OPERATING EXPERIENCE WITH CC2 AT FERMILAB'S SRF BEAM TEST FACILITY*

E. Harms#, J. Branlard, G. Cancelo, K. Carlson, B. Chase, E. Cullerton, A. Hocker, P. Joireman, T. Kubicki, J. Leibfritz, A. Martinez, M. McGee, Y. Pischalnikov, J. Reid, W. Schappert, K. Treptow, V. Tuikov, P. Varghese, T. Zmuda, FNAL, Batavia, IL 60510, U.S.A.

Abstract

Capture Cavity II (CC2) is the first operational component at the SRF Beam Test Facility now under construction at Fermilab. This 9-cell 1.3 GHz cavity, previously operated in another venue on the Fermilab site, was transported to this facility in early 2009. We will summarize its transport and operation in its new (permanent) home compared to previous performance and also present results of studies, particularly Low Level RF, microphonics/vibration, and Lorentz force de-tuning compensation that have been recently carried out with it.

INTRODUCTION

Capture Cavity II was originally sited at Fermilab in the Meson Detector Building. Its performance there has been documented previously [1].

Although the long-term for CC2 was to relocate it to the New Muon Laboratory as part of the front end of the SRF Test Beam facility now under construction, it was moved at this time to facilitate commissioning of the NML cryogenic plant with a known heat load. A summary of activities with CC2 from warm up at MDB to the present can be found in Table 1.

Table 1: Recent History of CC2 at Fermilab

Date	Activity
16 – 27 Feb 2009	Warm-up and preparation for transport to NML
2 March 2009	Transport to NML
June - July 2009	Warm Coupler conditioning
October 2009	Refrigerator commissioning
13 Oct 2009	Cooldown to 2K
July - Dec 2009	Cold Re-commissioning
30 Dec – 15 Jan 2010	300 kW klystron installation and commissioning
16 Jan – 16 Feb 2010	Operation at 2K, gradient limit = 24.5 MV/m
2 March – 3 June 2010	Operation at 4.5 K
June 2010 - present	No operation; at room temperature for NML expansion

CAVITY TRANSPORT AND INSTALLATION AT NEW MUON LAB

Over a span of approximately two weeks CC2 was warmed up, all external connections – RF, vacuum, cryo, controls, instrumentation removed, and the module prepared for its relocation.

Transport

The cryomodule transport design acceleration criteria were initially established by considering the previous SNS experience [2] and transport analysis completed by Babcock Noell [3]. During the Fermilab transport studies in 2007 and 2008 [4], an acceleration limit criteria for testing was established as 1.5 g (vertical), 5 g (transverse) and 1.5 g (longitudinal).

Six (6) inertial velocity sensors; Geospace HS-1 geophone [5] devices were attached to the outer vacuum shell and lower base frame. All geophones were connected to six National Instruments (NI) NI-9233 4-channel, 24-bit ADC modules sampled at 5K/s, and the data was recorded. Two SENSR GP1 Programmable Accelerometer devices [6] found directly above beam line level and at the base were used in DAQ mode to record acceleration with an epoch of 1 sec.

On March 2nd, 2009 CC2 was transported 3 km at an average speed of 3.9 km/hr from the Meson Detector Building to NML. The transport duration was 2 hours, 46 minutes and 45 seconds from loading onto the truck at MDB to unloading at the New Muon Lab.

Table 2: Summary of Maximum Acceleration

Device	Vertical Acceleration		Transverse Acceleration		Longitudinal Acceleration	
	Geo (g)	GP1 (g)	Geo (g)	GP1 (g)	Geo (g)	GP1 (g)
Shell	0.18	0.16*	0.16	0.17	0.15	0.09
Base	0.31	0.26*	0.26	0.20	0.09	0.10

* Data without inertial offset

Acceleration Response

Table 2 provides a summary of maximum vertical (y), transverse (x) and longitudinal (z) accelerations experienced during transport. The maximum responses occurred when passing over a depression in the road en route to the New Muon Lab. These values were well beneath the established acceleration criteria.

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harms@fnal.gov.

Re-commissioning

After a period of assembly in its new location CC2 was used as a test load for bringing the new cryogenic plant for NML into operation. This effort lasted approximately three months after which a standard suite of steps were undertaken to bring CC2 back into cold operation. These steps included:

- Warm (off-resonance) coupler conditioning
- Cooldown
- Adjustment of the coupler penetration for optimum Q
- Frequency adjustment with slow tuner
- Cold (on-resonance) coupler conditioning
- Determination of maximum gradient/quench limit.

An upper operating gradient of ~24 MV/m at 2K was achieved consistent with previous performance at MDB. This was with a 1.3 ms pulse length at a 5 Hz repetition rate. Photomultiplier Tube response on the coupler and attendant vacuum activity were the limiting factors. An upper quench limit has yet to be determined since its relocation.

