XT-MAP SYSTEM FOR LOCATING SC CAVITY QUENCH POSITION

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Abstract

XT-map system under development in collaboration between Kyoto University and KEK is a combined system of T-map and X-map. High resolution T-map at quench detection will give more information for improving yield in production of high performance SC Cavities. The high-density sensor distribution of the XT-map gives the high resolution. Because the huge amount of sensor lines are multiplexed at a hi-speed scanning rate in the vicinity of the sensors, the small number of signal lines makes the installation process easy and reduces the system complexity. The quench survey test with this XT-map system has been performed in the vertical test at KEK.

INTRODUCTION

The upper limit of the accelerating gradient of the superconducting (SC) cavity seems to be affected by the condition of the interior surface. Main causes of limiting accelerating gradient are thought to be the quench of local heat source and field emission due to defects such as scratches, dust particles in tens of µm and ruggedness of a few hundreds µm. Therefore, in order to improve the performance and the production yield of the SC cavities, non-destructive inspections for finding defects on the interior surface of SC cavity have important roles.

As a method for survey and observation of defects on the interior surface, the high-resolution camera system, so-called Kyoto Camera, was developed by collaboration between Kyoto University and KEK [1]. Kyoto Camera used in several research laboratories is an effective non-destructive inspection tool at the room temperature environment. On the other hand, the multi-point thermometry mapping measurements (T-map) and the multi-point X-ray radiation mapping measurements (X-map) are useful tools to survey the defect locations during the vertical test. T-map, X-map and the optical observation are complementary to each other for the purpose[2]. Those inspections are recognized as essential processes for the local repairing of the interior surface together with the micro grinder after identified the defect locations [3]. We developed the high-resolution T-map and X-map systems. Developed T-map system and the detected quench events will be reported.

XT-MAP SYSTEM

We have developed the high-resolution T-map and X-map system considering the non-destructive inspection for superconducting 9-cell 1.3GHz niobium (Nb) cavities in ILC. Our XT-map system is the combined system of T-map and X-map as shown in Fig. 1, and its main R&D is performed connected to the vertical tests of ILC cavities in KEK. XT-map system has following features.

- High-resolution.
- Low operation cost (less heat leak).
- Use of low-cost components on the market.
- Easy setting and operation.

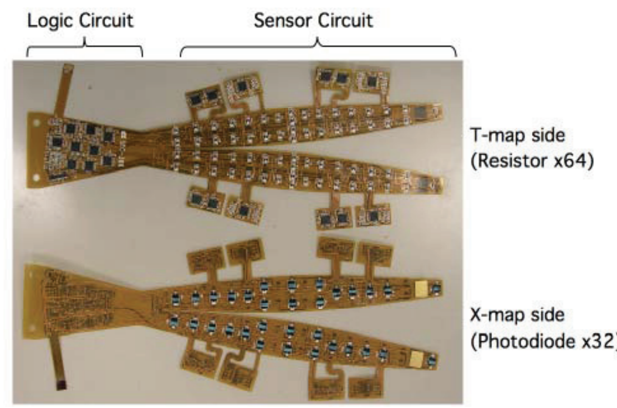

Figure 1: The double-leaf-shaped Flexible Printed Circuits films (polyimide film with several layers) for XT-map.

Multiplexing Design

The T-map sensors are distributed about one per cm^2 considering the wall thickness, thermal conductivity of Nb and practical density of installable sensors. Since the X-ray sensor has larger size, its density is a half of the T-map system. Therefore whole T-map assemblies for 9-cell cavity will contain about 9000 (X-map: 4500) sensors. Many cabling wires for this multi-point measurement would increase the heat intrusion into the cryostat. In order to reduce the number of the signal cables significantly, CMOS analogue multiplexers have been installed in the cryogenic area as shown in Fig. 2. This multiplexing design makes it possible to decrease the number of cables and vacuum tight feed-throughs.

