STATUS OF 3.9 GHz SUPERCONDUCTING RF CAVITY TECHNOLOGY AT FERMILAB*

E. Harms, T. Arkan, V. Bocean, H. Carter, H. Edwards, M. Foley, T. Khabiboulline, M. McGee, D. Mitchell, D. Olis, A. Rowe, N. Solyak, FNAL, Batavia, IL 60510, U.S.A.

Abstract

Fermilab is involved in an effort to design, build, test and deliver four 3.9 GHz superconducting rf cavities within a single cryomodule to be delivered to DESY as a 'third harmonic' structure for the FLASH facility to improve the longitudinal emittance. In addition to an overall status update we will present recent results from single 'dressed' cavity horizontal tests and shipping and alignment measurements.

INTRODUCTION

Fermilab is constructing a cryomodule containing four superconducting radio frequency (SRF) cavities operating at 3.9 GHz for the Free electron LASer in Hamburg (FLASH) facility at the Deutsches Elektronen-SYnchrotron (DESY) laboratory. This cryomodule was proposed to linearize the energy distribution along a bunch upstream of the bunch compressor. The four 9-cell cavities were designed to operate at 2 K in the TM_{010} π-mode at an accelerating gradient E_{acc} = 14 MV/m. Table 1 contains a list of parameters.

Table 1: Cryomodule Parameters

Number of Cavities	4
Active Length	0.346 meter
Gradient	14 MV/m
Phase	-179°
R/Q [$=U^2/(\omega W)$]	750 Ω
E_{peak}/E_{acc}	2.26
B_{peak} (E_{acc} = 14 MV/m)	68 mT
Q_{ext}	1.3×10^6
BBU Limit for HOM, Q	$<1 \times 10^5$
Total Energy	20 MeV
Beam Current	9 mA
Forward Power, per cavity	9 kW
Coupler Power, per coupler	45 kW

CAVITY FABRICATION AND TESTING

Eight cavities have now been fabricated and undergone various levels of testing. A summary of test results and status of each is found in table 2. Details as to cavity performance can be found elsewhere [1] and at this conference [2].

Table 2: Cavity Fabrication and Testing Status

Cavity	Assembled by	Completion date	Test results and status
#1: 2-leg HOM	Fermilab	January 2006	- Never tested: HOM membrane break during cleaning - Used as horizontal test prototype
#2: 2-leg HOM	Fermilab	February 2006	- Best vertical test: 12 MV/m limited by HOM heating - Fractured Formteils - Awaiting repair
#3: 2-leg trimmed HOM	Fermilab JLab	August 2006	- Best Vertical test: 24.5 MV/m, achieved after HOM trimming - Welded into Helium vessel - Dressed for Horizontal testing
#4: 2-leg trimmed HOM	Fermilab JLab	March 2007	- Best Vertical test: 23 MV/m - Final vertical test with HOM feedthroughs
#5: 2-leg trimmed HOM	Fermilab JLab	May 2007	- Best Vertical test: 24 MV/m - Welded into Helium vessel - Horizontal testing complete: 22.5 MV/m - Ready for string assembly
#6: 2-leg trimmed HOM	Fermilab JLab	May 2007	- Best Vertical test: 22 MV/m - Faulty welds repaired - Awaiting final vertical test with HOM feedthroughs
#7 single-post HOM	Fermilab JLab DESY	November 2007	- Best Vertical test: 24.5 MV/m - Welded into Helium Vessel - Awaiting dressing and horizontal test
#8 single-post HOM	Fermilab DESY	October 2007	- Vertical test: 24 MV/m - Welded into Helium vessel - Awaiting dressing and horizontal test

Fabrication

Cavity fabrication has been reported previously [3]. Recently, Jefferson Lab expertise was called upon to repair broken welds found on cavity #6 ends during vertical testing. Cavity #2, which failed early in the test process, is now being fitted with replacement HOM bodies. At this time, weld samples are being evaluated prior to attempting this novel repair.

