MULTIPOINT T-MAP SYSTEM FOR VERTICAL TEST OF THE SUPERCONDUCTING ACCELERATOR CAVITIES

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Abstract

The temperature mapping (T-map) system for inspection of cavity interior surface is developed for the vertical test. T-map system can find heat sources that may be caused by defects on the superconducting accelerator cavity. The purpose of our studies on T-map is to realize a high spatial resolution and easy installation of the sensors. The production yield of such cavities would be improved by using T-map system. The preliminary test under cryogenic temperature by the T-map system is reported.

INTRODUCTION

About 15000 superconducting 9-sell cavity (Fig. 1) of the average accelerating gradient of 35MV/m are scheduled to be produced for the first stage plan of the International Linear collider (ILC). It is thought that the upper limit of the accelerating gradient greatly depends on the condition of interior surface in the superconducting (SC) accelerator cavity. The high accelerating gradient is obtained by the surface treatment and inspection methods such as the high-pressure water jet cleaning, the electro-polishing, and the high-resolution camera system [1]. But the yield of the production of SC-cavities is still not satisfactory. In development and production of the SC-cavities, the interior surface in SC-cavity should be observed and be inspected non-destructively with ease of handling.

A main cause of limiting accelerated gradient is the quench of local heat source due to defects such as scratch, dust particle of a few ten μm, and ruggedness of a few hundreds μm on interior surface. So the inspection of interior surface by order of a few ten μm is necessary for the fabrication and the development of cavities.

Several research laboratories have adopted the temperature mapping (T-map) system as the inspection method. T-map is a good method for finding defects on the interior of SC-cavity under application of RF power in the vertical test. T-map is the thermometry measurement by many temperature sensors set on the exterior of SC-cavity. This way is more efficient than inspecting all area of the interior surface with a camera. Allen-Bradley carbon resistor that changes its resistance characteristically around superconducting temperature are utilized as temperature sensors [2]. However, the production of this resistor was ceased in 1997.

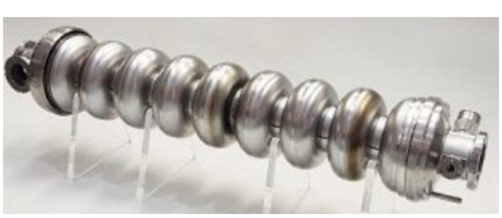

Figure 1: 9-sell superconducting accelerator cavity.

The setting of T-map is a troublesome though its system is simple. We have been developing T-map system that can quickly measure all sells in the vertical test. And this T-map system has to be easily operated for fabrication of SC-cavities.

T-MAP SYSTEM

The schematic diagram and the experimental sensor strip of our T-map system are shown in Fig. 2 and Fig. 3, respectively. In order to measure the exterior surface of SC-cavity in the vertical test, the temperature sensors also have to be installed into a cryostat. Assuming that multipoint measurement with one per cm^2 is adopted in order to realize a high spatial resolution, the sensor assemblies of 9-sell T-map system will contain about 10000 sensors.

Cabling such signals with separate wires for each sensor will make the number of wires enormous. And the heat leak will increase into the cryostat. In order to reduce the number of the signal cables dramatically, digital CMOS circuits such as analogue switches have been installed in the cryostat as shown in Fig. 2. This multiplexer circuit design lower the cost for the system components such as cables and vacuum flanges. The multiplexer circuits are worked fine in several test operation in cryogenic temperature. Compared with the resistance value of sensors, discrepancy in using the digital CMOS circuits was slight according to our measurement.

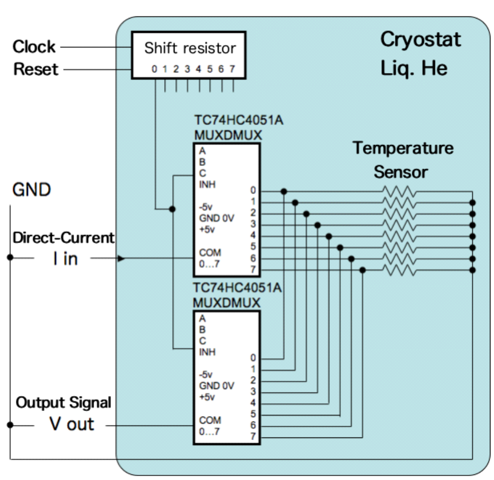

Figure 2: Test schematic diagram for T-map.

