DIAGNOSTIC INSTRUMENTATION FOR THE FERMILAB VERTICAL CAVITY TEST FACILITY*

C.M. Ginsburg[#], R. Carcagno, M. Champion, N. Dhanaraj, A. Lunin, A. Mukherjee, R. Nehring,
D. Orris, J. Ozelis, V. Poloubotko, D.A. Sergatskov
Fermilab, Batavia, IL 60510, U.S.A

W.-D. Moeller
DESY, Notkestrasse 82, 22607 Hamburg, Germany

Abstract

We describe the design and initial test results of the Fermilab vertical cavity test facility (VCTF) diagnostic instrumentation which is used to understand cavity performance, including thermometry to detect hot spots caused by quenches or field emission, and a variable RF input coupler to facilitate the TM_{010} passband mode measurements used to isolate poorly performing cells.

INTRODUCTION

The Fermilab vertical cavity test facility (VCTF), for CW RF vertical testing of bare ILC 1.3 GHz 9-cell SRF cavities, was completed in July 2007. The primary purpose of the test facility is to assess the performance of cavities, both as a study of their production and processing and as an acceptance test prior to insertion in a cryomodule. The complete facility description is given in [1] The first 9-cell cavity tests, of AES01, occurred in September 2007; and are described in detail in [2]. We describe here the design and initial performance of the VCTF diagnostic instrumentation which is used to understand cavity performance: two thermometry systems, and a variable input coupler.

FAST THERMOMETRY

The fast thermometry system [3] is used to perform fast, accurate temperature measurements to observe quenches or other thermal abnormalities during a cavity test. It consists of *Cernox* RTD sensors, in the SD package from *Lake Shore Cryotronics, Inc*., which are mounted to the cavity outer surface. The sensors provide an absolute temperature measurement in a small (3.175 mm x 1.905 mm) package. The placement of the sensors is flexible, and can be changed depending on test requirements. The sensors are wired in series with a 1 mA current source and shunt resistor for measuring the current. For attaching the sensors to the cavity, *Apiezon* vacuum grease is used to provide good thermal contact, and a G10 band or thin nylon cord is used to hold the sensors in place. The 10 kHz sampling rate is suitable for measuring both fast quenches and slower temperature rises. This fast thermometry system has been used reliably in several test systems since 2002, and has been used for our first cavity tests at the VCTF. These sensors are too expensive, however, to be used in a large thermometry system. Currently, 24 sensors are available.

The analysis of 9-cell cavity test ending in quench using the fast thermometry system would typically consist of three steps:

1) mode measurement to determine the performance limitation to within two cells,
2) a coarse thermometry measurement to determine which of the two cells quenched, and
3) a comprehensive thermometry measurement to determine the location of the quench to within a few cm or less.

Additional steps may be required if the quench location is randomly located within a cell, rather than on, e.g., an equator weld.

During the test of AES01, eight "fast" thermometry sensors were attached in a tightly packed pattern in the region of interest. The measured temperature as a function of time for all eight sensors is shown in Fig.1. Four quench-recovery cycles are observed, with the last rise not ending in quench. Note that the temperature rise is very reproducible. In Fig.2, the temperature rise for the eight sensors is again shown, but as a function of the cavity transmitted power. The heating is reproducible and consistent with a stationary hot spot.

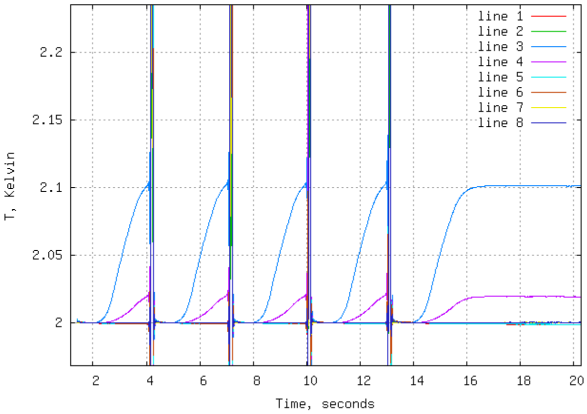

Figure 1: Temperature (K) vs. time (sec) over four quench-recovery cycles. Input power is constant.

