MSU RE-ACCELERATOR REA3 0.085 QWR CRYOMODULE STATUS*

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Abstract

ReA3 β=0.085 QWR cryomodule is the third cryomodule for the superconducting LINAC of ReA3 reaccelerated beam facility, which will bring the maximum beam energy to 3 MeV/u for heavy ions. This cryomodule consists of 8 β=0.085 QWR cavities and 3 9T superconducting solenoids and operates at 4K. Qualification of cavities and FPCs and the construction of cold mass was completed in 2013. The installation of the module was completed this summer. Functioning not only as an important part of the ReA3 facility, cryomodule 3 also serves as a test bed for FRIB driver Linac and demonstrated the technology needed for FRIB CMs. Here we report the construction, installation and testing of the β=0.085 cryomodule and the development of the critical components.

INTRODUCTION

ReA is a low-energy re-accelerator facility for nuclear physics experiments at FRIB/NSCL, MSU [1,2]. ReA3 will provide a maximum beam energy of 3 MeV/u for heavy ions with this third cryomodule as shown Figure 1. Not only an important part of the ReA facility, cryomodule 3 also served as a test bed for FRIB driver LINAC cryomodules. The technical development of this cryomodule started in 2009. The detailed technical obstacles and resolution of ReA quarter-wave resonators were described by previously [3]. The final certification tests of production cavities show that cavity performance is well above the ReA design goal and even reaches FRIB 4K field requirements [3]. Currently, the fabrication and installation of the cryomodule has been finished and integrated testing is underway.

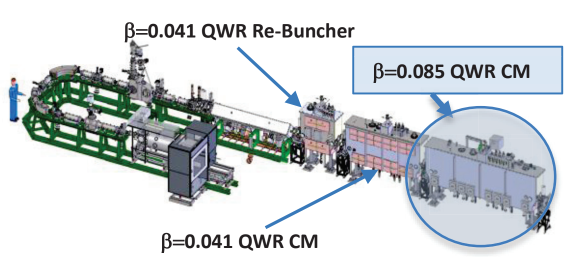

Figure 1: Isometric view of ReA3 Linac

Table 1: 0.085 QWR Cavity Specification of ReA3

Parameter	ReA3 0.085 QWR
RF frequency	80.5 MHz
β_{opt}	0.085
$L_{eff} = \beta_{opt}\,\lambda$	317 mm
R_a/Q_0	408 Ω
E_{peak}/E_{acc}	6.2
E_{acc}	3.4 MV/m
Operating temperature	4.5 K
Q_0	>5.0E+8
Aperture	30 mm

CRYOMODULE COMPONENTS

The cryomodule is equipped with 8 β=0.085 QWR cavities. The key parameters of the cavities are listed in Table 1. Three focusing superconducting solenoids with 9 T peak field and 1.8T-m integrated strength are located after 1st 4th and 7th cavities. Each solenoid also comes with sets of vertical and horizontal dipole corrector coils. The cryomodule utilizes a local magnetic shielding scheme

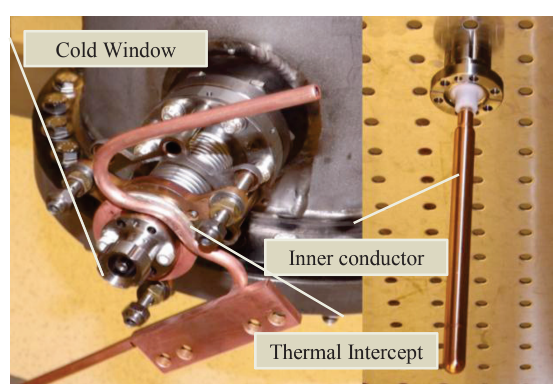

Figure 2: ReA3 β=0.085 QWR adjustable coupler

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ISBN 978-3-95450-142-7

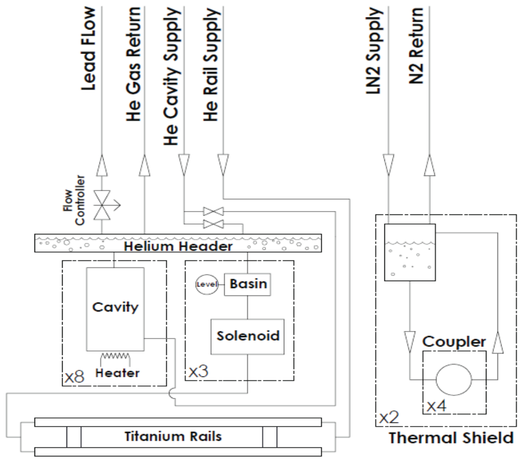

Figure 3: Simplified flow diagram of the cryomodule 3.

wherein individual cavities are shielded with CryoPerm®, while an iron return yoke mounted to the exterior of the magnet vessels reduce the fringe field at the cavities.

