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COMMISSIONING AND EARLY OPERATING EXPERIENCE WITH THE FERMILAB HORIZONTAL TEST FACILITY*

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Abstract

Fermilab has constructed a facility for testing dressed superconducting radiofrequency (RF) cavities at 1.8 K with high-power pulsed RF. This test stand was designed to test both 9-cell 1.3 GHz TESLA-style cavities and 9-cell 3.9 GHz cavities being built by Fermilab for DESY's TTF-FLASH facility. An overview of the test stand and a description of its initial commissioning is described here.

INTRODUCTION

After acceptable performance has been achieved in vertical dewar tests, SRF cavities undergo a number of "dressing" steps in order to prepare them for installation into a cryomodule. These steps include the welding of the cavity into its own helium vessel, the installation of a high-power input coupler, and the installation of a mechanical tuner. The relatively complex nature of these steps and the cavity handling involved warrant a re-test of the cavity to ensure its performance before it is assembled into a cryomodule. At DESY this test is performed at the CHECHIA facility [1], which served as the design basis for the facility described here: the ILCTA_MDB Horizontal Test Stand, or HTS (the name's leading acronym denotes the facility's location at Fermilab — the International Linear Collider Test Area at the Meson Detector Building).

FACILITY OVERVIEW

The heart of the HTS is a single-cavity cryostat designed at Fermilab and based heavily on the CHECHIA cryostat. The cryostat is housed in a 22' by 16' cave constructed from concrete blocks that provide a six foot X-ray shielding thickness (Fig. 1). The cryostat consists of a stainless steel insulating vacuum vessel with internal 80 K and 5 K thermal shields. It has hinged doors at both ends for easy installation and removal of dressed cavities, and a number of ports for vacuum lines, instrumentation feedthroughs, and the cavity input coupler.

The cavity/cryostat is cooled by three Tevatron satellite refrigerators operating in parallel, each with a refrigeration capacity of 625 W at 4.5 K. Liquid nitrogen and helium are distributed via a feed can on top of the cryostat. The liquid filling the cavity's helium vessel is pumped down to a 1.8 K superfluid via a modified liquid ring and roots blower vacuum pump with a capacity of about 10 g/s of helium at 12 Torr.

Cavities and couplers are actively pumped during the horizontal test. A clean roughing pump/turbomolecular pump system is used for the initial pumpdown and 75 L/s ion pumps are used to maintain pressures in the low 10^{-9} Torr range.

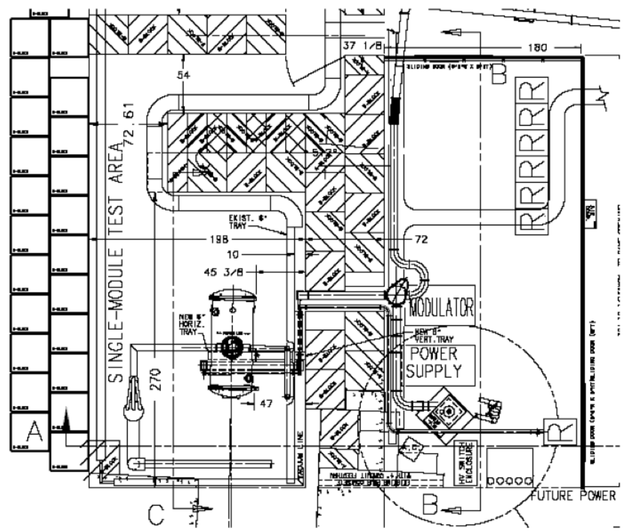

Figure 1: Layout of the ILCTA_MDB HTS

The remainder of the HTS is in a small enclosure just outside the shielding cave. The high level RF system, consisting of a 300 kW klystron, modulator, and charging supply, provides pulsed high-power RF to the cave via a waveguide that penetrates the wall between the cave and the enclosure. A low level RF (LLRF) system based on SIMCON 3.1 [2] provides control of the RF power in both feed-forward and feed-back modes. These RF systems have been operating the Capture Cavity 2 facility, located nearby, for over a year [3].

Various diagnostic instrumentation is employed to understand cavity performance. This includes ion gauges to measure cavity/coupler pressures, pickups to detect electron activity in the coupler, thermometry on the input coupler and higher-order mode (HOM) couplers, photomultiplier tubes to detect arcing in the waveguide or input coupler, Faraday cups at either end of the cavity to measure dark current, and X-ray detectors located at various locations around the cave. Many of these devices are used as inputs to a VME-based interlock system used to disable the RF power when diagnostics indicate the possibility of potentially damaging the cavity.

The instrumentation and RF signals are digitized and read out in an EPICS-based controls system for data display and archiving.

