STATUS OF BETA=0.53 PRE-PRODUCTION*

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Abstract

The Facility for Rare Isotope Beams (FRIB) project is now in the production phase of β=0.041 and 0.085 cryomodule (CM) fabrication and assembly. In addition to these CMs, the assembly of the pre-production β=0.53 CM started in May 2016. The basic mechanical design concept of the β=0.53 CM is similar to the β=0.085, however the β=0.53 CM includes a different type of cavity, some new components, and design features. This paper will describe the recent progress and the lessons learned of the pre-production β=0.53 CM assembly.

INTRODUCTION

FRIB is a new joint project for nuclear science facility funded by the DOE Office of Science and Michigan State University [1, 2]. The FRIB driver accelerator is a superconducting heavy ion linac with a beam power of 400 kW at the target and a beam energy over 200 MeV/u. This driver linac consists of 48 CMs with six types of CM including matching CMs. Figure 1 shows four types of superconducting cavity (β=0.041, 0.085, 0.29, and 0.53) used in these CMs. Quarter-wave resonators (QWRs) at 80.5 MHz are used for low velocities: β=0.041 and 0.085, and half-wave resonators (HWRs) at 322 MHz are for medium velocities: β=0.29 and 0.53.

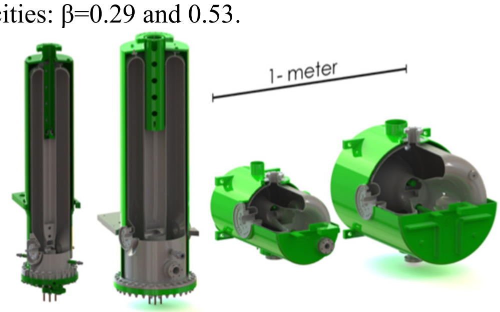

Figure 1: FRIB cavities, from left: β=0.041QWR, β=0.085QWR, β=0.29HWR, and β=0.53HWR.

Figure 2 shows the CM development executed at FRIB. The FRIB CMs adopt the modular bottom-up assembly design for assembly friendly and more tight alignment tolerances. This design was successfully validated by an engineering test cryomodule (ETCM) [3]. As for the QWR CMs, ReA6 and the pre-production β=0.085 CMs successfully demonstrated the FRIB performance. Now the QWR CMs are in the production phase [2].

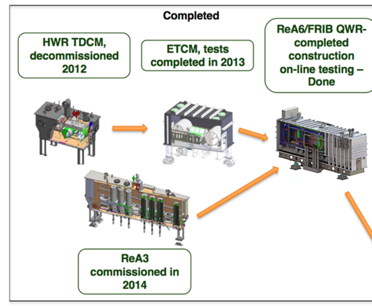

Figure 2: Cyomodule development at FRIB.

In addition to the QWR CMs, the assembly of the pre-production β=0.53 CM started in May 2016 (Fig. 3). The basic design concept is the similar to the β=0.085 CMs, however several differences are introduced, especially fundamental power couplers (FPCs) and mechanical frequency tuners [4]. The magnetic shield design was also changed from a cylinder-like shape to a rectangular box, which is assembled from small plates.

This paper will present the overview and the recent progress of the pre-production β=0.53 CM, particularly focusing on the lessons learned from the build of the CM.

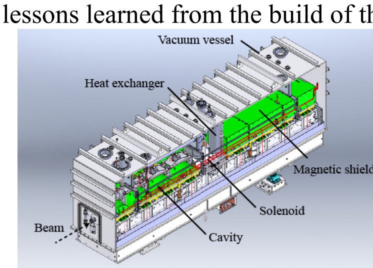

Figure 3: FRIB β=0.53 cryomodule.

PROGRESS, ISSUE AND MITIGATION OF CM ASSEMBLY

Cleanroom Assembly

The coldmass assembly began in the SRF Highbay production cleanroom from the end of March 2016, and then it was moved to the CM assembly area in the East Highbay on 1 May, it took approximately one month. The net throughput was approximately two weeks. Many of the time was spent for waiting the cavity vertical test, the FPC conditioning, and other components, for instance solenoid packages.