ReA3 β=0.085 QWRs use adjustable side coupled Fundamental Power Couplers (FPC). The coupler uses a cold RF window (ceramic feedthrough) as shown in Figure 2. The bandwidth of all FPCs was set at 70 Hz at room temperature. The measurement after cool down and cold alignment shows a range of 53-73 Hz among the 8 couplers. The RF cable used to connect the cold window and warm window (ceramic feedthrough) at the vacuum vessel end is a 1/2" HELIFLEX® air-dielectric coaxial cable (RFS HCA12-50JPL). Liquid nitrogen intercepts are provided at both the cold window location and the cold end of the cable to avoid RF joint overheating.

Table 2: ReA3 0.085 Cryomodule Heat Load

Temperature	Heat Load (W)		
	Static	Dynamic	Total
4.5 K	37	46	83
80 K	142	25	167

Cryomodule 3 is designed to be cooled by saturated liquid helium at approximately 1.2 atma. Figure 3 shows the simplified flow diagram of the module. Solenoids and cavities have separated cool down paths but are connected at the top by the helium header. During normal operation, helium only flows through the titanium rails and feeds to the bottom of the magnet vessels. Vapour cooled current leads with active flow controllers are used to minimize the heat leak to the helium circuit. The cryomodule thermal shield is cooled by liquid nitrogen with nitrogen tanks at the ends of module functioning as phase separators. The nitrogen system also provides cooling to the FPC RF joints using parallel thermal syphon loops. The connection between the module and cryo-distribution is field welded with vacuum breaks between the two. Projected heat loads based on the minimum design Q_0 value are listed in Table 2. The ReA3 LINAC is supported by a dedicated helium refrigerator (Linde LR280) and cold distribution system.

CRYOMODULE FABRICATION AND INSTALLATION

Cleanroom Coldmass Assembly

The ReA3 cleanroom coldmass assembly was completed in November 2013 (Figure 4). The fundamental power couplers were the last components to be tested and installed. The coldmass was evacuated slowly over two hours and each vacuum seal, ceramic feed through, and helium vessel was leak checked and diagnostic components tested. Significant challenges during the project were the quality of the copper plating of the FPC outer conductor bellows. Detailed copper plating specifications and acceptance criteria [4] were established during the project and aspects will be applied

Figure 4: Final ReA3 beta=0.085 cleanroom assembly.

to FRIB production couplers. Processing and clean beamline assembly techniques were succesfully developed for quarter wave resonators, which include differential etching for frequecy tuning, hydrogen degassing and 120 C low temperature bake [5]. The ReA3 coldmass is the first MSU operational coldmass to contain hydrogen-degassed cavities.

Cryomodule Assembly

A top-down structure is used in this cryomodule design. Helium header, cleanroom coldmass assembly (cavity string) and thermal shield are suspended from the top plate independently as shown in Figure 5; while cleanroom assembly and helium header are connected by bellows. This allows the adjustment of the cavity string position after cool down for alignment purposes.

Before the cleanroom coldmass assembly was connected to the helium header, passive dampers were installed into each cavity. The functionality of dampers were checked using cavity detuning as a function of time after an impulse was imparted onto each cavity. The desired damping behaviour (reduction in the Q of the mechanical resonance) confirmed proper installation.