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COMMISSIONING EXPERIENCE

The HTS was commissioned using cavity C22, a 1.3 GHz 9-cell TESLA-style cavity (Fig. 2). This cavity was last tested at DESY in 1998 and performed poorly, whereupon it sat open to air for years and was mainly used for mechanical fit-ups and tests. C22 was first shipped to Thomas Jefferson National Laboratory (TJNL) for a high-pressure rinse and a vertical test, where it achieved a gradient of 17 MV/m before quenching.

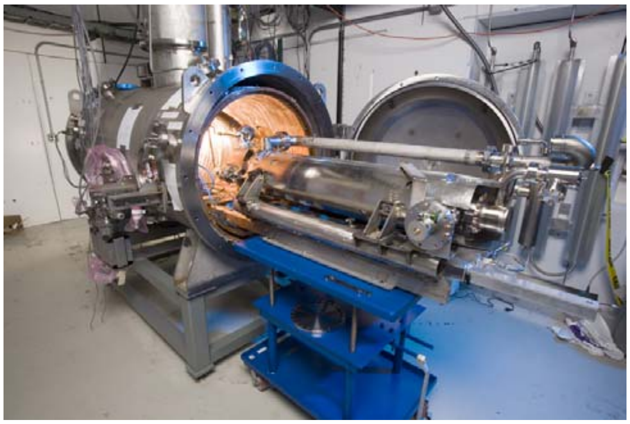

Figure 2: C22 prior to installation in the test cryostat

Room Temperature Operation

After installation of C22 into the horizontal test cryostat and completion of instrumentation check-out, the input coupler was conditioned with high-power pulsed RF. At room temperature the cavity's resonance frequency is 2 MHz less than the nominal 1300 MHz of the RF system, so all input power is reflected from the cavity, setting up a standing wave in the coupler. With a pulse length of 20 μs and a repetition rate of 1 Hz, the input power was slowly increased to its maximum (about 240 kW). When diagnostic instrumentation indicated potentially dangerous emission in the coupler, the power was decreased. The process was then repeated for longer and longer pulse lengths, up to a maximum of 1300 μs. This logic was implemented by an automated sequencing application controlling the input power via a GPIB interface to the signal generator.

After some time spent debugging the sequencer, instrumentation and controls, conditioning went very smoothly; only a small amount of emission activity was observed at the highest input powers. This is illustrated in Fig. 3.

Cooldown

Several attempts were made to cool down C22, only to be foiled when leaks were detected upon the introduction of helium into the cavity cooling circuit. These leaks were traced to improperly made seals and a faulty cold electrical feedthrough. These leak sources were repaired and C22 was then successfully cooled to 1.8 K.

One discovery upon cooldown was that the cryostat 5 K shield never reached 5 K. This is under investigation; possible explanations are a heat leak from the 80 K shield or heat exchange between the 5 K shield cooling line supply and return. The warm 5 K shield results in an unexpectedly large static heat load of around 10-15 W, however this has not resulted in any major operational difficulties.

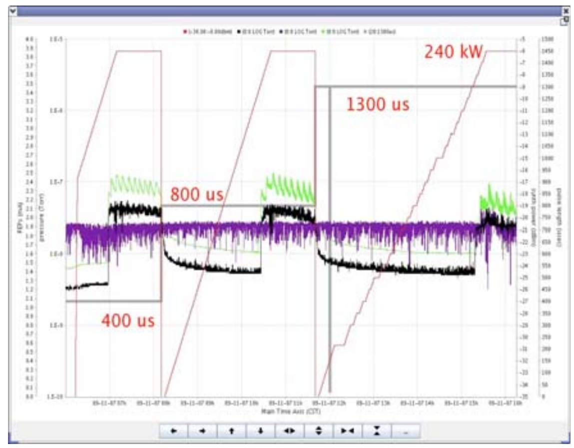

Figure 3: Several hours' worth of coupler conditioning. The black, green, and purple traces show cavity/coupler pressure; the thin red trace shows output from the signal generator.

1.8 K Operation

After cooldown, C22's resonanace frequency was about 126 kHz above the nominal 1.3 GHz. C22 was outfitted with a Saclay-type lever-arm tuner operated by a stepping motor. About 450,000 steps of the motor were needed to tune the cavity resonance to 1.3 GHz (Fig. 4).

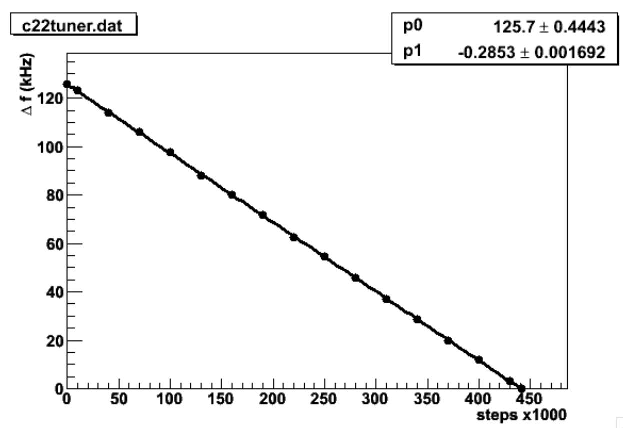

Figure 4: Difference between the cavity frequency and 1.3 GHz, as a function of tuner motor steps. The values in the upper right are the parameters determined from a linear fit to the data; the uncertainties shown are not meaningful.