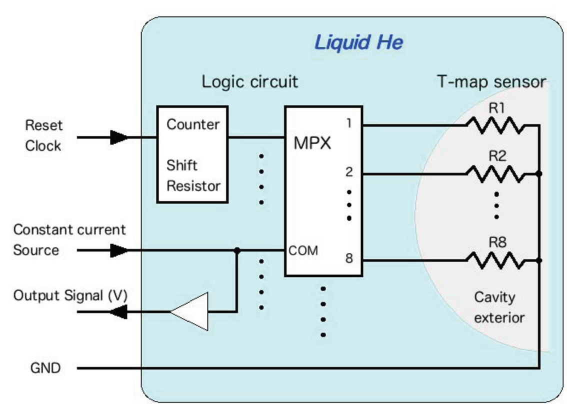

Figure 2: Block diagram of T-map system.

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Sensor

Although the performances of cryogenic temperature sensors commercially available are very good, the cost makes it difficult for us to apply them to the high density T-map. The carbon resistors, which increase their resistance around cryogenic temperature, manufactured by Allen-Bradley Company have been utilized as low-cost temperature sensors. The production of this resistor, however, was ceased in 1997 [4]. Thus ruthenium oxide chip resistors instead of the carbon resistors are adopted as the temperature sensors in our XT-map system. This kind of surface mount technology (STM) resistor has good availability at a low cost. In our initial investigation on RuO_2 STM resistors, the larger the resistance is, the more the temperature sensitivity is. The time constant of large resistance sensor, however, becomes large and the signal's rise-time increases [5]. Therefore we adopt 10kΩ resistor as T-map sensor considering the balance of the sensitivity and the signal's rise-time at cryogenic temperature. The sensitivity as a function of temperature is shown in Fig. 3.

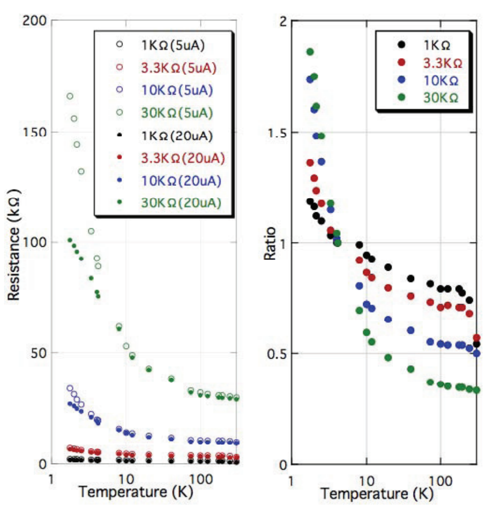

Figure 3: The sensitivities of RuO_2 resistors as functions of temperature. Values in brackets are the applied current values. Left: The resistances as functions of temperature for RK73B by KOA. Right: The resistance relative to the values at 4.2K (measured at 5μA,).

PIN photodiode is adopted as X-ray sensor in consideration of performance, package size, cost, and availability on market. Although the SMT photodiode (BPW34FS by OSRAM) has less sensitivity as a X-ray detector because of small sensitive area compared with a big size metal-can package device, a brief integrating amplifier in the X-map circuit compensates the poor sensitivity. A charge accumulated during the scan interval is collected by the integrating amplifier.

Flexible Printed Circuits

In order to realize the super-multipoint measurement (with high-density sensors), we mounted the SMT components such as chip resistors on XT-map circuits. The double-leaf-shaped device that consists of the SMT components on flexible polyimide film (Flexible Printed Circuits: FPC) was designed as shown in Fig. 1. Another major advantage of this configuration is an easy installation on SC-cavity with simple fixtures. The installation time can be reduced in spite of the large number of sensors. T-map sensors (64 points) on the FPC have arranged to contact with an exterior surface of SC-cavity while the X-map sensors (32 points) are installed on the backside space (outer side). The logic circuits are separated from sensor area as shown in Fig. 1. The T-map FPC boards were designed to keep contacting the cavity exterior surface by applying a tension to the FPC board at 2 irises of a cavity.