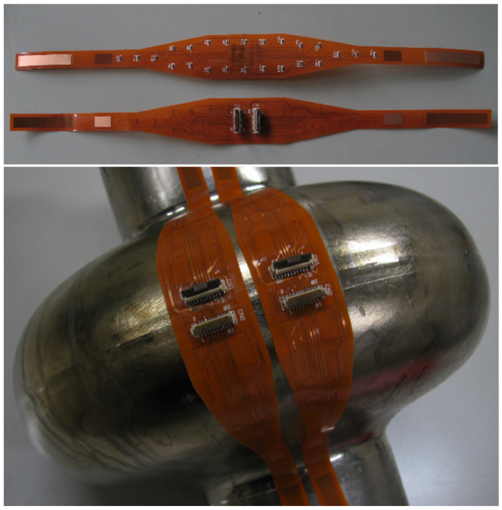

Figure 3: Experimental sensor strips. Resistors on flexible polyimide film contact with surface of Niobium cavity. In the final design of T-map system, the sensor assembly per sell consists of 32 strips (32 sensors per strip).

Low cost surface mount resistor of typical Ruthenium oxide was adopted as the temperature sensor. And the sensor strip that consisted of resistors on flexible polyimide film was adopted as shown in Fig. 3. A major advantage of this sensor strip is easy installation of T-map equipment to the SC-cavity. So, the inspection time for SC-cavities is expected to be short.

TEMPERATURE SENSOR

Fig. 4 shows the results of measured resistance for variation of resistors from 1 kΩ to 100 kΩ by using the experimental circuits of Fig. 2 at cryogenic temperature. As shown in Fig. 4, the larger resistance gives the larger the output voltage. Fig. 5 shows sensitivity of resistance about the temperature. We investigated the rate of change of the resistance values at specific temperature as sensor sensitivity. The sensitivity in the temperature rise from 2 K to 4 K due to the heat source at the defects is important for the cavity diagnostics. The ratio of 1.6 K / 4.2 K for 10 kΩ and over 20 kΩ are about 1.5 and 2, respectively. However, the time constant of large resistance sensor become large, and intensity of the signal' rise attenuate as shown in Fig. 4. Therefore we adopted 10 kΩ resistor as the temperature sensor considering the balance of the sensitivity and the time constant.

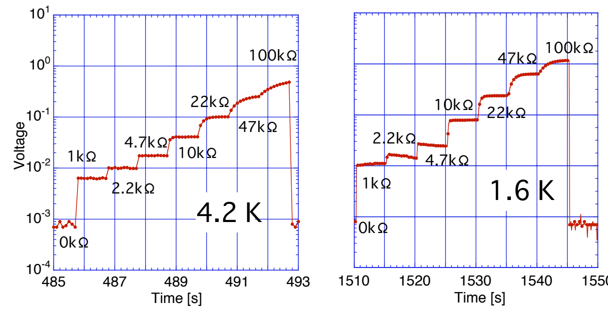

Figure 4: The output signals of Ruthenium oxide resistors. The left figure and the right were measured under cryogenic temperature of 4.2K and 1.6 K, respectively.

CAVITY TEST RESULT

Fig. 6 shows the measured output signals of the T-map during the vertical test of SC-cavity by utilizing the experimental circuits in Fig. 2 and the sensor trips in Fig. 3. One channel is assigned with one sensor (resistor). Low direct current was given only one of resistors by multiplexer circuits as like the output channel. But the heat generation that may be caused by defects did not occur at places of our T-map sensors, which were intentionally placed at several part of surface of SC-cavity.

Fig. 7 is the output signals when the input current is constant value and the acquisition of the sensor channel is changed. With the switching speed (frequency) of 500 Hz, the signal peak is clear. It is guessed that attenuation of the signals right after the channel switch is due to decrease in resistance by self-heating of the resistor. In the high speed switching over 2.5 kHz, the output signals

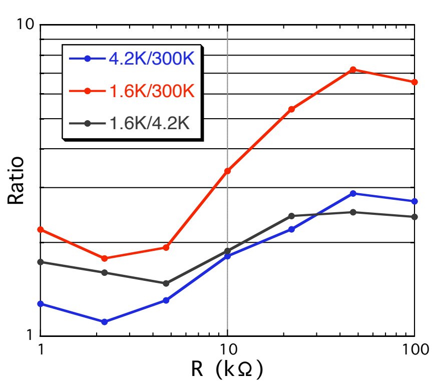

Figure 5: Sensitivity of Ruthenium oxide resistor.

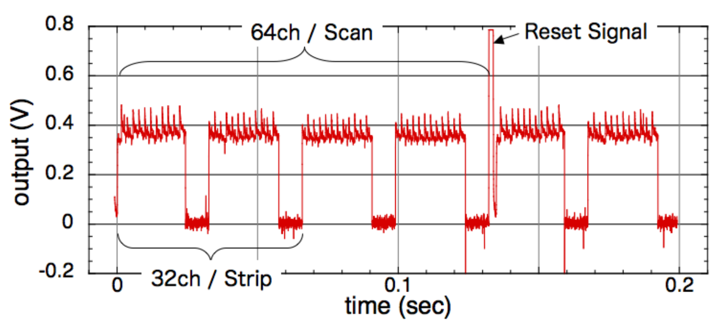

Figure 6: Output signal of experimental T-map system. 64 channels (12x4 sensors and 4x4 unused channels) are measured in one scan time. Temperature inside the cryostat, channel switching speed (frequency) and input current are 4 K, 250 Hz and 20 μA, respectively.