In order to meet beam physics requirements, three alignment steps were performed during the cryomodule fabrication and installation: 1) cleanroom coldmass assembly alignment to insure the relative position of the

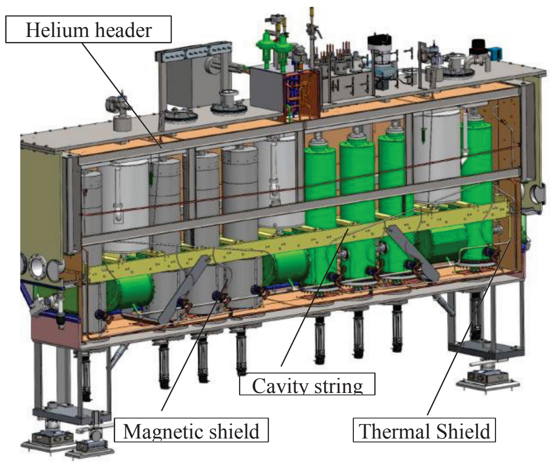

Figure 5: 3D view of ReA3 β=0.085 QWR cryomodule.

cavities and solenoids; 2) vessel alignment after installation to make sure the correct position of the warm beam port flanges; 3) cold alignment to adjust cold mass position after cool down to correct shifts caused by thermal contraction.

After the module was assembled, it was lifted onto the ReA deck for the final installation in June 2014. The main tasks included cryogenic connections, control system wiring and debugging, RF and DC power supply connections and lead shielding installation. The cryomodule fabrication and installation was completed in July 2014.

CRYOMODULE INITIAL COOL DOWN

The first cool down of the module started at the end of July. During cool down, liquid nitrogen was first sent to both sides of the thermal shield. Flow was regulated to have approximately the same cool down rates for both shields by monitoring the shield temperature sensors.

Shown in Figure 6 is the helium cool down temperature plots. Since the cavities were baked for hydrogen degassing, there was no cool down rate requirement to prevent Q disease. Cool down began by starting flow to both solenoids and cavities at the same time. Cavity temperature dropped much faster than the titanium rail temperature (solenoid circuit) because of the relatively small thermal mass compared to that of the solenoids and rails. As shown in the plot, liquid helium started to accumulate inside the module after the rails reached 4.5K. Helium cool down took about 36 hours which is comparable to the ReA3 β=0.41 QWR cryomodule. Helium bath pressure stability is critical for sustained cavity operation. Figure 7 shows helium bath pressure over a couple hours period, which represents the normal running condition of the module. A regular slow oscillation is present with amplitude of 3-4 mbar and period of 6-7 minutes. The amplitude of high frequency (>1 Hz) oscillations in bath pressure is very low and meets the requirement of +/- 1 torr needed to ensure cavity lock.

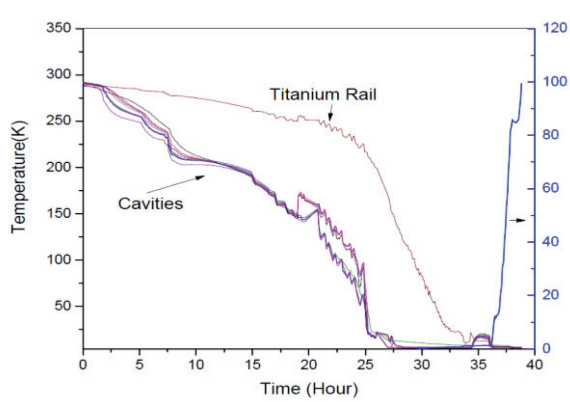

Figure 6: Cool down of ReA3 β=0.085 QWR Cryomodule.

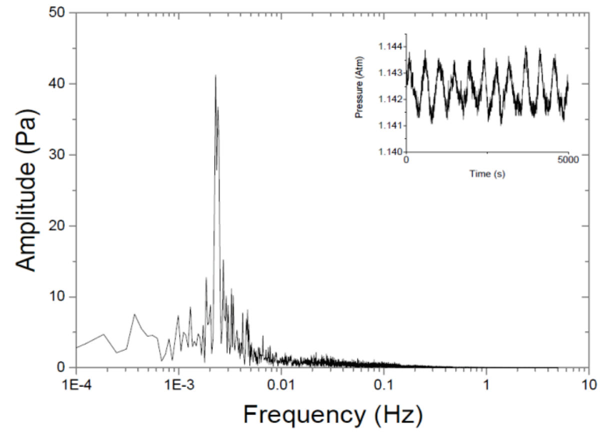

Figure 7: Helium bath pressure of cryomodule.

SUMMARY

ReA3 β=0.085 QWR cryomodule assembly was completed and installed this summer, and the module was cooled down successfully. Integrated testing of cavities and magnets is underway.

ACKNOWLEDGMENT

We thank R. Laxdal for his contribution and valuable advice to this project during weekly teleconferences.

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ISBN 978-3-95450-142-7