STATUS OF 3.9-GHZ SUPERCONDUCTING RF CAVITY TECHNOLOGY AT FERMILAB*

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Abstract

Fermilab is involved in an effort to design, build, test and deliver 3.9 GHz superconducting RF cavities with a goal to deliver one 'third harmonic' cryomodule containing four cavities in 2007 for use at the DESY TTF/FLASH facility. The design gradient of these cavities is 14 MV/m limited by thermal heat transfer. This effort involves design, fabrication, intermediate testing, assembly, and eventual delivery of the four cavity cryomodule. We report on all facets of this enterprise from design through future plans. Included will be early test results of single 9-cell cavities, lessons learned, and other findings.

INTRODUCTION

Fermilab has entered into an agreement with DESY to provide a cryomodule containing 4-3.9 GHz superconducting RF cavities to be placed in TTF-FLASH. These cavities are TM010 structures designed to linearize the accelerating gradient of the 1.3 GHz cavities, thus providing improved longitudinal emittance. The required operating gradient is 14 MV/m. As a byproduct, another goal of this project is to develop SCRF infrastructure at Fermilab and build a cryomodule with four 3.9 GHz cavities for the TTF/FLASH facility. Thhis specifically includes:

- Cryomodule for 4 cavities
- 4 (+2 spare) dressed cavities with couplers
- Tuners, magnetic shielding, assembly tooling
- All cavities have to be treated (BCP, HT, HPWR)
- Tuned and tested in Vertical vessel (undressed cavity) and Horizontal cryostat (dressed cavity and coupler)
- Assemble cavity string & cryostat and ship to DESY
- Assist with assembly at DESY.

With the design effort virtually complete, effort has turned towards fabrication and testing. It is hoped that this project will be completed during the first half of 2007 and the cryomodule delivered to DESY in this time span.

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COMPONENT FABRICATION & PROCESSING

This project has been subdivided into the components necessary to produce a single cryromodule. A summary of the status of fabrication of selected elements: cavities, input couplers, and Higher Order Mode (HOM) couplers is presented here.

Cavities

The processing and testing program for the FNAL 3.9 GHz cavity effort is modeled after the DESY SRF buffered chemical polishing (BCP) processing sequence. This sequence is designed to reliably produce 25 MV/m in 1.3 GHz ILC-style cavities without the complications associated with electropolishing. Because of the lower operating accelerating gradient in the 3.9 GHz 3rd Harmonic cavities, BCP is an adequate polishing method to reliably achieve the required gradient[1]. FNAL has shown that the basic BCP procedure will reliably achieve the required accelerating gradient on a 3-cell 3rd Harmonic cavity[2]. The basic BCP processing sequence that FNAL is following for the 3rd Harmonic cavity program is shown in Table 1

Table 1: BCP processing and testing program for FNAL 3rd Harmonic cavity program

Step	Procedure
1	Outside surface BCP (20μm)
2	Inside surface BCP (80μm)
3	H2 degasification bake (800C 2hr plateau)
4	Field flatness tune
5	Inside surface BCP (20μm)
6	High pressure rinse (50 surface passes)
7	Vertical Performance Test & Certification
8	Weld on liquid He vessel
9	Inside surface BCP (20μm)
10	High pressure rinse (50 surface passes)
11	Horizontal Performance Test & Certification

Construction of eight cavities is the objective of this effort. Four are to be built at Fermilab and the remainder to be built by JLAB using parts supplied by Fermilab. To date two cavities have been constructed at Fermilab and subjected to various levels of processing and testing. All BCP is undertaken at a dedicated facility at Argonne National Laboratory by qualified Fermilab personnel.

Cavity #1 fabrication was completed in December 2005 and processing was carried out until a failure of one HOM tuning membrane that occurred during an ultrasonic rinse following the initial inside surface etch. These membranes have since been redesigned to a greater thickness.

Cavity #2 has received the most extensive processing which is summarized in table 2. Cavity 2 also suffered an HOM failure, however, it occurred during vertical performance testing when the leading leg of the Formteil (F-piece) in both HOM couplers fractured. This failure is discussed below. Thus far, the processing sequence is not viewed as a likely cause of the HOM failures. Additional inspections have been added between process steps to ensure that damage to the HOM F-piece was not occurring during polishing or high pressure rinsing.

Table 2: Summary of Cavity #2 Processing and Testing

Date	Process	Description
02-03-06	Receive cavity	Receive from fabrication. Preliminary RF measurement and tuning.
02-10-06	Leak Check	Leak checked to 4.9E-10 mbar l/s
03-06-06	Outside Etch #1	20 µm BCP. Only achieved 10 µm due to low acid mixing.
03-14-06	Outside Etch #2	20 µm BCP
03-17-06	Inside Etch #1	20 µm BCP
03-20-06	RF Measurement	RF measurement with light tuning.
03-22-06	Degasification Bake	800C bake with 2 hr. plateau
03-28-06	High Pressure Rinse	25 passes
04-04-06	Vertical test #1	Mechanical assembly worked well
04-19-06	Inside Etch #2	30 µm etch in one direction, followed by another etch with acid flow in opposite direction
04-28-06	Inside Etch #3	30 µm etch
05-01-06	RF measurement	Final field flatness tuning
05-03-06	Inside Etch #4	20 µm final BCP before vertical test
05-03-06	HPR	25 passes
05-22-06	HPR	25 passes
05-26-06	Vertical Test #2	
06-07-06	Vertical Test #3	Installed thermometry on HOM couplers. Camera and lights installed to view cavity external inside dewar.
06-10-06	Vertical Test #4	Installed additional thermometry on HOM coupler bodies
06-12-06	Store cavity in cleanroom	Begin HOM coupler study.

