COMMISSIONING AND EARLY OPERATING EXPERIENCE OF THE FLASH THIRD HARMONIC RF SYSTEM*

E. Harms#, FNAL, Batavia, IL 60510, U.S.A., H. Edwards, DESY, Hamburg, Germany & FNAL, Batavia, IL 60510, U.S.A., M. Hüning, E. Vogel, Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany

Abstract

A Third Hamonic/3.9 GHz superconducting RF module was recently installed in the FLASH facility at DESY. Ultra short bunches with high peak current are required to efficiently create high brilliance coherent light and these can be produced by means of a 2-stage transverse magnetic chicane bunch compression scheme coupled with off-crest acceleration. The long bunch tails and reduced peak current which result from the nonlinearities of the RF sine wave can be eliminated by the addition of a 3rd harmonic RF system. Such a system can also allow for the creation of uniform intensity bunches of adjustable length necessary for seeded operation. We present here a summary of commissioning and early operating experience of the newly-installed device.

INTRODUCTION

Bunch compression can be improved thus leading to enhanced performance of Free Electron Lasers (FEL) with the addition of higher harmonic RF systems which can provide phase space linearization. This has been realized at the DESY Free Electron Laser, FLASH, with the addition of a Third Harmonic module, ACC39. The addition of this module was a cooperative venture between DESY and Fermilab. While Fermilab designed and built the four-cavity module, DESY has provided the support systems – RF, controls, vacuum, interlocks. Table 1 lists the main design 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 X 10^6
BBU Limit for HOM, Q	<1 X 10^5
Total Energy	20 MeV
Beam Current	9 mA
Forward Power, per cavity	9 kW
Coupler Power, per coupler	45 kW*

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

The motivation for, design, fabrication, challenges, and testing of the cavities and module is well-documented [1-12].

In comparing cold tests performed at Fermilab and DESY on individual cavities, it can be seen that the results are well above design and compare favorably as seen in Figure 1. At Fermilab vertical test were performed on bare cavities while horizontal tests were carried out on 'dressed' cavities. At DESY tests of the module at the Cryo Module Test Bench (CMTB) were conducted both on the individual cavities within the module as well as as a system.

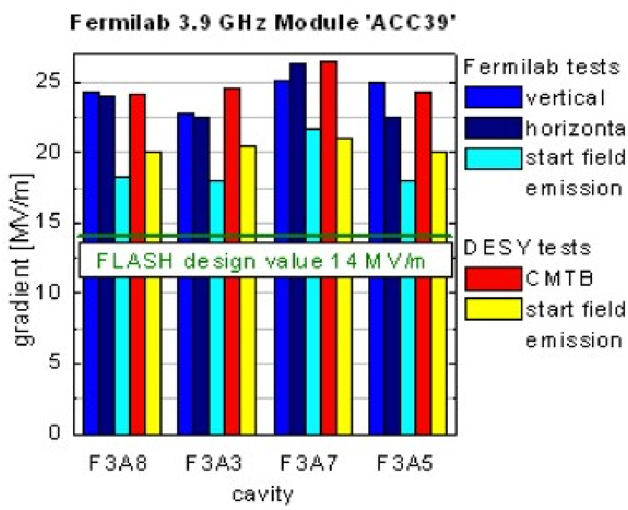

Figure 1: Cavity quench limits and onset of field emission as measured at Fermilab test stands and DESY CMTB.

HISTORY

It has taken roughly ten years to move from concept [13, 14] to reality. Table 2 summarizes the notable milestones over this period.

Table 2: ACC39 Historical Development

Date	Achievement
2002	TESLA Facility Phase 2 Report with 3.9 GHz module for bunch compression (TESLA-FEL 2002-01)
March 2002	Cavity design documents (TESLA-FEL 2002-05, 2003-01/FNAL TM 2210)
2005	DESY-FNAL MOU on 3.9 module
March – June 2006	F3A1, F3A2 failures: Multipacting & HOM wall thickness
August 2006	F3A3 fabrication finished, first usable cavity
May 2007	F3A3 good vertical test after HOM

	formteils cut, 24MV/m
October 2007	F3A5 vertical tests with HOM feed-throughs complete, 19MV/m
Feb – Sept 2008	F3A5 in horizontal test stand (HTS)
April 2008	F3A5 achieved 22.5MV/m in HTS
December 2008	F3A7 last cavity of four removed from HTS
Jan 2009	String assembled in MP9 Clean Room
February 2009	Cold mass transported to Industrial Center Building
April 2009	Module finished and shipped to DESY
Sept 2009	ACC39 installed in CMTB
Nov 2009	Testing at CMTB completed
Jan 2010	Installation in FLASH complete
March 2010	Cool down to 2K
April 2010	First powered operation with beam
May 2010	Demonstration of phase space linearization
June 2010	4.5 nm lasing demonstrated