With the cavity properly tuned, the cavity gradient at low forward power (≈1 kW) was determined from

$$E_{acc} = 2\sqrt{(R_s/Q_o)Q_L P_f}\,(1-e^{-\omega t/2Q_L})/L$$

where R_s/Q_0 = 1036 Ω and L = 1.038 m for TESLA cavities, P_f is the forward power, and Q_L is the loaded Q of the cavity (≈ the external Q of the input coupler, 3×10^6). By measuring the transmitted power P_t at the same time, the calibration factor $k_t = E_{acc}/\sqrt{P_t}$ was determined to be 1.4×10^7 V/[m $W^{1/2}$].

Using a pulse length of 1.4 ms, the power to the cavity was increased until, at 15 MV/m, electron activity in the coupler prevented any further increase in power. Nominally the HTS test cycle includes an additional conditioning sequence, similar to the one described above, which would serve to eliminate this kind of emission activity. However, in the interest of time, this step was skipped for C22. Instead, C22 was left to condition overnight at 15-16 MV/m and full pulse length. This processed away the remaining emitters (Fig. 5) and subsequently C22 reached its quench limit of 17 MV/m, (Fig. 6) in agreement with the results of its vertical test at TJNL.

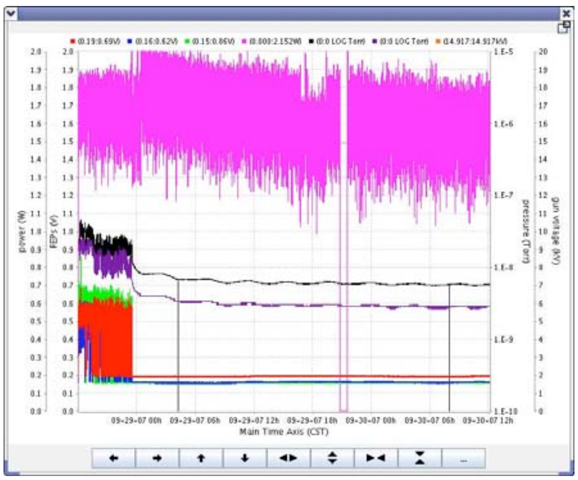

Figure 5: Processing away electron emitters with high-power pulsed RF. The blue/green/red traces are coupler electron pickup signals, the purple/black traces are coupler pressure readings, and the pink trace is the cavity transmitted power. Note how the electron signals disappear and the pressure abruptly settles after a few hours on this plot.

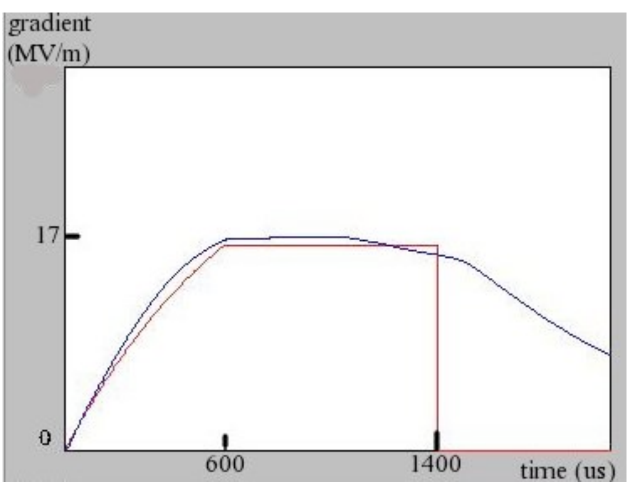

Figure 6: C22 gradient (blue trace) over 2 ms, showing a quench at 17 MV/m. The red trace is the LLRF system's gradient target

FUTURE PLANS

The horizontal test cryostat is currently undergoing modifications to provide for a cavity vacuum line that can be unmounted and ultrasonically cleaned when necessary. Following this, C22 will be reinstalled in the HTS to check the reproducibility of results and to do further investigations of dynamic heat loads (due to instrumentation uncertainties, the dynamic heat load for C22, and thus Q_0, could not be determined). The first "production" cavity tested in the HTS will be the first of four 9-cell 3.9 GHz cavities being built by FNAL to augment the operation of DESY's TTF-FLASH facility. This testing will require a switch-over from the 1.3 GHz RF system currently in use at HTS to a 3.9 GHz RF system currently in use at the Fermilab-NICADD Photoinjector Laboratory. Following the completion of the 3.9 GHz cavities, the HTS will be testing all 1.3 GHz cavities fabricated for ILC-style cryomodules built in the United States.

ACKNOWLEDGMENTS

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