CM2, SECOND 1.3 GHZ CRYOMODULE FABRICATION AT FERMILAB*

T. Arkan#, M. Awida, P. Berrutti, E. Borissov, C. Ginsburg, C. Grimm, E. Harms, A. Hocker, T. Khabiboulline, Y. Orlov, T. Peterson, R. Pilipenko, Y. Pischalnikov, K. Premo, L. Ristori, W. Schappert, V. Yakovlev, FNAL, Batavia, IL 60510, USA

Abstract

CM2 is the second 1.3GHz Cryomodule assembled at the Cryomodule Assembly Facility (CAF) in Fermi National Accelerator Laboratory. The string has a corrector coil magnet, a beam position monitor and eight cavities. All cavities are qualified at >= 33 MV/m gradient at the Horizontal Test Facility (HTS) before assembly. The dressed cavities were outfitted with magnetic shielding, blade tuner. The cold mass was assembled based on the Tesla TTF Type III+ cryomodule design. CM2 is currently being installed into the test stand in NML where it will be cooled down and high power tested. CM2 will also be the first cryomodule to be tested with an electron beam at the NML facility. This paper describes the assembly steps, the quality assurance methods and the challenges experienced during assembly and qualification at CAF.

INTRODUCTION

Fermilab's second 1.3 GHz cryomodule (aka CM2 or RFCA002) was assembled between July 2011 and March 2012. During the installation of this module at NML test facility, a vacuum leak was discovered in the 2-phase helium circuit. The module was brought back to CAF in June 2012 and was partially disassembled to find the location of the leak and to repair it. The module was then reassembled and transported to NML in April 2013. The module is currently being installed on the test stand. The cool-down and high power radio frequency (RF) test of the module is planned to start in September 2013.

CAVITIES AND COLD MASS COMPONENTS

All eight cavities manufactured by industrial vendors were specifically selected to be likely to achieve the ILC design goal based on their performance in individual RF tests [1]. The cavities were first tested "bare" in a vertical liquid helium dewar using low-power continuous-wave RF. Cavities which met the ILC vertical test specification ($E_{acc} \geq 35$ MV/m, $Q_0 \geq 0.8 \times 10^{10}$) were then welded into individual helium jackets at CAF and outfitted with a high-power input coupler. The high power couplers were purchased from CPI. The couplers were cleaned and high power conditioned at SLAC. These "dressed" cavities were then tested in the HTS using high-power pulsed RF. Qualified cavities along with a corrector coil magnet outfitted with XFEL style helium jacket and a button style beam position monitor (BPM) were all assembled into a cavity string in the CAF cleanroom. INFN design blade tuners [2] were purchased from Incodema. The tuner motors and gears were purchased from Phytron and Harmonic Drive Inc. The magnetic shielding parts were designed by Fermilab and were purchased from Amuneal. The vacuum vessel, gas return helium pipe (GRHP) assembly and cold mass support posts were procured from Zanon in Italy.

*Work supported by the U.S. Department of Energy
#arkan@fnal.gov

CRYOMODULE ASSEMBLY

Cavity String Assembly

The assembly of the cavity string was done in the CAF cleanroom situated in the CAF-MP9 building. Eight qualified cavities, a magnet, a BPM and two gate valves were interconnected using bellows in the Class 10 cleanroom. The assembly of the cavity string is the most important step throughout the cryomodule assembly to ensure that the measured gradient of the qualified cavities is preserved. Particulate-free-flange-assembly techniques were developed and optimized throughout the years at various institutions working on SRF R&D. CAF cleanroom technicians have over 7 year experience in particulate free ultra-high vacuum applications. CM2 cavity string (See Figure 1) was assembled while following the assembly travelers and working with strict adherence to the CAF cleanroom working protocols.

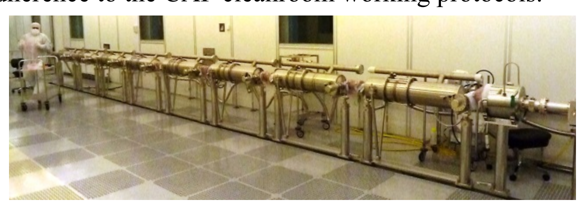

Figure 1: CM2 cavity string in the cleanroom.