As shown in Fig. 4, the daisy-chained the FPC boards pass a token sequentially during data scan of all analog data on each board, which reduces the number of cables. In our present design of XT-map system, the sampling time for each point on T-map are about 1 ms (2 ms on X-map), while 1024 sensors are installed on one cell. Therefore a scan of 9-cell cavity takes about 1 sec since the nine units work in parallel, where only one signal line from a multiplexed data is needed for each cell in addition to common four power supply lines and two timing signals. The sampling time would be reduced if necessary.

As shown in Fig. 5, the daisy-chained 16 double-leaf FPC boards covers one cell of ILC SC-cavity. Only 25 cabling wires are required to operate 9-cell XT-map system.

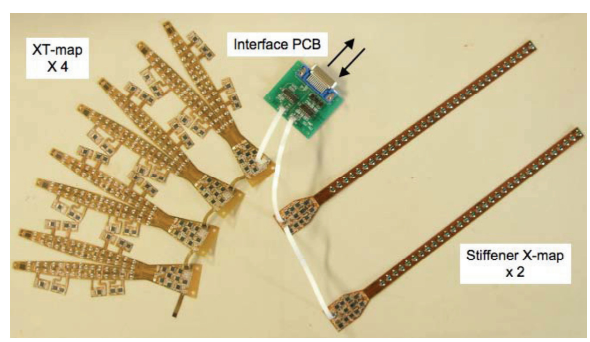

Figure 4: Experimental assembly consists of XT-map sheets and Stiffener X-map sheets. The sheet cables are used for the daisy chain. The lines are connected to room temperature area through an interface circuit.

Stiffener X-map

X-ray measurement around the narrow cavity iris zone is interfered by the stiffener ring. Therefore a special X-map system is separately developed so that X-map sensors can be installed under the stiffener rings as shown in Fig. 6. This Stiffener X-map system consists of the eight strips, where each strip has 32 photo diodes, a 32-ch MPX, and an integrating amplifier. The outputs of the amplifiers connected to a signal line is sequentially turned on for the scan.

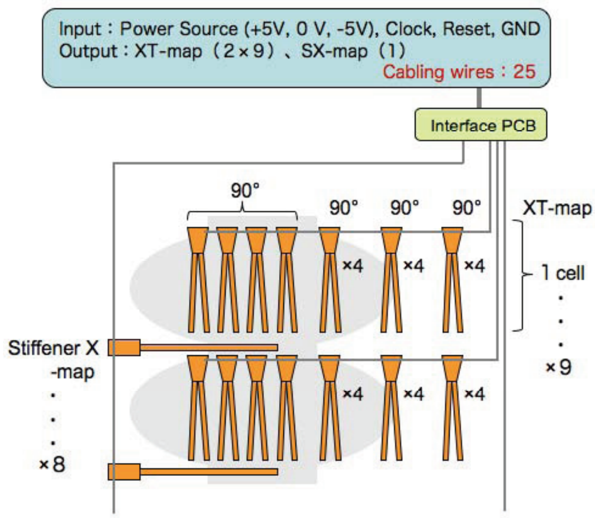

Figure 5: The schematic drawing of our inspection System (XT-map and Stiffener X-map system).

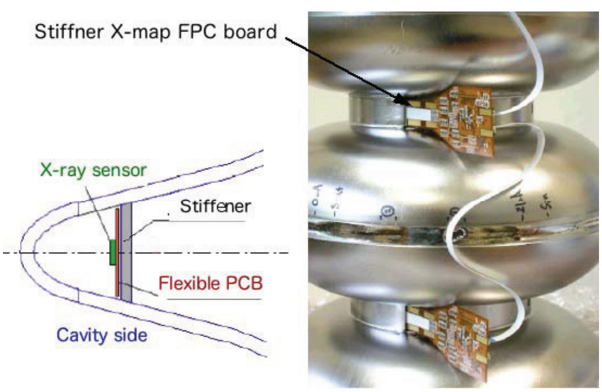

Figure 6: Stiffener X-map test circuits and its installation. The ribbon shaped FPC boards are installed under the stiffener ring.