PERFORMANCE IN FLASH

In calendar year 2010 ACC39 was installed in FLASH together with the supporting infrastructure and has become operational in FLASH. At this early stage it has provided the expected performance enhancement as described elsewhere at this conference [15]. In figure 2 one can see a comparison of the phase space distribution with ACC39 on and off and the clear demonstration of linearization with the module. The module has been in routine operation at FLASH during the recent beam commissioning period. Qualitatively, SASE operation appears more stable and easier to achieve [16].

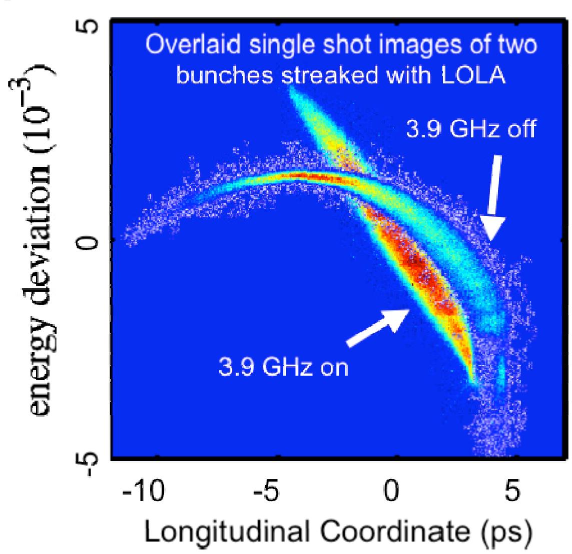

Figure 2: Comparison of longitudinal distribution in FLASH with/without ACC39 on.

RECENT CAVITY DEVELOPMENTS

The MOU between DESY and Fermilab for the 3rd harmonic module stipulated that spare cavities would be provided. In fact, nine cavities have now been fabricated four of which are contained within the module. Cavities one and two are prototypes and failed prior to testing – HOM membrane compromise and Formteil cracking were the respective culprits. Both cavities F3A4 and F3A6 reached gradients in excess of 20 MV/m early in vertical testing but suffered significant performance degradation with a signature of mulitpacting in the HOM's accompanied by indication of excessive heating during quasi-cw operation during vertical tests. The Formteil pieces within the Higher Order Mode (HOM) couplers for both are of the original 2-post design albeit trimmed following findings in early tests that the original design required modification [17]. Various attempts at BCP and cleaning were unsuccessful as were investigations by optical and mechanical vibration means.

It was possible to finally confirm fractured Formteils in the HOM's as the source of this degradation by means of 3-D X-ray computed tomography. Cavities were subjected to X-ray scans at NorthStar Imaging, Inc. [18] where off-line analysis software allows a high resolution re-created image of the suspected regions to be made. Figure 3 shows such an image with a fracture clearly visible. Both cavities show such damage. Figure 4 shows a 3.9 GHz cavity undergoing a scan at the NorthStar facility in Roger, MN USA. The cavities were tested in a commercially available unit providing X-ray's of up to 225 kV. Resolutions as fine as 10's of microns are possible. This potentially powerful imaging technique is now being investigated for inspection of other suspected faults, such as weld regions, where conventional means of inspection are difficult if not impossible.

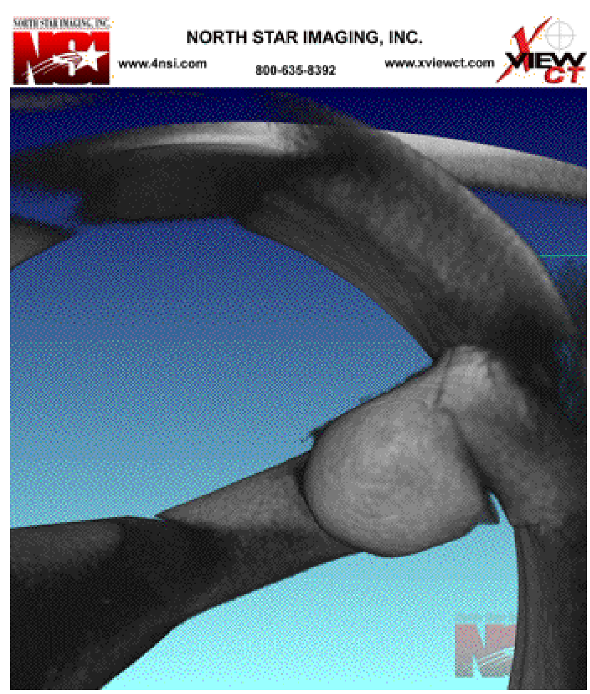

Figure 3: Fractured Formteil on Cavity F3A6 as determined using 3-D, X-ray computed tomography.