Cold Mass and Final Assembly

After the string assembly was completed, the string was rolled out of the cleanroom into the cold mass assembly area at CAF-MP9 using the assembly rail. The 2-phase pipes of the cavities were interconnected using titanium (Ti) bellows welded using an automated orbital welding machine conforming to the ASME piping code. The cavities were then outfitted with magnetic shielding and blade tuner components. The cavity string was then lifted from the assembly fixtures and married to the GRHP assembly forming the cold mass assembly. The cold mass assembly was then transported to CAF-ICB building (See Figure 2). The X-Y axis alignment of the cavities to 250 microns was done using a laser tracker instrument. The cold mass was then transferred to the Big Bertha cantilever fixture for the welding of heat shields and multi-layer insulation (MLI) installation. (See Figure 3) The cold mass was then moved to the final assembly area in CAF-ICB where the warm end high power couplers and waveguides were assembled.

Figure 2: CM2 cold mass transport.

Throughout the cold mass assembly, several temperature sensors were installed on the critical components; RF measurements of the cavities were done several times and various vacuum leaks and pressure tests were conducted.
After the final quality assurance checks, the fully assembled cryomodule was transported to the NML test area (see Figure 4).

Figure 3: CM2 cold mass on the Big Bertha fixture.

Figure 4: CM2 transport to NML.

CHALLENGES EXPERIENCED

Tuner Motor and Harmonic Drive Reliability

First tuner prototypes were designed and built at INFN and delivered to Fermilab. 50 blade tuners were later fabricated in U.S. industry. The Phytron brand tuner motor and the Harmonic Drive gearbox used for CM2 tuners were also used on most tuners worldwide. (See Figure 5)

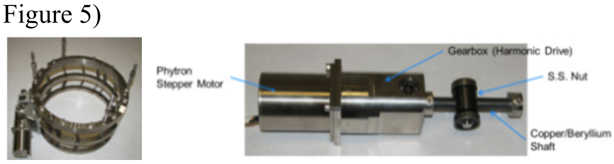

Figure 5: Blade tuner, motor, gearbox.

During the qualification and testing of the tuner components prior to the assembly of CM2 cavities, several mechanical problems were encountered:

1. Harmonic drive wave generator connection to the motor shaft: (See Figure 6)

- Phytron motor shaft has no provisions for a mechanical hard stop
- Dog-point set screws may lose grip on the shaft causing the wave generator to slip

Corrective Action – the motor shaft was cross-drilled and pointed set-screws were inserted with cryogenic grade Loctite.

Figure 6: Harmonic drive wave generator connection to the motor shaft.

2. Harmonic drive flex gear connection to copper/beryllium shaft: (See Figure 7)

- Screws may loosen causing gear to disengage from shaft causing gears to bind

Corrective Action – Internal lock washers were added under the screws and cryogenic grade Loctite was added.

Figure 7: Harmonic drive flex gear connection to copper/beryllium shaft.

Addressing CM2 coarse tuner reliability issues one tuner was tested at warm condition on the bench test. An automatic program ran actuator for 6 million steps to simulate real operating conditions. RF measurements were taken during the process to validate tuning progress.
After test decision was made that "6millions steps at warm condition test" is too harsh to the shaft/nut coating. Instead all the eight CM2 motors installed on the cavities during cold mass assembly were subjected to 400-ksteps (~1% of the lifecycle).
In parallel with the warm testing, there was an opportunity to perform a cold full lifecycle test with a prototype cavity in HTS. The goal was to test the motor over a 10 day period to reach 30 million steps. The 30 million steps represents about 15-20 years of thermal cycling and cryomodule operation. This part of the test was completed successfully with the tuner/motor still functioning as predicted. Decisions were made to continue the cold test until a failure occurred or the system reached 60-million steps. At 31-million steps, the system suffered a failure. (See Figure 8) An autopsy was performed on the motor assembly and it was determined that the harmonic drive gear stripped and the wave generator got stuck in the spline gear.

ISBN 978-3-95450-138-0

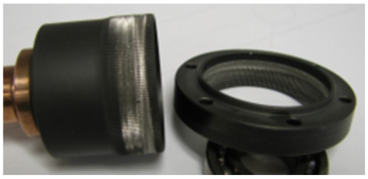

Figure 8: Harmonic drive gear failure.

