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FAST THERMOMETRY FOR SUPERCONDUCTING RF CAVITY TESTING*

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Abstract

Fast readout of strategically placed low heat capacity thermometry can provide valuable information of Superconducting RF (SRF) cavity performance. Such a system has proven very effective for the development and testing of new cavity designs. Recently, several resistance temperature detectors (RTDs) were installed in key regions of interest on a new 9 cell 3.9 GHz SRF cavity with integrated HOM design at FNAL. A data acquisition system was developed to read out these sensors with enough time and temperature resolution to measure temperature changes on the cavity due to heat generated from multipacting or quenching within power pulses. The design and performance of the fast thermometry system will be discussed along with results from tests of the 9 cell 3.9GHz SRF cavity.

INTRODUCTION

During performance testing of cavities for the 3.9 GHz effort it became apparent that there were heating issues, particularly in the Higher Order Mode Coupler regions. These issues required closer scrutiny than afforded by the existing thermometry readout system, which was limited by a sampling rate of only a few Hz; particularly since the RF pulse widths are on the order of milliseconds. For this reason, a system capable of simultaneously capturing up to 16 channels of temperature sensors with a time resolution of 100 microseconds was requested. Such a system was initially developed for the Charged Kaons at the Main Injector (CKM) 3.9 GHz cavity testing program but was recently upgraded for 3.9 GHz 3rd harmonics cavity testing diagnostics to meet this request.

Sensor mounting techniques were also developed to quickly attach small Cernox RTDs to the SRF cavities. Other methods have been developed to map the surface temperatures of RF cavities such as DESY's rotating temperature mapping system [2]. However, this system is fixed, with sensors mounted to specific areas of interest. Coupled with the fast readout system, this technology has proven to be an invaluable tool for identifying and diagnosing heating issues of superconducting RF cavities.

TECHNIQUES DEVELOPED FOR SENSOR INSTALLATION

Cernox RTDs in the SD type package from Lakeshore. Cryotronics, Inc. was chosen for this system. These sensors have a mass of 0.03grams and a fast thermal response time, which is ~15ms. Three methods for mounting these sensors have been developed: 1) Two sensors are mounted to a G10 band, which is wrapped around a cavity cell equator; 2) Single sensors are mounted directly to the cavity surface with cryogenic varnish; and 3) Four or eight Cernox sensors are mounted at the ends of small G10 rods that are constrained to the cavity iris via a G10 ring with internal springs. This last method was used for deflecting mode CKM cavities in which hot spots were expected at the iris location.

For method 1, two Cernox sensors are attached on the opposite sides of their substrates (thermal sensing side) to the surface of a thin G10 band (see Fig. 1). The band provides strain relief to the wires and equally spaces the sensors around the equator of the cavity. Lakeshore Varnish (VGE-7031) is used to attach the sensors to the G10 and to the cavity to insure good thermal contact.

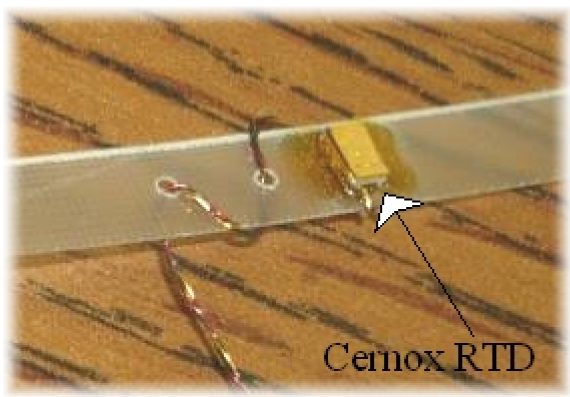

Figure 1: Example of a Cernox sensor mounted to a G10 band.

The G10 band is wrapped around the equator of the cavity and held in place with glass tape (see Fig. 2).

Figure 2: Cernox RTD thermometry G10 band wrapped around the cavity equator.

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The second method of directly attaching the sensors on their substrate sides to the cavity uses varnish. This method is advantageous for tighter regions

For the third method, developed for the CKM project, the sensors are installed in sockets machined at the tips of G10 rods, which are held in contact with the cavity by G10 rings with internal springs (see Fig.3). These rings are designed to be installed around the cavity iris; and up to eight spring-loaded G10 rods can be installed in a ring. The springs apply a constant force in order to keep the sensors in contact with the cavity. To assure good thermal contact, a half-dome made of indium is varnished to the Cernox substrate. When the spring-loaded rod presses against the cavity iris, the half-dome indium in contact with the cavity surface deforms and adopts the curvature of the iris surface. This method was designed for quick mounting and dismounting of sensors to the iris of CKM cavities. It was used on 3-cell CKM cavities and was extended to 9-cell cavity use.