Once performance was verified at 2K a series of studies were initiated as described below. 2K operation was cut short by construction activities which allowed only 4.5K operation.

LOW LEVEL RF STUDIES

System Overview

For the most part, the studies carried with Capture Cavity 2 had operating conditions of 1.3 ms pulse length at a gradient E_{acc}=25 MV/m. The cavity was cooled down to 4.5K and the loaded Q was measured to be Q_L=2.7x10^6. Two separate LLRF controllers were running in parallel (ESECON and MFC [7]), cross-checking measurements and operations. The LLRF system uses an 8 channel down converter, 1 channel up converter [8]. The 1300 MHz RF reference, cavity probe, forward and reflected power signals are down converted and then digitized by the controller. The LLRF controller uses feed forward and proportional and integral feedback gain to regulate the cavity gradient. A beam compensation feature was added to create an external perturbation and assess the performance of the controller. The digital IF signals (reference, cavity probe, forward power and reflected power) are sent to the cavity resonance system allowing for piezo control of the cavity resonance frequency.

ESE LLRF Controller

The cavity was first controlled only regulating the RF fields. For this purpose the ESECON controller [9] was operated with a fixed feed forward plus combined proportional-integral (PI) feedback control. The best regulation was achieved operating in closed loop with proportional gain K_p = 100 and integral gain K_i = 6.2x10^6.

During the first few tens of microseconds, a small overshoot or undershoot is observed as a consequence of the very large cavity detuning. The integral function of the PI controller causes these fluctuations to dampen out to values of 10^{-4} RMS in amplitude and 0.01 degrees RMS in phase after the first 20 to 30 microseconds of the flattop.

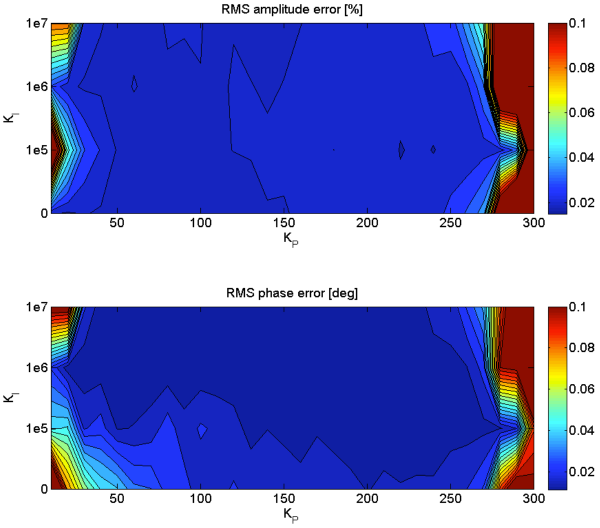

Figure 1: Controller stability region as a function of K_p and K_i for amplitude and phase regulation.

The second part of the studies added active piezoelectric tuner compensation together with the RF control. The piezoelectric tuner is used to track and compensate low frequency fluctuations of pulse to pulse detuning. During this experiment the Lorentz force detuning was not compensated. The RF regulation with PI control and the piezoelectric tuner compensation turned on is shown in the figures below. The piezoelectric tuner compensation managed to lower the low frequency detuning fluctuations bringing the noise down to 50Hz RMS. As a consequence the RF regulation is also improved by about an order of magnitude.

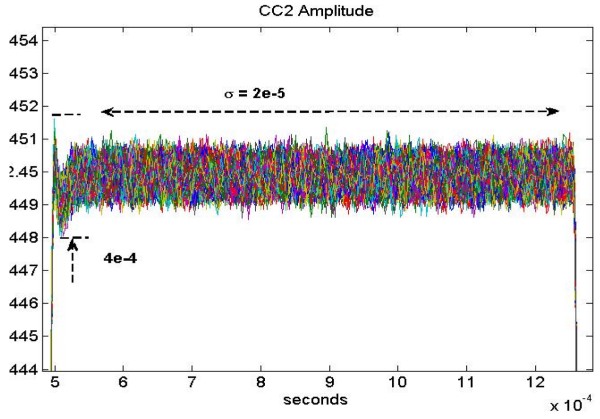

Figure 2: CC2 Amplitude stability with RF & Piezo Control.

At the beginning of the flattop, the peak-to-peak overshoot is 4 x 10^{-4} in amplitude and 0.04 degrees in phase. Compared to the preceding results, this overshoot is 10 to 15 times smaller than it is when piezoelectric compensation is turned off. The regulation for the remainder of the flattop is better than 2 x 10^{-5} in amplitude and 0.001 degrees in phase respectively. These studies demonstrate that excellent field regulation can be achieved when RF and resonance (piezoelectric) control work together. It is worth mentioning that the RF gradient plots represent regulation error plots and not the actual cavity gradients, which are not directly accessible.