Cavity HOM Antenna Shorts

During the electrical quality assurance checks of CM2 cryomodule, electrical shorts were found in three cavities at the high order mode (HOM) feedthrough connectors. An investigation of component dimensional tolerance stack up was undertaken to determine the cause. As it can be seen from Figure 9, the design distance between the antenna tip and the formteil is 0.5 mm. Taking into account that the antenna is assembled on the connector with a press-fit method in the cleanroom prior to the assembly of the feedthrough flange to the cavity, a tolerance stack up due to out of spec dimensions of individual components might cause an electrical short when the tip of the antenna touches the formteil.

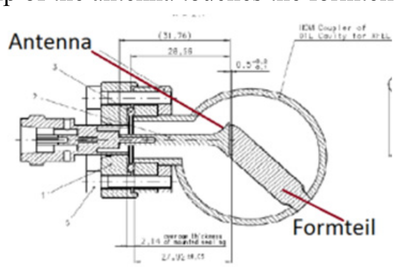

Figure 9: HOM Antenna assembly to the HOM coupler.

It was deemed that this problem will not be a critical issue for CM2 operations. However, all components in inventory were measured and the antenna tips were trimmed appropriately. It was also decided to conduct capacitance measurements on feedthrough flanges after these are assembled on the cavity in the cleanroom to ensure that there are no shorts.

Vacuum Leak on the 2-phase Circuit

During the vacuum leak checks of CM2 at NML testing facility, a vacuum leak was observed on the 2-phase helium circuit pipe. Initial leak checks at NML showed that the leak was in the vicinity of the Ti bellows between Cavity #8 and the magnet. (See Figure 10) The module was then transported back to CAF for partial disassembly and repair. The vacuum vessel, MLI and lower heat shields were disassembled in order to access the 2-phase pipe. After disassembly, it was observed that the magnet moved approximately 14 mm towards Cavity #8. Further investigation showed that the invar rod clamp designed to hold the spacing between the magnet and the cavity failed to restrain the magnet during vacuum pump down due to vacuum forces exerted on the clamp. After the magnet was moved back to its design distance, new clamps were designed and installed for the magnet and the cavities. We then started the leak check efforts and surprisingly no vacuum leaks were observed. Various leak checks, pressure tests in different configurations were done throughout a 3-month period to replicate the leak that was observed at NML.

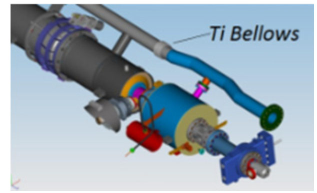

Figure 10: Ti bellows between magnet and cavity #8.

After several months of effort, a leak was observed. The leak appeared while checking the 2-phase helium circuit with the cold mass fully bagged and filled with helium. Further leak checks in the same morning without the bag showed a leak (mid 10^{-7} mbar x l/s) on the same Ti bellows that we observed a similar range leak at NML. Without changing the setup, the leak check inspector tried to confirm the leak in the afternoon. Surprisingly, the leak disappeared. We decided to replace the questionable Ti bellows with a new one. CM2 was then re-assembled. Further investigation was done on the removed Ti bellows to understand the strange leak behaviour. The bellows was sent out to an x-ray vendor but the analysis did not produce any useful results. Eventually, we were able to replicate the leak at Fermilab. First the bellows were cleaned and handled with UHV standards. The bellows were then pumped down and leak checked. The same range leak was observed on the seam weld of the bellows. If the technician touched the leak even with gloved fingers, the leak disappeared. Wiping with lint free cloths and using cleaning agents were not successful to open the leak. The bellows needed to be cleaned again with UHV standards in order to replicate the leak. It was deemed that the leak is so small that airborne dust particles, any residue from gloves might clog the leak and make it disappear. No further study was done on this bellows. Action items for future Ti bellows are to clean the bellows with UHV standards before incoming leak checks and always handle the UHV components with gloves and extreme care.

SUMMARY

The lessons learned during the fabrication of CM2 will be applied for future module assemblies at CAF.

ACKNOWLEDMENT

Special thanks to all the support (QC, RF, electrical, alignment & metrology, material handling) groups who helped CAF team during the CM2 fabrication.

REFERENCES

[1] C. Ginsburg, “Fermilab 1.3 GHz Superconducting RF Cavity and Cryomodule Program for Future Linacs”, LINAC’12, MOPB052.
[2] Y. Pischalnikov et al, “Test of a Coaxial Blade Tuner at HTS/FNAL”, PAC’11, TUP082.