Cavity #3 final assembly at JLAB began once the issues with cavity #2 were uncovered. It is expected to be shipped to Fermilab shortly.

All of the necessary pieces for cavities 5 and 6 are at JLAB and will be assembled when requested. Dumbbells for cavities 7 and 8, to be built at Fermilab, are also complete except for trimming

Input Couplers

As of June 2006, six couplers have been received from the vendor. Inspection and final assembly is now in progress. Coupler conditioning will be carried out at the A0 SCRF facility at Fermilab where the necessary infrastructure improvements and test stand construction is in progress. Automated controls software is in the testing stages. The test stand is expected to be ready to receive couplers in September 2006. Coupler conditioning should begin shortly thereafter.

HOM Coupler Feedthroughs

Two designs based on DESY and JLAB experience are being developed for the HOM coupler feedthoughs.

The first is based on a high alumina ceramic insulator. Procurement from an outside vendor is in progress. Four of sixteen have been received and tested to date. RF and vacuum qualifications have been made on three. The bulk of the order is expected within one month.

The other design employing a sapphire insulator has been completed and reviewed. Sample pieces will be fabricated in the near future.

CAVITY COLD TESTING

Cavity #2 has been subjected to a series of four vertical performance tests with superfluid helium. Full details on cold testing performance are provided in a separate paper at this conference [3].

While the cavity remained vacuum tight between each test, additional instrumentation was added to the dewar based on information gleaned or the desire for further information. Thermometry was placed on the cavity for all tests, but the majority was moved to the ends and HOM coupler bodies following the third test. Thermometry was originally designed to be read back at a

1 Hz rate, too slow for some observed phenomena, so 10 kHz electronics was added for test #4. The vertical dewar is outfitted with a viewing port through which video images of the exterior of the cavity under test can be captured. This involved the installation of localized high intensity lighting.

HOM COUPLER FINDINGS

Following its fourth cold test, cavity #2 was opened for visual inspection in an attempt to find indications of multipacting. It was found that one leg of the F-piece antenna had been fractured through. Inspection of the other end of the cavity revealed a fracture though not as severe.

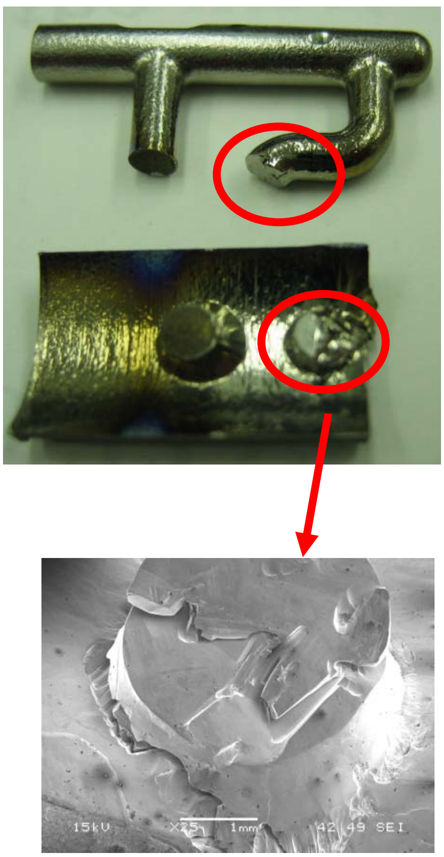

Figure 1: Fractured F-piece removed from Cavity 2 and SEM image of same. The break occurred on the right leg.

Physical analysis of the failure is being carried out both under Fermilab auspices and at DESY. One of the broken F-pieces and a sample have been sent to DESY and are await testing at a nearby analysis laboratory. SEM analysis has already been done at Fermilab, which also shows cracking at the base of the weld, as seen in the lower image of figure 1.

Recent analysis, though not fully conclusive, indicates that the failures are likely due to high stresses induced by overheating of the F-piece when power is applied, with multipacting being a possible cause. Finite element analysis (FEA) of the F-piece indicates maximum thermal stresses at the exact same location where the fracture occurred. The fact that the maximum stresses always occur at this same location for different heating scenarios indicates that this 'weak spot' is a characteristic of this particular geometry. Future FEA work includes simulating the e-beam weld on the F-piece/HOM assembly to evaluate residual stresses during cooldown. This might help explain recently-discovered cracking at the base of the weld.

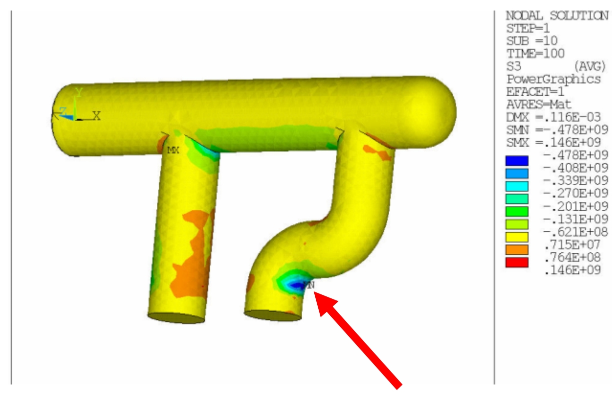

Figure 2: FEA stress analysis of fractured F-piece. The highlighted area indicates high compressive stress at the bend where the break occurred.

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