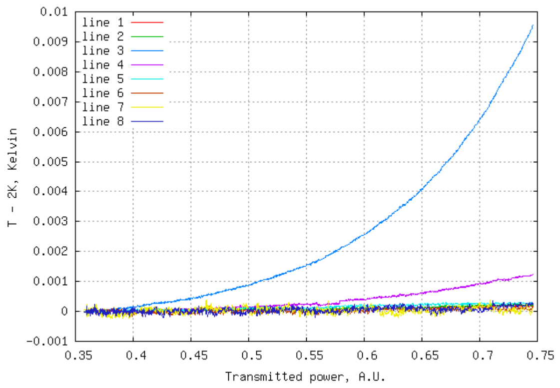

Figure 2: Temperature (K) vs. transmitted power (arbitrary units).

9-CELL THERMOMETRY

The 9-cell thermometry system is also designed to locate hot spots due to quenches or other thermal abnormalities during a cavity test. Accurate measurement of absolute temperature is typically not required, we need only measure temperature rise when RF power is applied. To speed investigation of the cause of failures, we want to localize problems to as small an area as possible. This is done by placing sensors on a fine grid, with spacing ~1cm × 1cm (of order the material thickness). We end up with 960 sensors per cell, 8640 sensors in a 9-cell cavity.

To handle the large number of sensors without introducing an overwhelming number of cables into the cryostat, we must use a multiplexing system. Rather than develop a custom multiplexer which will function at cryogenic temperature, we have chosen to use diodes as the sensors. These can be configured as a multiplexed system without a separate multiplexer. We can then read out all 8640 sensors using as few as 336 conductors.

Despite the large number of sensors, we want to keep the fraction of the cavity that is covered by sensors (and therefore not in contact with the helium bath) as low as possible, and certainly no higher than with existing thermometry systems. This requires using a very small package. At the same time, we would like to use diodes which have been used for cryogenic thermometry in the past. The system is required to be readily reproducible so it can be used at multiple test sites, and the option to produce additional systems must be available over a period of many years. We therefore give priority to using standard, widely available parts.

The combination of size, future availability, and wide spread use as a cryogenic sensor, led us to choose the classic 1N4148 diode in a SOD523 package (~1mm × 1mm).

To the extent possible, we also use commercial manufacturing techniques. The diodes are mounted on a flex (Kapton) board in the flat state; such assembly is routine in the PCB industry. The Kapton is then laminated to a G10 carrier board, and loops are formed from the Kapton to act as springs. The lamination step is not a standard commercial process, but it is quick and simple. The resulting board is shown in Fig. 3.

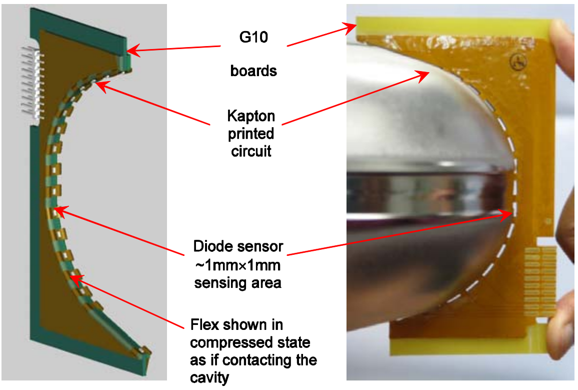

Figure 3: 9-cell thermometry card layout.

The intent is to install thermometry for every test. This allows immediate diagnostics, rather than having to remove the cell to install diagnostics after an initial failure. To make this possible, the system must monitor all 9 cells in parallel; the installation must be fast; and there must be a minimal overhead for cabling.

We designed the system as two half-shells which bolt together. The boards would be loaded into the half-shells once. Thereafter, for each test, they would only move in (for testing) or out (for assembly/disassembly). A partially loaded cage is shown in Fig. 4.

