CAPTURE CAVITY II AT FERMILAB*

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Abstract

Capture Cavity II (CCII) is a high gradient TESLA style cavity intended to upgrade the photoinjector to 40MeV. The cavity, provided by DESY, was tested in the TTF horizontal test cryostat Chechia. CCII was prepared for shipment to the United States. Upon arrival at FNAL vacuum certification, cryovessel installation, input coupler conditioning, and high power RF testing has provided FNAL facilities and personnel the opportunity to gain experience in SCRF. Capture Cavity II has also proved to be an opportune facility for testing various sub-systems related to SCRF cavity research.

INTRODUCTION

The FNPL Photoinjector is composed of a high brightness 3.5MeV RF gun followed by a TESLA Type I superconducting cavity which operates at 12MV/m – it is named Capture Cavity I[1]. The photoinjector supports an advanced accelerator R&D program as well as an injector for the Module Test Facility at Fermilab. There has been a strong collaborative effort between DESY, FNAL, Saclay, and Orsay to make this effort possible.

DESY & FNAL PREPARATION

Preparing & Testing CCII at DESY

Capture Cavity II, fully dressed with magnetic shielding and cold tuner assemblies, went through the standard DESY regiment of horizontal testing. The input coupler required approximately one week of conditioning. Once the input coupler was processed the cavity was tested for peak gradient performance, which was measured to be 33MV/m. X-ray radiation dose rate was measured to be 2 rads/min at peak operating gradient.

After the horizontal test, CCII was moved into the DESY TTF class 10 clean room where FNAL supplied warm to cold beam tubes were connected and leak checked. Each warm to cold transition possessed an all metal VAT gate valve positioned as near the cavity as possible. A final integral leak check was completed on the assembly to an ultimate pressure better than 1E-9 Torr and the VAT all-metal valves were sealed. Two right-angle all-metal valves sealed the volume between the VAT valves and the flanges on the warm to cold transitions.

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Shipment to FNAL

The dressed cavity was shipped from DESY to Fermilab using an aluminum shipping fixture which was connected to a welded carbon steel tube frame and housed in a large wooden shipping crate. Four equally spaced helical 16 mm diameter stainless steel cables constrained by clamping pads, existed between the shipping fixture and steel frame. The helical cables provided both spring and damping in the longitudinal and both transverse directions. A ShockLog (model RD298) device was attached to the shipping fixture and activated[2]. This device recorded the acceleration in x, y and z with a 10 sec frequency and had a warning and alarm threshold (a sensor wake-up limit) set at 1g and 3g, respectively. Over-the-road and air travel legs of the shipment revealed little or no response with the single exception of a 3g vertical acceleration during forklift handling.

Vacuum Verification and Preparation at FNAL

The first task upon CCII's arrival at FNAL was to verify the integrity of the three vacuum volumes. Verification was confirmed in the A0 Class 10 clean room, both the up-stream and down-stream warm to cold transitions were found to have pressures 1E-4 Torr. The cavity volume was found to have a pressure better than 4E-6 Torr. At time of the verification process, the three volumes had not been pumped on for over three weeks.

INFRASTRUCTURE

High Level RF System

High Level RF power is provided by a Valvo-Philips YK-1240 1.3GHz Klystron, capable of producing 300kW for 1.5 msec. Before installing a rebuilt klystron in June 2006, power was limited to approximately 100kW for initial RF operations.

The high voltage pulse to the klystron's cathode is regulated through a series tube tetrode modulator fed by a raw charging supply and 40kJ capacipt bank. The high voltage system is capable of supporting 1.4msec pulse at a 5 Hz rate. The modulator interlock system provides fast Klystron gun spark detection and crowbars through an Ignitron.

Cryogenic System

An ambient temperature pumping cycle was chosen to provide super-fluid helium for the CCII. Liquid nitrogen and liquid helium are supplied to the Meson Detector Building (MDB) through vacuum insulated transfer lines from the Cryogenic Test Facility (CTF). CTF is located about 500m southwest of MDB and was formerly known as Meson Central Cryogenics.

The refrigeration system is comprised of three Tevatron Satellite style refrigerators operating in parallel. Each refrigerator is capable of providing 625 W of refrigeration at 4.5 K when operated in refrigerator mode and approximately 4 g/s of 4.5 K liquid helium in a liquefier mode. To achieve superfluid for CCII, a modified liquid ring and roots blower vacuum pump system is used. The skid has a capacity of approximately 10 g/sec of helium at 1600 Pa inlet pressure, which corresponds to 1.8K saturation temperature.

