CONSTRUCTION OF A 3.9 GHZ SUPERCONDUCTING RF CAVITY MODULE AT FERMILAB*

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Abstract

Fermilab is in a collaboration with DESY to provide a cryomodule containing four 3.9 GHz superconducting RF cavities to be placed in TTF/FLASH. The purpose of this 'Third Harmonic' module is to linearize the nonlinear beam energy-time profile produced by the 1.3 GHz accelerating gradient. The completed module has now been shipped to DESY and is awaiting cold, powered testing and installation into FLASH later this year. We report on experience with fabricating, testing, assembling, and shipping the module and its components with a focus on cavity test results.

INTRODUCTION

Fermilab has constructed 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, known as ACC39, 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 been fabricated and undergone various levels of testing. A summary of test results and status of each is found in table 2. All fabricated cavities underwent a series of tests at the A0 vertical test stand as 'bare' cavities. Those welded into helium vessels were given an additional test prior to dressing to ensure that the welding process did not significantly degrade each cavity's performance. Results of these tests have been described previously [1].

Five cavities are now welded into helium vessels and have undergone Horizontal tests at the Fermilab Horizontal Test Stand (HTS) located in the former Meson Detector Building (MDB) as complete 'dressed' cavities outfitted with magnetic shielding and blade tuners. All cavities tested to date have reached gradients of at least 18 MV/m, with most achieving a gradient in excess of 22 MV/m. HTS is described elsewhere [2]. Figure 1 shows Q_0 vs E results for the four cavities of the string assembly. Onset of field emission and magnitude of x-rays produced is shown in Figure 2.

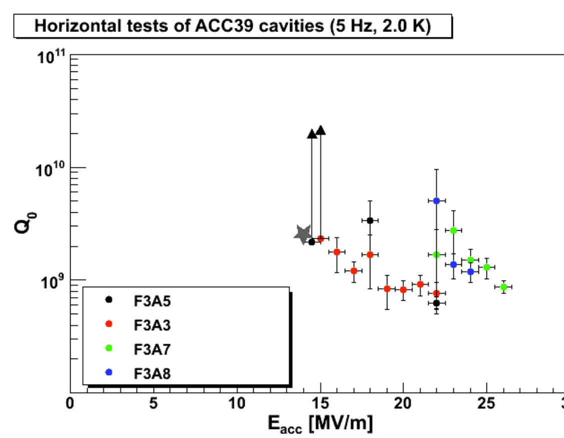

Figure 1: Q_0 vs E for the 4 cavities in the String assembly. The star indicates the design goal.

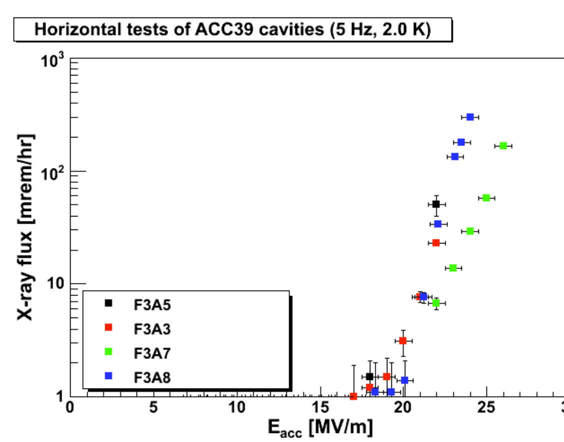

Figure 2: Onset and magnitude of x-ray production as a function of gradient.

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STRING ASSEMBLY

The first four cavities to be tested at the Horizontal Test Stand exceeded design specification and were assigned to be part of the 4-cavity string assembly. Two of the cavities contain the original 2-post Formteil Higher Order Mode (HOM) couplers while the remaining two were fabricated with the re-designed single-post Formteil [3].

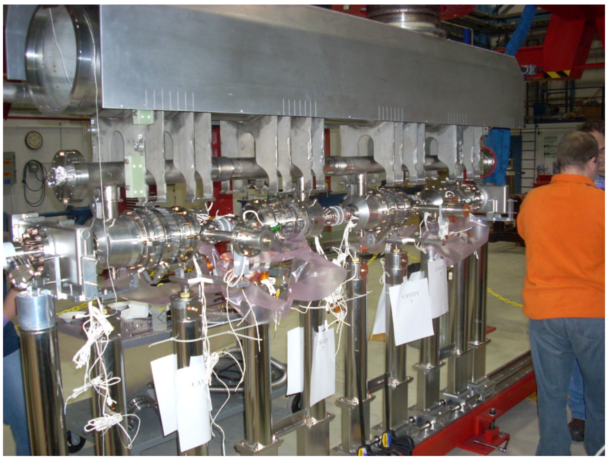

Figure 3: Completed string assembly .