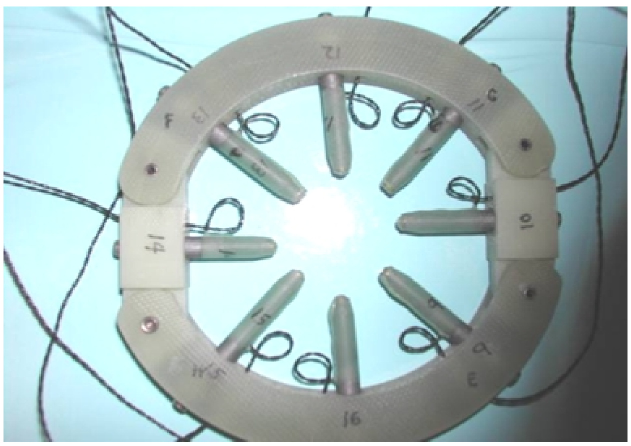

Figure 3: Eight Spring Loaded G10 Rod RTD Assembly

FAST THERMOMETRY DATA ACQUISITION SYSTEM

The fast thermometry data acquisition system can accommodate up to eight sensors, which are mounted in key regions of interest on the cavity, and are measured simultaneously at typical sample rates of 10kHz. Fast thermometry systems have been developed at other labs to measure large numbers of temperature sensors mounted on the cavity surface [3]; however, this system was designed to allow quick installation of a small number of sensors and fast readout to characterize the sharp temperature rise relative to the RF pulse. This system is capable of resolving temperature spikes (between RF power pulses) on the order of a few milliKelvin in amplitude and a few milliseconds in duration. It consists of a current source, a National Instruments 18-bit, 16-channel, 500kS/s ADC, and front end signal conditioning with amplification. Connecting the Cernox sensors directly to the ADC input would result in excessive leakage current compared to the 1µA excitation level, resulting in large measurement errors. Most high speed ADC data acquisition cards require fairly large bias currents and have relatively low input impedances. It is therefore important to buffer the sensors from this input and amplify their voltage with an amplifier that requires very little current from the sensor to operate. The 1NA116 instrumentation amplifier was selected for this task since its input bias current is about 3 to 4 fAmps.

The software was written in LabView and has two modes of operation: 1) Measurement mode; and 2) An off-line Analysis mode. The measurement mode provides system/measurement configurations, thermal offset compensation, and RTD measurements. The configuration step allows the user to select the RTDs to be measured and provide setup parameters such as the sample rate (usually 10kHz), the data window (typically >1sec), and digital filtering options; it also loads calibration parameters for the selected RTDs. Temperatures are calculated using the loaded calibration data specific to each RTD. The offset step measures the offsets in the signal channels due to contact potentials in the wiring and thermal EMFs. These offsets are subtracted from the measured data since the current source polarity cannot be reversed during the measurement window. In the measurement step, the user can manually trigger data or capture data via an external trigger. For instance, the cavity RF gate pulse can be used to trigger the measurement for synchronization. Raw data can be saved to a file, which additionally contains all the parameters needed to restore the measurement configuration during off-line analysis. Captured data can be displayed with or without filtering both in the measurement mode and in the off-line analysis mode.

Fig. 4 is an example of the capability of the fast thermometry system. Heating on the iris of a CKM 3.9 GHz cavity (C15-3C-5) can be seen corresponding to the location of sensor “C” during a 250 ms RF pulse.

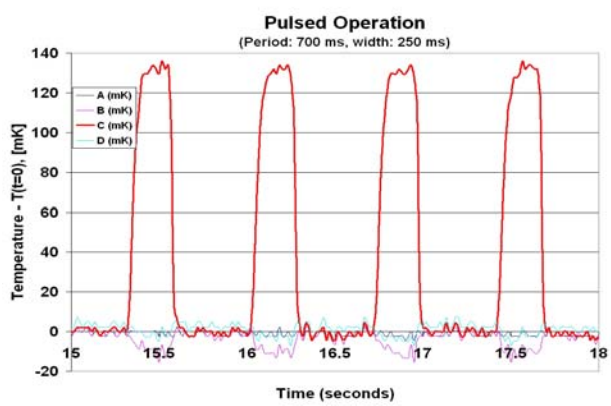

Figure 4: Heating evidence at sensor “C” location during a 250 ms RF pulse (CKM 3.9 GHz cavity C15-3C-5).

Increasing the RF power leads to a cavity quench around this location about 2 ms after the RF pulse starts, as shown in Fig. 5. The cavity undergoes a series of quench and recovery events, with a repetition rate of approximately 9.3 Hz. The temperature spikes agree with RF breakdown indications.