All the delivered cavities were visually and dimensionally inspected, processed (heat treatment, buffered chemical polish, high-pressure rinse), RF (cold vertical) tested, and assembled into the coldmass [5]. Figure 4 shows the

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cavity performance: Q_0 vs. E_{acc} curve of β=0.53 cavities for the pre-production CM. All the cavities were certified to meet the FRIB requirement: Q_o = 8x10^9 and E_{acc} = 7.5 MV/m at 2 K.

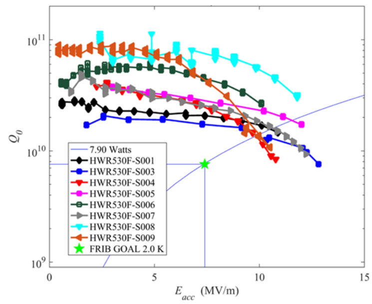

Figure 4: Cavity performance validation at 2K.

Meanwhile, the FPCs were conditioned in the SRF Highbay before the coldmass assembly[6]. The nine FPCs were RF tested, however heating around the coaxial part was observed in six out of nine (Fig. 5). The temperature reached up to 80°C regarding the successfully conditioned ones, and one of the FPCs achieved 120°C and could not be accepted. The accepted eight FPCs were installed on the coldmass.

As a backup plan, FRIB has also developed a multipacting-free (MPF) coupler and successfully RF conditioned two prototype MPF couplers without any heating. One of two was integration tested with a 0.53HWR in the vertical dewar and showed stable operation at 2 K. The MPF couplers will be adopted for the FRIB production HWR CMs [6].

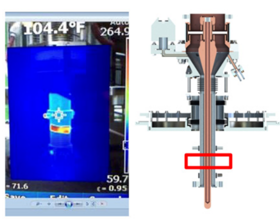

Figure 5: Heating of FPC coaxial part.

Coldmass

Figure 6 shows the assembly sequence of the pre-production CM. Before lifting the coldmass onto the baseplate, many components and some cryogenic piping were installed or welded on it: heaters, temperature sensors, magnetic shields, FPC cooling piping, cavity and solenoid filling piping, and mechanical cavity tuners.

Cavity mechanical tuner is pneumatic [7], and the tuner bars are attached on the cavity beam port flange via adapter flanges (Fig. 7). The alignment of the tuner bars depends on the alignment of beam port flange. However, some cavities deviate, especially for ones fabricated in the early production phase. Some of the adapter flanges, therefore, had to be modified in order to correct the alignment of the tuner bars.

Figure 7: (Left) Rotational misalignment of RF tuner bar. (Right) Special adapter with slotted hole.

During the CM assembly, a magnetic contaminant incident was occurred, where a Laboratory employee, with no business needed to be in the CM assembly area, went into the area and touched the coldmass, with a small button magnet. Some stainless bolts on the cavity beam ports were magnetized (as high as 39 G) by this act. The coldmass did not have the magnetic shield yet at the time, therefore, had to be inspected for residual magnetic field to ensure the requirement of residual magnetic field less than 15 mG. Significant effort has been expended to investigate the magnetization and demagnetize the highly magnetized spots with a handy demagnetizer, and finally we confirmed the

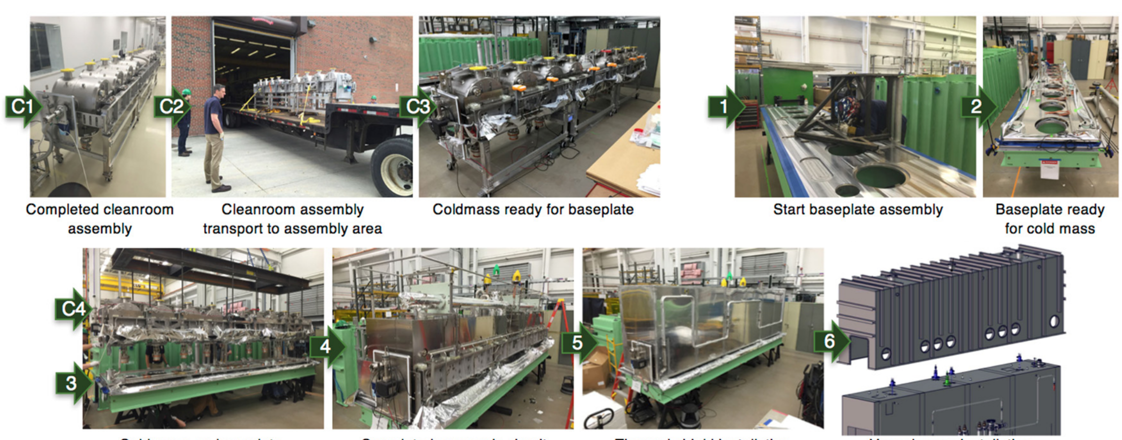

Figure 6: Assembly sequence of the β=0.53 pre-production CM.

recovery. This work delayed the CM assembly for 1.5 months. (Fig. 8).