The vacuum pump skid was originally designed and fabricated at Thomas Jefferson National Accelerator Facility in 1993, and has since been refurbished and altered for continuous helium service at Fermilab. The most significant modifications include controls and instrumentation upgrade, variable speed drive for the blower, and the addition of dual helium guarded dynamic shaft seals for both pumps.

RF OPERATION

Input Coupler Processing

Although the input coupler, a TESLA type III waveguide to coaxial transition, supplied with CCII was used during the original high power horizontal test, exposure during disassembly, shipping, and reassembly prescribed re-processing. After installation, the input coupler displayed electron emission phenomena, a significant portion of which was identified as multipacting (MP). The MP displayed dependency on RF power level as well as the voltage from a DC bias placed on the coaxial center conductor. Caution and education dictated a fully manual processing program. A retrofitted interlock system monitoring electron emission, breakdown light, temperatures, and vacuum provided the necessary fast RF inhibits during processing. Initially short, 20usec, RF pulses off cavity resonance were administered at a 1 Hz repetition rate. The power level was increased at the rate of 1000W/min until maximum power was achieved, then a dwell period of 1 hour was maintained before proceeding to a longer pulse width. This continued until a pulse length of 1.4 msec at full RF power could be sustained without MP. Processing began with the onset of MP, at which time the RF was power metered by a variable inhibit delay such that no more than 1 Joule could be delivered to the MP event. Repetitive RF power pulses narrowed the power regions where MP could be sustained. Persistent RF conditioning greatly reduced the MP but did not completely mitigate it. The operators identified that a center conductor DC bias of +1500 VDC permitted RF operation of the complete power span up to 225kW with an infinite VSWR without MP. Interestingly, a four week maintenance period, including a thermal cycle yielded slight relaxation of the MP onset boundaries. Figure 1 shows the CCII multipacting map post processing. The solid black regions are MP free.

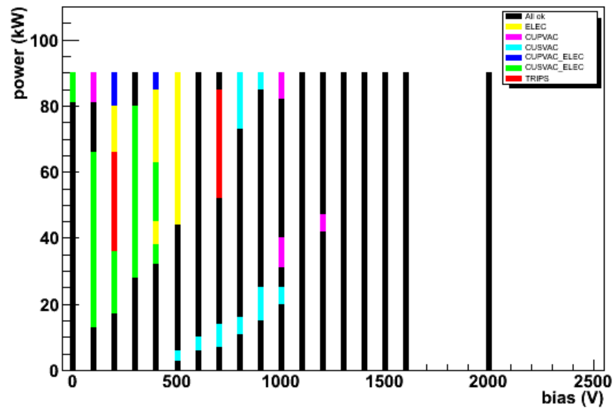

Figure 1: Multipacting map post processing.

Cold Piezo Tuner Test

CCII was fitted with a modified piezo tuner assembly with instrumentation that provided piezo preload force changes during cooldown and stepping motor operation. The instrumentation consists of calibrated strain gauges mounted on a stainless steel section between the piezo and its holding frame. 4.5K static piezo measurements showed a tuning range of approximately 1.3 KHz.

As will be discussed, operating the piezo as a sensor, good correlation between the RF measurements and piezo microphonics measurements was seen at both 4.5K and 1.8K.

4.5K RF Operation

Early RF testing was performed at 4.5K while the equipment for 1.8K operation was readied for service. Utilizing full available power the gradient was allowed to grow exponentially until quenching was noted. Quenching was observed at 27.6MV/m. The DESY SimCon3.1 Low Level RF (LLRF) control system was employed to operate the RF system in closed loop[3]. Operating with the liquid helium bath at atmospheric pressure was significantly unstable. Still limited in RF power the maximum flat top gradient achieved with CCII at 4.5K was 15MV/m in a 1.4 msec RF pulse.

1.8K RF Operation

The first goal was to reach a peak gradient in CCII at 1.8K using the LLRF system. This was readily achieved, with a peak gradient of 31.3 MV/m obtained by applying a feed forward step function of 1300 µs. No flat top was maintained during this measurement.

The next objective was to maintain the same high gradient for a flat top duration around 600 µs. The RF pulse is 1300 µs long, which corresponds to a 700 µs filling time followed by a 600 µs flat top. Reaching the peak gradient of 31.3 MV/m with a shorter filling time revealed to be difficult due to the loaded Q of the cavity. The highest gradient obtained for a flat top of 600 µs is approximately 27 MV/m. The amplitude of this measurement is plotted in Figure 2, where the cavity probe and set point are indicated in black and blue respectively.