*Operated by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the United States Department of Energy.

Helium Vessel Welding

Once vertical test goals are met, each cavity is welded into a titanium helium vessel. Helium vessels have been welded on to five cavities (including one prototype) [4]. The frequency spectrum of each cavity was measured at appropriate intervals during the welding process to assess any changes. For the five vessels welded to date, the two electron beam welds have had no significant effect on the tune of any of the dressed cavities. This was expected because the cavities are not restrained during this welding step.

TIG welding is done in segments to avoid overheating and plastic deformation. Once the helium vessel is tack welded to the cavity, the support rods are removed from the blade tuner flanges so that the bellows can relieve limited thermal expansion. A cool down period of several minutes is allowed after each succeeding TIG weld segment. A continuous flow of argon gas is passed through both the cavity and the helium vessel during welding to facilitate cooling. The frequency spectrum of the cavity is monitored after every step of the TIG welding process to ensure the elastic limit of the cavity is not exceeded.

This critical assembly step can now be considered a mature and reproducible process. Detailed documentation exists to ensure that future welds are completed with the same care.

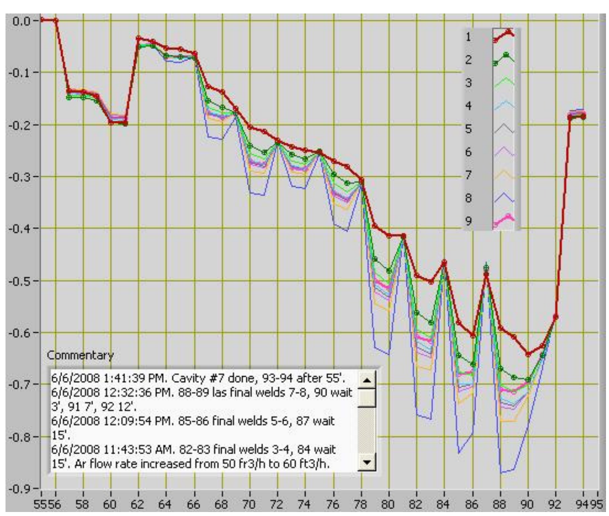

Figure 1: Frequency Spectrum for Cavity #7 during TIG welding. Time proceeds from left to right. Frequency spring-back due to cool down periods can be seen, particularly in later steps.

Dressing

Following the helium vessel mating, each cavity receives a final 20 μ internal BCP etch, then is outfitted with its main input coupler, HOM coupler feed throughs, transmitted power probe, magnetic shielding, and blade tuner. Once this 'dressing' is completed a pressure vessel test is performed on the helium vessel to meet regulatory requirements. Assemblies are tested to 2.3 bar, 1.15 times the Maximum Allowable Working Pressure (MAWP) of 2.0 bar.

The resulting 'dressed' cavity is again RF tested, in a horizontal orientation, so as to ensure that the steps just completed have not compromised cavity performance. This test also provides the most realistic evaluation of single cavities prior to assembly as a string. As of this writing only one cavity, #5, has been subjected to this sequence. A description of the Horizontal Test stand and the test of #5 is described elsewhere [5].

String Assembly

The 4-cavity string will be assembled in Fermilab's MP-9 clean room. Fit-ups with mockup cavities have helped to ensure that once a sufficient number of cavities are available, assembly will proceed in a relatively trouble-free manner.

SHIPPING AND ALIGNMENT

Extensive modeling and studies have been carried out in preparation for transporting the entire 4-cavity module to DESY once completed. Much of this work has been documented elsewhere [6,7]. The design was peer reviewed verifying its fundamental soundness and providing valuable ideas based on past experience with transporting similar devices. This work has been carried out in four distinct phases:

- Modeling
- Transport studies utilizing a string of mock-up cavities driven around the Fermilab site
- Refinement of the transport/support scheme based on transport experience
- Transport from Fermilab to O'Hare International Airport to validate the transport scheme and document expected forces.