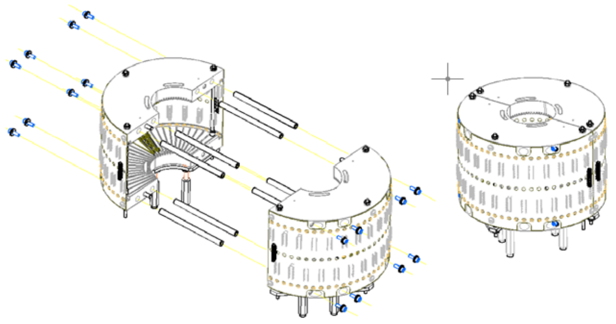

Figure 4: 9-cell thermometry mounting cage.

A concern in a vertical cavity test is the high dose of radiation in the vicinity of the cavity. Fortunately, in such a test radiation exposure occurs only while the sensors are cold (below 4°K), where silicon diodes can tolerate large radiation doses. Below about 50 K, diodes are less sensitive to radiation than classic carbon-glass sensors, as shown in Fig 5.

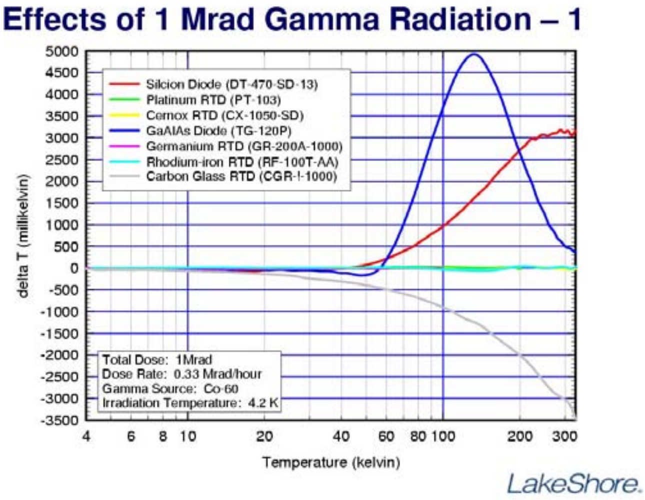

Figure 5: Effect of radiation on various Lake Shore thermometers.

The 9-cell thermometry system is currently under construction. A prototype appropriate for a single-cell Tesla-shape cavity will be built and tested in the VCTF during the next few months. A full 9-cell system for all nine cells will follow shortly thereafter.

VARIABLE INPUT COUPLER

A variable input coupler has been designed to provide some flexibility in the test stand RF measurements. The variable coupler allows the cavity to be critically coupled for all RF tests, including all TM_{010} passband modes, which will simplify or make possible the measurement of those modes with very low end-cell fields, e.g., π/9 mode.

The mode measurements were key to the determination of the quench location in the AES01 cavity performance. Eight out of the nine TM_{010} passband modes were measurable using a fixed input coupler. During those tests, the coupling ranged from β=0.2 (2π/9 mode) to β=2.7 (7π/9 mode); π/9 mode was not measurable.

The variable coupler mounts to the standard input coupler port of the Tesla-style cavity, primarily to conserve vertical space in the cryostat. The RF simulation used to calculate the coupler requirements is shown in Fig.6. The coupler motion, R, is perpendicular to the cavity axis. The required Q_{ext} range was determined from experience at the DESY TTF to be 2×10^{9} . Q_{ext} . 4×10^{10}. The corresponding required mechanical movement range of the coupler is about ΔR=15 mm, as shown in Fig.7.

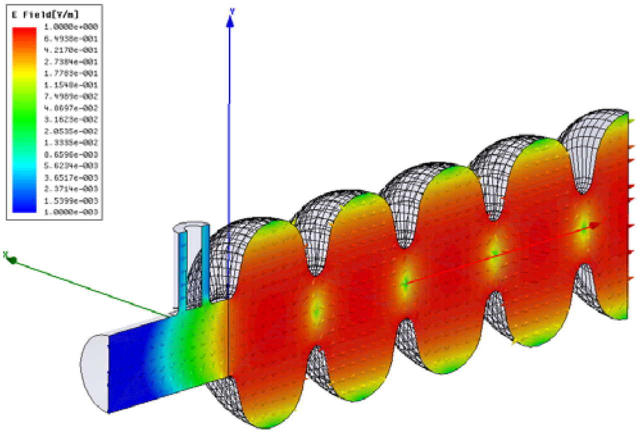

Figure 6: RF simulation for the variable coupler design.