String assembly commenced on 11 December 2009 when three cavities were first available. They and a gate valve were joined in Fermilab's MP-9 clean room in a little over three days. When the fourth cavity was available in early January 2009, it as well as the other vacuum gate valve and a manifold to allow remote monitoring of the vacuum in the string were attached. Once a successful leak check of the string was completed, the string was rolled out of the clean room for mating to the 300 mm gas return pipe, which acts as the cold mass spine, and return pipe welding. Welding these titanium pipes proved to be tricky and it was necessary to cut out and re-weld two sections due to a momentary loss of Argon purge gas.

The completed string assembly was transported by truck on 6 February 2009 to the Fermilab Industrial Center Building for cold mass assembly. This move afforded an opportunity to prepare for actual transport of the completed module. The assembly was loaded onto the shipping fixture designed for the complete module and outfitted with vibration and g-force sensors to measure the response during truck transport. The adequacy of the transport design was confirmed with this exercise.

COLD MASS ASSEMBLY

The final major assembly work at Fermilab was the Cold Mass assembly. This consisted of encasing the cavity string in first a 4K, then 80K thermal shields interspersed with multiple layers of MLI. All additional piping was installed as well. The entire assembly was then inserted into its vacuum vessel and final alignments performed. In addition, instrumentation cabling needed to be routed, terminated, and checked for functionality. Final quality assurance checks including

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 - Repair attempted
#3: 2-leg trimmed HOM	Fermilab JLab	August 2006	- Best Vertical test: 24.5 MV/m, achieved after HOM trimming - Horizontal testing: 22.5 MV/m, limited by quench - ***Part of final string assembly***
#4: 2-leg trimmed HOM	Fermilab JLab	March 2007	- Best Vertical test: 23 MV/m - Horizontal testing: 18 MV/m, limited by warm-end input coupler vacuum excursions
#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, limited by quench - ***Part of final 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 - Horizontal testing: 26.3 MV/m, limited by quench - ***Part of final string assembly***
#8 single-post HOM	Fermilab DESY	October 2007	- Vertical test: 24 MV/m - Horizontal testing: 24 MV/m, limited by quench - ***Part of final string assembly***

vacuum leak checking and a test fit of warm part input couplers was carried out. All external joints were verified leak tight and finally the vacuum vessel was slightly pressurized to 50 mbar with dry nitrogen just prior to shipment. A review of the Operation Readiness of ACC39 was performed prior to shipment.

TRANSPORT TO DESY

With Cold Mass assembly complete, the module departed Fermilab on 24 April 2009 and was delivered to DESY four days later. Transport was accomplished:

- Via truck from Fermilab to Chicago O'Hare airport

- Air cargo transport to Paris, Charles de Gaulle airport
- Overland transport via truck from Paris to Hamburg.

All critical transfer points were witnessed by Fermilab personnel.

Great care went into the design and construction of the carrier fixture and techniques to minimize shock and vibration to components within the vacuum vessel – input couplers and cavities most notably. The choice and placement of diagnostics to monitor shock and vibration during transport was also done with deliberation. The transport system proved to fulfill its purpose as the cavity string resting on its isolation fixture experienced acceleration of no more than 1.2 g during transport and off-loading, roughly half as much as measured on the base frame. A full description of the transport system and complete results from the transatlantic shipment are reported elsewhere at this conference [4].

The cavity string was shipped under vacuum and instrumentation was installed during cold mass assembly to allow one to monitor the vacuum pressure prior to, during, and after shipment. A pressure of 4.8×10^{-4} Torr was measured prior to departure from Fermilab on 23 April, some two weeks after active pumping was ceased on the string. Upon arrival in Paris late on 27 April it was found to be 7.7×10^{-4} Torr and remained at this level when checked during overland transport and upon arrival at DESY.

At this time the module is receiving a post-transport checkout to verify vacuum leak tightness and that no significant misalignment of the cavity string occurred during transport.

Figure 4: ACC39 delivered to DESY.

FUTURE STEPS & SCHEDULE

Once entry checkout is completed, the warm parts of the input couplers will be installed in clean room conditions by visiting Fermilab personnel. External electrical connections to internal instrumentation and tuner motors will also be operated and verified. It is planned to cool down and RF power test the module in DESY's Cryomodule Test Bed Facility (CMTB) as its schedule permits, now expected to be beginning this October. The current schedule calls for installation in FLASH in late 2009 followed by beam commissioning in March of 2010.

SUMMARY

Fermilab has now successfully completed construction of a Superconducting RF module consisting of four 3.9 GHz cavities each of which have achieved a gradient in excess of 22 MV/m and met all other design criteria. The module was transported to DESY without incident and is now being prepared for testing at CMTB. Installation and beam commissioning in DESY's FLASH free electron laser is to follow beginning in late 2009.

ACKNOWLEDGEMENTS

The success of this venture would not have been possible without the dedication and efforts of many people in the Accelerator and Technical Divisions at Fermilab who are part of the expanding SRF effort. Of particular note are the AD/A0 SRF and TD/MP-9 mechanical technicians without whom ACC39 and its contents would exist. Contributions by PPD and CD staff are also noted. Significant advice and technical support from colleagues at DESY and Jefferson lab were invaluable in this achievement.

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