Figure 8: Magnetic field measurement of coldmass.

Cryomodule

The coldmass was installed on the baseplate on 11 July 2016, and almost completed except some components outside the vacuum vessel at the end of September.

The thermal shield was mechanically interfered with the bottom magnetic shield. The interference was caused due to the G10 posts assembled incorrectly, so that the position of the bottom thermal shield was corrected by adding spacers (Fig. 9). The route cause was that the G10 posts were assembled without checking the drawings and confused with the other type of CM.

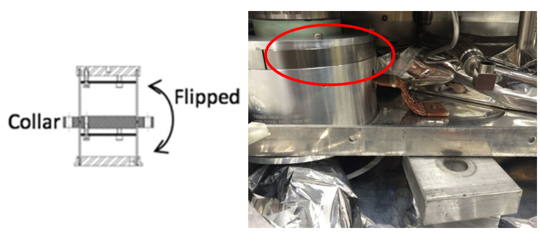

Figure 9: (Left) G10 posts assembled incorrectly, (Right) Inserted spacer to lower the thermal shield.

The 2K header was slightly twisted by the rotational moment by the weight of the heat exchanger. The heat exchanger support was, therefore, redesigned and directly attached to the 4K header (Fig. 10). This modification required to wait for a new support assembly and added complication to the order of pipe welding.

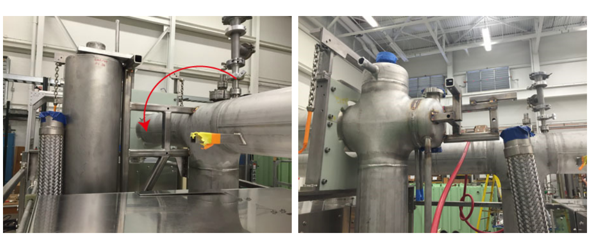

Figure 10: Improvement of heat exchanger support. (Left) Original: supported by 2K header, (Right) New: attached to 4K header.

The pressure tube driving the pneumatic tuner uses 1/8" tube to minimize the heat leak. However, the small tube welding reduced welding reliability, and the failed tubes needed to be cut and replaced. The tube between the flange and the thermal anchor was enlarged to 1/4" to facilitate the welding (Fig. 11).

Figure 11: Tuner pressure tube assembly. Some tubes needed to be cut and repaired.

COLD TESTING

The cold test of the pre-production CM will be performed in a cryomodule test facility (CMTF) in the SRF Highbay as shown in Fig. 12 [8]. The CMTF consists of two cold test CM bunkers. Cryogenic distribution, RF power lines, low-level controls, and instrumentation systems were already completed for the one bunker. The CM will be moved into the CMTF by using a tugger and wheels attached to the CM. The yellow-painted carbon steel door is to be closed and shields radiation from X-rays produced during testing of cavities.

Figure 12: Cryomodule test facility in the SRF Highbay.

The RF test will validate 4K and 2K cavity performance including coupler and tuner operation, solenoid packages, and alignment. The first cold test is planned before the end of 2016, which will be dedicated to commissioning of the new test systems and the first β=0.53 CM.

In the FRIB production phase, the bunker test is scheduled to test one CM per month: one cavity and solenoid testing for two weeks; cooldown, warmup, and replacing a CM within totally two weeks. This throughput has been already demonstrated in the second β=0.085 CM.

SUMMARY

Assembly effort is focusing on finishing the pre-production β=0.53 CM. Meanwhile equipment installation and bunker test preparation are ongoing in the SRF Highbay. The first CM test is scheduled before the end of 2016.

The lessons learned from the β=0.53 pre-production CM build including the mechanical design improvement and the assembly procedure optimization will be fed back to the production phase of the β=0.53, which will begin in 2017.

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