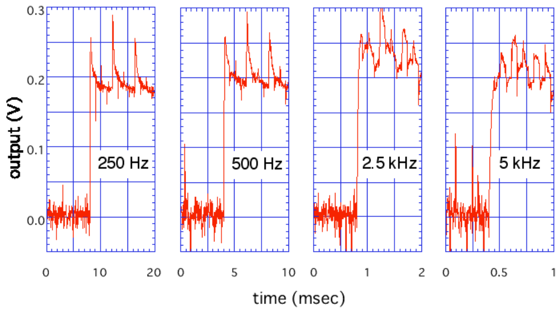

Figure 7: The output signal shape about difference of the switching speed (frequency).

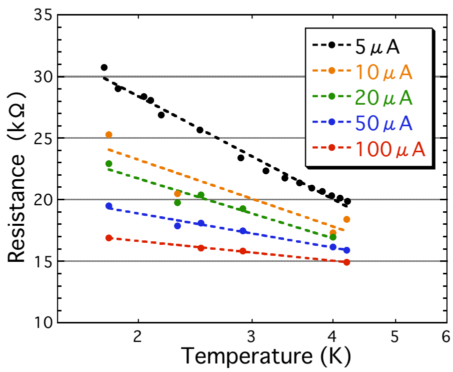

Figure 8: Plots of resistance value, as a function of temperature for various input current setting.

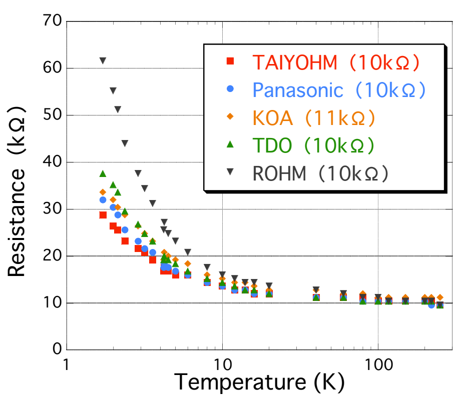

Figure 9: Plots of resistance values as a function of temperature for various manufacturers. The input current is 5 μA.

attenuate because of the time constant relating to the signal's rise. We will adopt the switching speed of 1 kHz when the signal output time of all sensors on surface of SC-cavity is about 10 sec per scan.

The resistance values were measured for various input current setting as the switching speed of channels being fixed. As shown in Fig. 8, the resistance decreases at the high current input because of self-heating of resistor. Fig. 8 shows that the sensor with the input current of large value has poor sensitivity at cryogenic temperature. So the input current of 5 μA is adopted as the noise to signal rather deteriorate at current less than 5 μA. The ratio of 2 K / 4 K is about 1.5 for 10 kΩ resistor.

The sensitivity of typical surface mount type Ruthenium oxide resistor from several manufacturers was investigated at the cryogenic temperature. Fig. 9 shows the measurement results of the average resistance values of 5 resistors from each manufacturer. The difference of resistor's sensitivity among the manufacturers is more obvious under cryogenic temperature. The sensor sensitivity, as defined as the ratio of resistance at 1.7 K to 4.7 K is summed up in Table 1. In our present research, 10 kΩ resistor by ROHM is best suitable to the temperature sensor from the sensitivity standpoint under cryogenic temperature.

Table 1: Sensitivity under cryogenic temperature about manufacturers

Manufacturer	Resistance	Ratio 1.7K/4.2K
TAIYOHM	10 kΩ	2.1
Panasonic	10 kΩ	2.4
KOA	11 kΩ	2.2
TDO	10 kΩ	2.6
ROHM	10 kΩ	3.9

SUMMARY

Basic design of T-map system has been clearly fixed. 100 Ω Allen-Bradley carbon resistors has about 8 ratio at 1.7 K / 4 K [2]. Compared with this carbon resistors, the sensitivity of 10 kΩ Ruthenium oxide resistor under cryogenic temperature is about 1/3. But we consider the Ruthenium oxide resistor has enough sensitivity as the temperature sensor of our T-map. We will investigate the sensitivity of other kinds of resistors to find if there is better resistor.

And X-map, which detects the radiation distribution due to emitted electron system by photo diodes, has been developed as well as T-map. Same multiplexer circuit as T-map operates the channel switching of X-map system. We are planning to build 9-sell XT-map system consists of the sensor assemblies and its data taking system.

REFERENCES

[1] Y. Iwashita, et al., "Development of high resolution camera for observations of superconducting cavities", Phys. Rev. ST Accel. Beams 11, 093501 (2008).

[2] A. Canabal, et al., "DEVELOPMENT OF A TEMPERATURE MAPPING SYSTEM FOR 1.3-GHz 9-CELL SRF CAVITIES", Proc. PAC07 2406 - 2408 (2007).