A scheme is being developed to remove the ends of these damaged cavities and replace the last end cells and groups with new ones containing single post Formteils. In addition, a completely new cavity of modern design designated as F3A9 has been fabricated and will shortly undergo the standard suite of BCP processing and testing.

Figure 4: 3.9 GHz cavity undergoing X-ray scanning at NorthStar Imaging, Inc.

SUMMARY

The Third Harmonic RF system designated for FLASH is now operational, largely integrated, and has demonstrated its impact on FLASH performance. Meanwhile, work is in progress to complete the spare cavities at Fermilab.

ACKNOWLEDGEMENTS

The authors acknowledge the significant contributions from numerous colleagues at DESY and Fermilab to see this effort through to completion. Many people at Jefferson Lab have contributed to this effort as well. Advice from colleagues at Argonne National Laboratory, Cornell, and INFN, Milano has also proven to be invaluable.

REFERENCES

[1] M. Champion, et al, "Superconducting RF Cryomodule Production and Testing at Fermilab", this conference, TUP081.

[2] E. Vogel, et al, "Test and Commissioning of the Third Harmonic RF System for FLASH," IPAC'10, Kyoto, Japan, THPD003.

[3] E. Harms, et al, "Third Harmonic System at Fermilab/FLASH," SRF2009, Berlin, Germany, MOOBAU01.

[4] T. Khabiboulline, et al, "Vertical and Horizontal Test Results of 3.9 GHz Accelerating Cavities at FNAL," Applied Superconductivity Conference 2008, Chicago, August 2008, 2LPC07.

[5] E. Harms, et al, "Performance of 3.9 GHz Superconducting Cavities," this conference, THP029.

[6] E. Harms, et al, "Status of 3.9-GHz Superconducting RF Cavity Technology at Fermilab," LINAC 2006, Knoxville, TN, August 2006,THP051, p. 695 (2006); http://www.JACoW.org.

[7] M. Foley, et al, "Welding Helium Vessels to the 3.9 GHz Superconducting Third Harmonic Cavities," this conference, THP027.

[8] E. Harms and A. Hocker, "Performance of 3.9 GHz SRF Cavities at Fermilab's ILCTA_MDB Horizontal Test Stand," Applied Superconductivity Conference 2008, Chicago, August 2008, 2LX08.

[9] V. Bocean and M. McGee, "Referencing and Stability Studies of the Fermilab 3.9 GHz (3rd Harmonic) Cryomodule for DESY TTF/FLASH," The 10th International Workshop on Accelerator Alignment, Tsukuba, Feb. 2008, FR004.

[10] Li, et al, " RF Design and Processing of a Power Coupler for Third Harmonic Superconducting Cavities," Proceedings of PAC07, Albuquerque, WEPMN100, p. 2265; http://JACoW.org.

[11] E. Harms, et al, "Performance of 3.9 GHz Superconducting Cavities," Linac 2008, Victoria, September, THP029.

[12] McGee, et al, "Transatlantic Transport of Fermilab 3.9 GHz Cryomodule to DESY," PAC '09, Vancouver, May 2009, TU6RFP052.

[13] M. Ferrario, et al, "Conceptual design Report of the XFEL Photoinjector", February 20, 2001 TESLA-FEL 2001-03.

[14] The TESLA Test Facility FEL Team, "SASE at the TESLA Facility, Phase2," June 2002 TESLA-FEL 2002-01.

[15] H. Edwards, "3.9 GHz Cavity Module for Linear Bunch Compression at DESY FLASH," this conference, MO304.

[16] S. Schreiber et al, Proc. FEL2010, Malmö, Sweden, August 2010, TUOB12.

[17] T. Khabiboulline et al, "New HOM Coupler Design for 3.9 GHz Superconducting Cavities at FNAL," PAC '07, WEPMN098.

[18] NorthStar Imaging, Inc., Rogers, MN, U.S.A, www.4nsi.com