Part of the difficulty in reaching a high gradient comes from large pulse to pulse amplitude and phase fluctuations. While the cavity forward power is constant from one pulse to another, we observed large fluctuations in the reflected and transmitted power, corresponding to variations in the cavity resonance frequency. Without feedback, the cavity's fluctuations correspond to detuning of approximately ±55Hz (±2 MV/m)

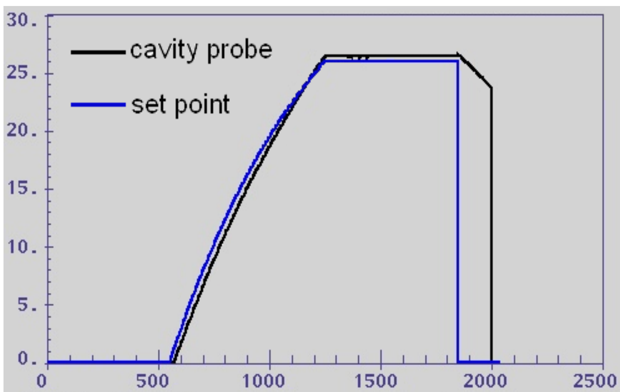

Figure 2: Amplitude plot obtained for a 600 µs flat top at 27 MV/m.

To better understand the origin of these fluctuations, the mechanical behavior of the cavity has been analyzed using the piezo tuner as a sensor (for longitudinal displacement), combined with readings from two accelerometers placed inside and outside the cryomodule (for vertical vibrations). This combined analysis evidenced several mechanical resonant frequencies out of which 18 Hz and 180 Hz stand out as the most significant. These two resonant frequencies are observed with and without RF power driving the cavity. However, when the RF is off, the 18 Hz component clearly dominates the other frequencies by one order of magnitude, as measured by the piezo sensor. We were able to excite the 18 Hz component by tapping on the cryomodule, which resulted in a jump in amplitude by two orders of magnitude. This component is clearly a natural resonant frequency of the system and can easily be excited by broadband noise.

When RF power is being pulsed, 180 Hz becomes the dominant resonance frequency, closely tailed by 18 Hz in amplitude. This is illustrated in figure 3, which shows the FFT of the signal detected by the piezo when RF is on. This measurement was obtained with an accelerating gradient of 20 MV/m.

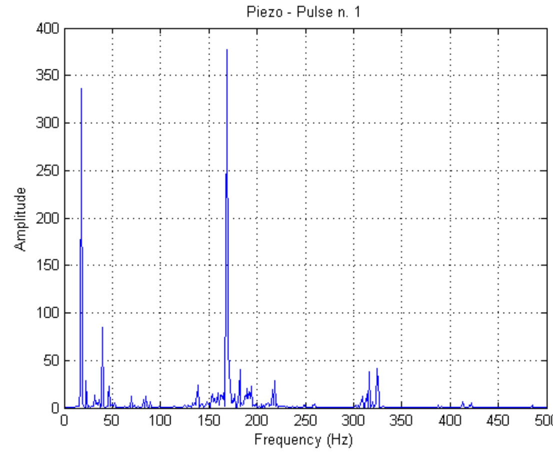

Figure 3: Background spectrum measurement with piezo.

A mechanical model of the cavity and its surroundings was also developed using ANSYS. A stress simulation of the system was performed and confirmed the existence of theses two natural resonant frequencies [4].

Understanding the mechanical modes of the cavity is a crucial step as the large amplitude and phase fluctuations from one RF pulse to another stand in the way of driving the cavity at a high and stable gradient. Further investigation of the cavity's mechanical vibrations will be possible by driving the cavity in continuous wave (CW) mode. Finally, the external Q of the cavity was found to be around 4.28E6. This value is higher than what is anticipated for typical ILC module operation. Increasing the coupling to the ILC value of Q_e = 2.6E6 should help reduce the sensitivity of the cavity to external excitations and will make this cavity system a closer model of an ILC cavity response.

CONCLUSIONS

The combined efforts of DESY and FNAL have successfully tested, transported, installed and operated a high gradient superconducting ILC like cavity. Significant strides have been made in operating FNAL SCRF infrastructure. It remains to test CCII with beam, which envisioned upon the photoinjector upgrade.

ACKNOWLEDGEMENTS

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