DESY has indicated the overall alignment tolerance requirement of the cold cryomodule for the TTF/FLASH accelerator to be 0.5 mm. An error budget analysis, including, among others, the referencing of the cavities centerline, thermal cycling (warm up cool down), cavity string alignment and referencing to the vessel, string misalignments due to shipping, gave a maximum tolerance for alignment and cavities shift during transport of 0.25 mm.

Analyses from the transport studies and follow-on alignment checks indicate that the cavities maintain their relative alignment of 0.1 mm with respect to a straight line within the cavity string; however, the alignment with respect to the vacuum vessel is only marginal to the allowable tolerance. During the early transport studies the cavity string was affected by transverse and longitudinal shock at low frequencies (beneath 10 Hz). Cavities moved coherently (as one) in the transverse direction, responding to shock and vibration.

After modifications to the base frame and isolation system, this effect was minimized. This deformation study indicates that the cavity string ensemble was subject to very small (less than 0.1 mm) displacements between subsequent tests while still maintaining their relative horizontal and vertical alignment with respect to a straight line within 0.1 mm. Also, the overall maximum transversal shift of the cavity string among those tests was less than 0.1mm horizontal and vertical.

OTHER COMPONENTS

Input Couplers

Three of the six procured input couplers have been assembled and conditioned on the test stand assembled for this purpose. Coupler design and early test stand experience is previously documented [8]. A conditioning protocol following the DESY experience is followed. Protection against damage is afforded by an interlock system using thermometry mounted close to the ceramic windows, electron and light detectors, and vacuum activity as inputs.

Couplers are conditioned in pairs. The first pair was conditioned as the stand was commissioned in late 2007. Only vacuum activity was noted, especially at higher powers, but this decreased over time. One of these couplers was mounted on Cavity #5 for horizontal testing and behavior here was similar during warm operation. For cold operation, no coupler-related trips were noted.

A second pair of couplers was mounted on the conditioning stand and operated in May 2008. One of these couplers was trimmed by an additional 1mm prior to conditioning based on the results of cold measurements on cavity #5 at HTS. This sequence, too, was fairly uneventful as evidenced by only seven 'hard trips' signifying excessive electron emission or visible sparks over the 3-day span of conditioning. The shorter of the two couplers conditioned here is now mounted on Cavity #3 for evaluation during the next horizontal test. The remaining couplers will be trimmed and conditioned once the proper coupler length is determined. As these couplers are of fixed length, it is obviously vital that this dimension is precisely known.

HOM Coupler Feedthroughs

The HOM coupler feedthroughs mounted on the cavities for final vertical and horizontal testing are a 2nd generation design based upon Jefferson Lab experience with sapphire insulators. Each antenna probe is trimmed uniquely for the cavity and location to which it is placed. Extensive cold testing and vacuum leak checks ensure reliable feedthoughs. Some pieces have developed vacuum leaks following cool down to 2K and discarded. Of eighteen pieces received from the vendor, four have been deemed unusable.

SUMMARY

Fermilab is in the process of providing a 4-cavity 3.9 GHz cryomodule to DESY for installation in the FLASH facility. A sufficient number of cavities have now passed vertical testing and have helium vessels welded onto them. Horizontal testing of dressed cavities is in progress and string assembly will commence shortly.

It is intended to ship the completed module to DESY and RF test it in the Cryo-Module Test Bed (CMTB) prior to installation in FLASH.

ACKNOWLEDGEMENTS

The authors acknowledge the significant assistance and counsel received from numerous colleagues at DESY. Many people at Jefferson Lab have contributed to this effort as well. The dedicated efforts of the growing SRF staff at Fermilab, particularly members of the Accelerator and Technical Divisions, especially the A0 SCRF technical support group, have been critical to the progress made to date.

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