiffness measurements of the tuning bellows assembly showed that the bellows with 6 convolutions were stiffer than the bellows with 8 convolutions. Figure 4 shows the photos of these two bellows.

The additional stiffness of the bellows resulted in a 33% decrease in the tuning range of the cavity when using the same actuating motor. To solve this problem the 6 convolution bellows were excluded from use on the β=0.041 cavities.

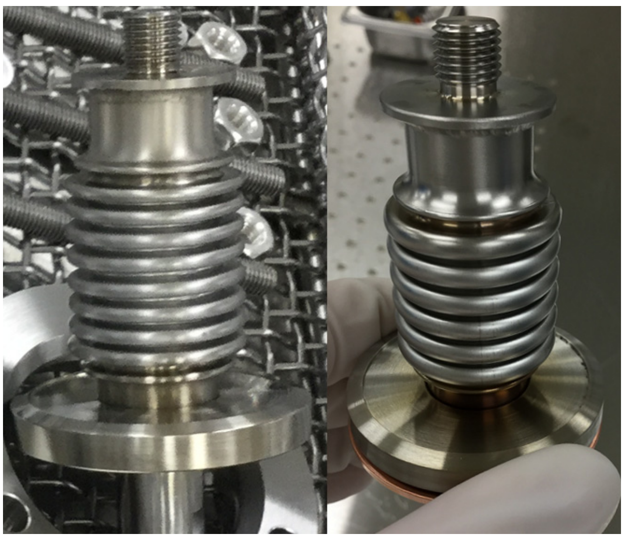

Figure 4: Two β=0.041 tuner bellows assemblies. More flexible 8 convolutions bellow (left), stiffer 6 convolutions bellow (right).

Cavity Helium Vessel Leak

Shortly after delivering the second β=0.041 coldmass for CM assembly, a leak was found at the titanium to stainless steel bimetal transition. In order to repair this issue, the coldmass was brought back into the cleanroom, purged with filtered dry nitrogen, and the leaking cavity was swapped with a different cavity.

The cavity helium vessel is leak checked prior to certification testing of the cavity. There were no indications of a leak prior to testing, or during the test. Since that incident, all cavities receive a post-test helium vessel leak check before they are installed to a coldmass.

Superconducting Solenoid Windings

The first β = 0.085 and β = 0.53 coldmasses were assembled using solenoids fabricated in-house at FRIB. Subsequent coldmasses were built with solenoids from a vendor. Unbeknownst to the cleanroom processing team, the coil winding binder was also changed from Stycast, used at FRIB, to paraffin wax. This became an issue because the solenoids are cleaned in an ultrasonic cleaning bath at 60°C, which is very near the melting temperature of the wax.

In order to reassure confidence in the solenoids a borescope inspection was done to look for any evidence of melted wax. The solenoid coil resistances were also checked to verify that no unexpected electrical shorts occurred after the cleaning. All solenoids are now cleaned at 37°C.

CONCLUSION

All three of the β=0.041 coldmasses have been assembled by the FRIB cleanroom assembly team and delivered for cryomodule assembly. The first cryomodule test results are expected in October 2016.

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