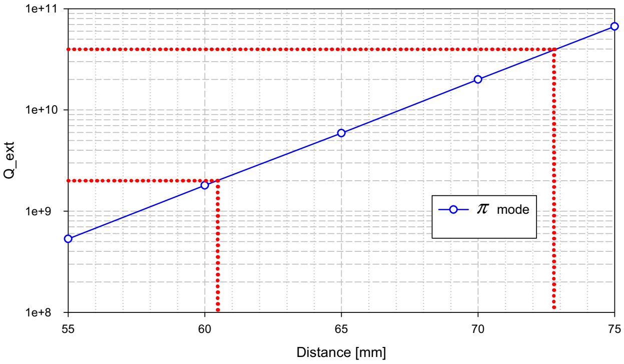

Figure 7: VCTF variable coupler Q_{ext} as a function of coupler movement range, from RF simulation.

The mechanical design of the variable input coupler is shown in Figs 8 and 9. The coupler features a 75 Ω copper antenna with a diameter of 12.74 mm. The smaller diameter of the antenna, with respect to a 50 Ω antenna, was chosen to accommodate cleanroom preferences. The impedance mismatch was simulated, and found to cause an 11 dB return loss; however there was no resonance observed in the antenna itself.

The position of the antenna is varied by a *Phytron* UHV motor, which is expected to operate well in a liquid helium environment, allowing the assembly to be controlled with only four wires passing through the cryostat top plate. Two additional wires will be added for a platinum sensor to be attached to the motor body for an equipment safety interlock.

The variable input coupler for VCTF is at an advanced design stage. The parts have been ordered and are starting to arrive. Assembly and system test are expected to occur within the next few months.

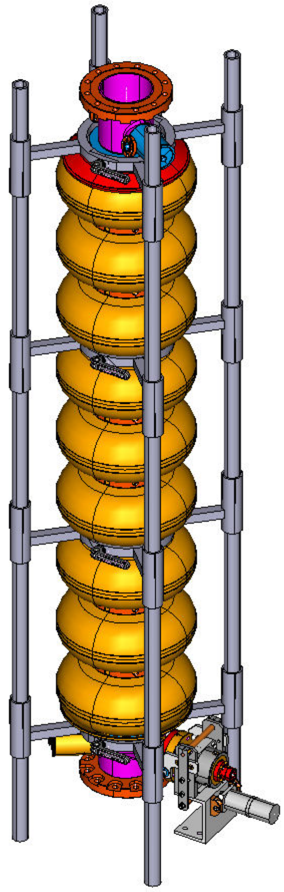

Figure 8: Mechanical design of the VCTF variable coupler, shown attached to the input coupler port of a Tesla-style cavity.

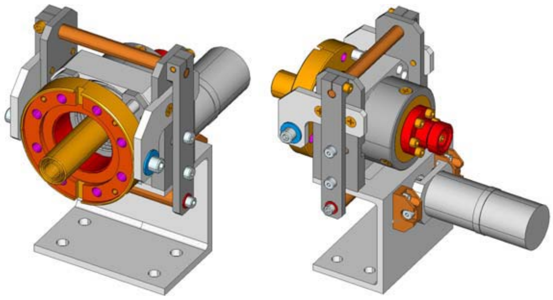

Figure 9: VCTF variable coupler mechanical design, shown from two angles.

CONCLUSIONS

The Fermilab vertical cavity test facility (VCTF) has recently begun operation. The design and initial performance of the VCTF diagnostic instrumentation have been described. The fast thermometry system has been very useful in finding the quench location in AES01. The design and status of the 9-cell thermometry and variable input coupler for VCTF have been described; these projects are expected to facilitate the uing of cavity performance significantly.

ACKNOWLEDGEMENT

We greatly appreciate the assistance of the VCTF technical staff to prepare cavities and test instrumentation for measurements.

REFERENCES

[1] J.P. Ozelis et al,, “Design and Commissioning of Fermilab’s Vertical Test Stand for ILC SRF Cavities,” WEPMN106, PAC’07, Albuquerque, NM, USA, June 2007.
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