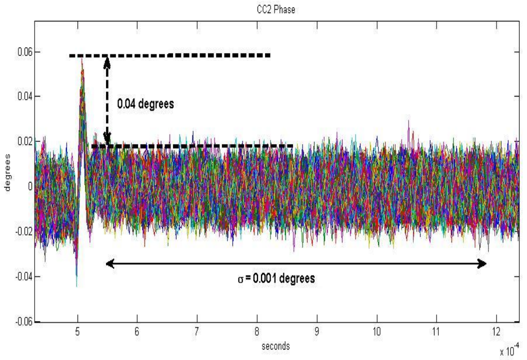

Figure 3: CC2 Phase stability with RF & Piezo control.

PRESSURE COMPENSATION STUDIES

Attempts have been made to stabilize the pressure-induced variations in the resonance frequency of CCII using the fast tuner. LLRF study data shows that the piezo was able to reduce the variations of the cavity resonance frequency several hundred Hz sigma to about 50 Hz sigma. The fast tuner system was kept running with the cavity at low gradient (4 MV/m) for about 28 hours.

During this period the fast tuner system was able successfully lock the resonance frequency to the RF frequency except for one period when the pressure fluctuations were as large as 100 Torr peak-to-peak, which caused the cavity to detune more than the range of the fast tuner leading to a loss of frequency lock.

The following conclusions can be made, supported by data shown in Figures 4 and 5:

- dF/dP of CCII is 43 Hz/torr. This is close the value of 55 Hz/Torr measured at HoBiCaT for Tesla style elliptical cavities – the discrepancy might be due to differences in the mechanical stiffness.
- During periods of stable operation the fast tuner was able to lock the cavity resonance frequency to within 16 Hz (sigma) of the RF frequency.
- The peak detuning of the cavity was as high as 120 Hz or 7.5 sigma.

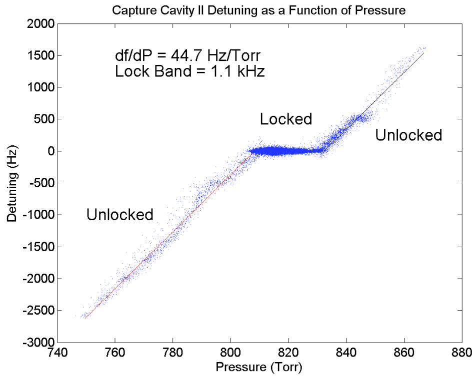

Figure 4: Cavity de-tuning as a function of pressure.

The smaller value for the variance of the cavity resonance frequency, 16 Hz, as compared to that obtained during ESECON LLRF studies, 50 Hz, might be due to the differences in the operating conditions, differences in the way the detuning is determined, or some combination of the two. More investigation is needed.

While this data illustrates that it is possible to actively control detuning due to pressure, it also illustrates that there are limits to the ability to compensate and that it is critical to minimize the detuning at the source by minimizing both variations in the pressure and the dF/dP of the cavities.

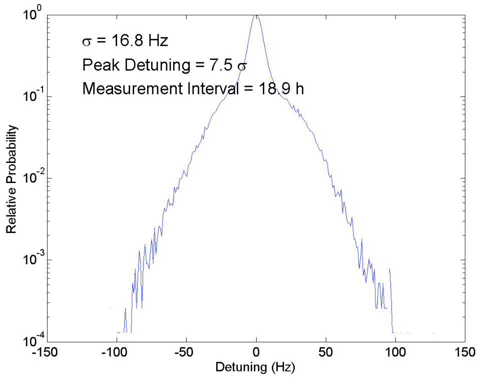

Figure 5: De-tuning probability.

SUMMARY

Capture Cavity 2 has been relocated at Fermilab to the SRF Beam Test Facility and has resumed operation. Limited LLRF and compensation studies have been carried out. In the near future Lorentz Force de-tuning compensation and microphonics will be conducted.

REFERENCES

[1] T. Koeth, et al, “Experience with Capture Cavity II,” PAC07, Albuquerque, USA, WEPMN094.

[2] T. Whitlatch et al., “Shipping and Alignment for the SNS Cryomodule,” PAC’01, .

[3] G. Sikler, “Transport of Cryomodules,” Babcock Noell, Wurzburg Germany, DESY EV 010-94-S1 Draft version, p. 48 (September 2007).

[4] M.W. McGee, V. Bocean, C. Grimm and W. Schappert, “Transatlantic Transport of Fermilab 3.9 GHz Cryomodule for TTF/FLASH to DESY,” EPAC’08, MOPP022.

[5] http://www.geospace.com

[6] http://www.sensr.com

[7] P. Varghese, et al, “Multichannel Vector Field Control Module for LLRF Control of Superconducting Cavities”, PAC07, Albuquerque, USA, WEPMN112.

[8] U. Mavrič, et al, “A 96 channel receiver for the ILCTA LLRF system at Fermilab,” PAC07, Albuquerque, USA, WEPMN102.

[9] G. Cancelo, et al, “ESECON, 14-channel LLRF Controller,” LLRF 2007, Knoxville, USA.