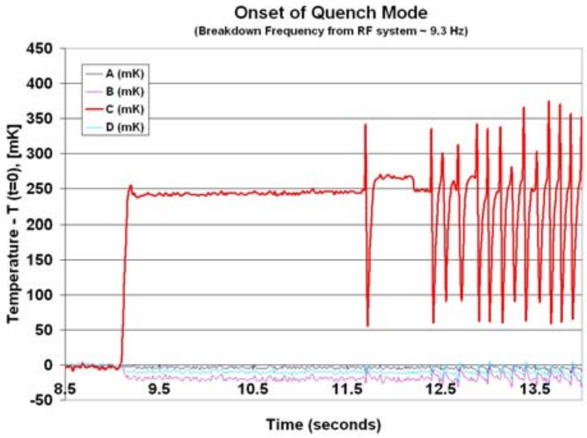

Figure 5: Increasing RF power results in a series of quench and recovery events at sensor "C" location (CKM 3.9 GHz cavity C15-3C-5).

Fig. 6 shows a more detailed view of quench and recovery events. The detail of the quench temperature pulse shows a behavior consistent with crossing the Lambda point at 2.17 K: The hot spot temperature slowly rises, eventually reaching the Lambda point, and quickly increases after that. The cavity quenches, recovers, and then the process repeats. The temperature rise after crossing the Lambda point lasts about 5 ms.

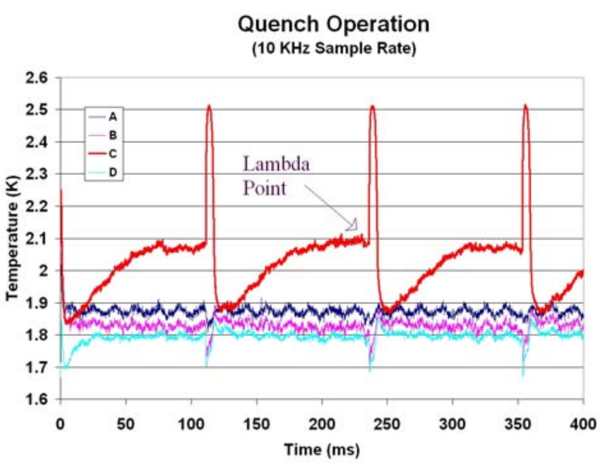

Figure 6: Quench location temperature response (CKM 3.9 GHz cavity C15-3C-5).

CAVITY TEST RESULTS

Vertical tests of 3rd harmonic cavity HOM couplers were carried out in order to understand thermal breakdown issues [3]. Fig. 7 is an example of a thermal breakdown (quench) occurring in the F-part of the bottom HOM coupler. Note that this data was post-processed using wavelet filtering to remove noise while minimizing signal distortion.

Cold tests were also performed on a cavity with HOM coupler antennas installed. In this case, sensors installed in the middle of the cavity showed a small 30 mK temperature rise when the cavity was operated at Eacc=20MV/m in 50 msec pulsed regime. However, sensors installed near the feed though ceramic window exhibited a temperature rise, occurring 100 msec later with a 500 msec recovery time. These results demonstrated that the quench location was in the HOM antennas tips.

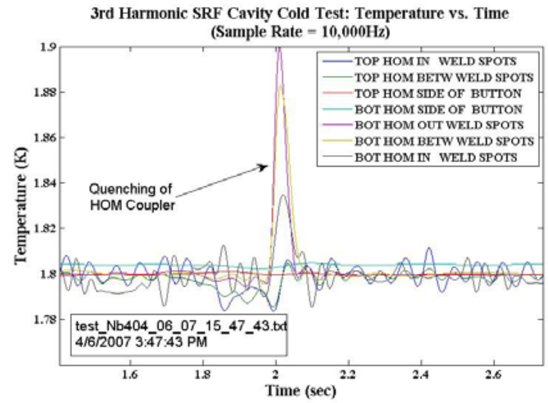

Figure 7: Cold test of 3rd harmonic cavity HOM couplers. Eacc=20MV/m with a 50 microsecond pulse length.

SUMMARY

A system for measuring the fast dynamic temperature response on the surface of superconducting RF cavities was developed along with techniques for instrumenting the cavities with RTDs. The results of this system are very promising so there is interest to improve the design and increase the number of channels supported. To date, two 3rd harmonic cavities have undergone a total of ten vertical tests using this system. It has been possible to identify heating/quenches in both the HOM bodies and cavity cells. With the help of the fast thermometry data obtained, modifications to the internal parts of the HOM couplers were made allowing better performance of the cavities. As a result, gradients in excess of 20 MV/m were achieved with no indication of HOM heating, which was seen previously. The improved performance was verified in later tests.

The entire system, including hardware, software, and sensor assemblies, have also proven to be very portable as evidenced by its recent transport from Fermilab to Jefferson Lab for the diagnosis of a 1.3 GHz cavity. A working system was achieved in less than two days.

REFERENCES

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