DETECTION OF QUENCH

A preliminary quench detection test of XT-map was performed on a SC cavity which was known to have a quench location by a previous vertical test at KEK. As shown in Fig. 7, 4 XT-map FPC boards were installed on 1/4 area (90 degrees) of a cell, where a heat generation is predicted. Fig. 8 is a typical measurement result of T-map with a heater installed on the cavity (a pseudo heat generation) in the detection test. Not all the sensors worked correctly in these results. They are supposed to have insufficient thermal contact between the sensors and the cavity exterior surface, which has to be improved. The quench detection itself were possible with other sensors because of the super-multipoint measurement (high-density sensors). Fig. 9 shows the typical measurement results at actual quench events. The amplitudes of measured T-map outputs were above 100 mV for sensors around a heat generation point. 100 mV corresponds to a temperature rise from 2 K to 10 K.

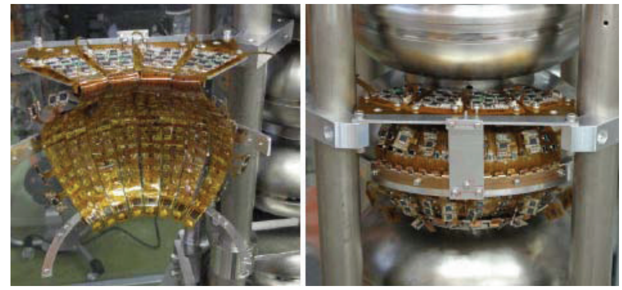

Figure 7: Installation of test of XT-map assemblies for the quench detection at KEK.

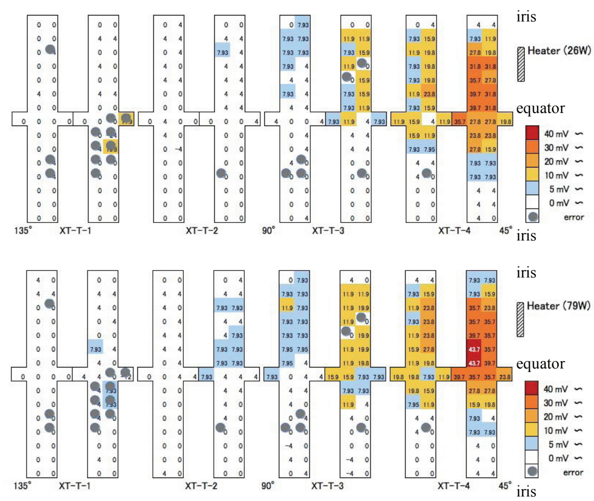

Figure 8: Measurement result of the temperature rise survey with 26 W and 79 W heater.

Almost all of the obtained events during this test are similar to these two measured patterns shown in Fig. 9. The temperature rise time is estimated about 0.5 sec, because a scan cycle is about 0.216 sec (the measurement time per sensor is about 0.85 msec) in this test. If the temperature rise time is 0.5 sec, a detection miss of a quench may happen at the 1 kHz sampling rate (a scan of 9-cell cavity takes about 1 sec). Fig. 10 is row output signals with 1 kHz sampling rate. The signals in a channel have data sufficient to reduce the sampling time less than 1/2. So, our T-map system can operate over 2 kHz sampling rate.

SUMMARY

Basic design of XT-map system for non-destructive inspection during the vertical test has been established. Although sensitivity of the adopted X-map and T-map sensors are less than those used in other laboratories, both sensors show sufficient performance in our XT-map system. Issues such as insufficient thermal contacting of sensors were found in this quench detection test, which will be resolved in a next version.

Brushing up of the installation assemblies of the XT-map, and optimization of the operation parameter, will be performed.

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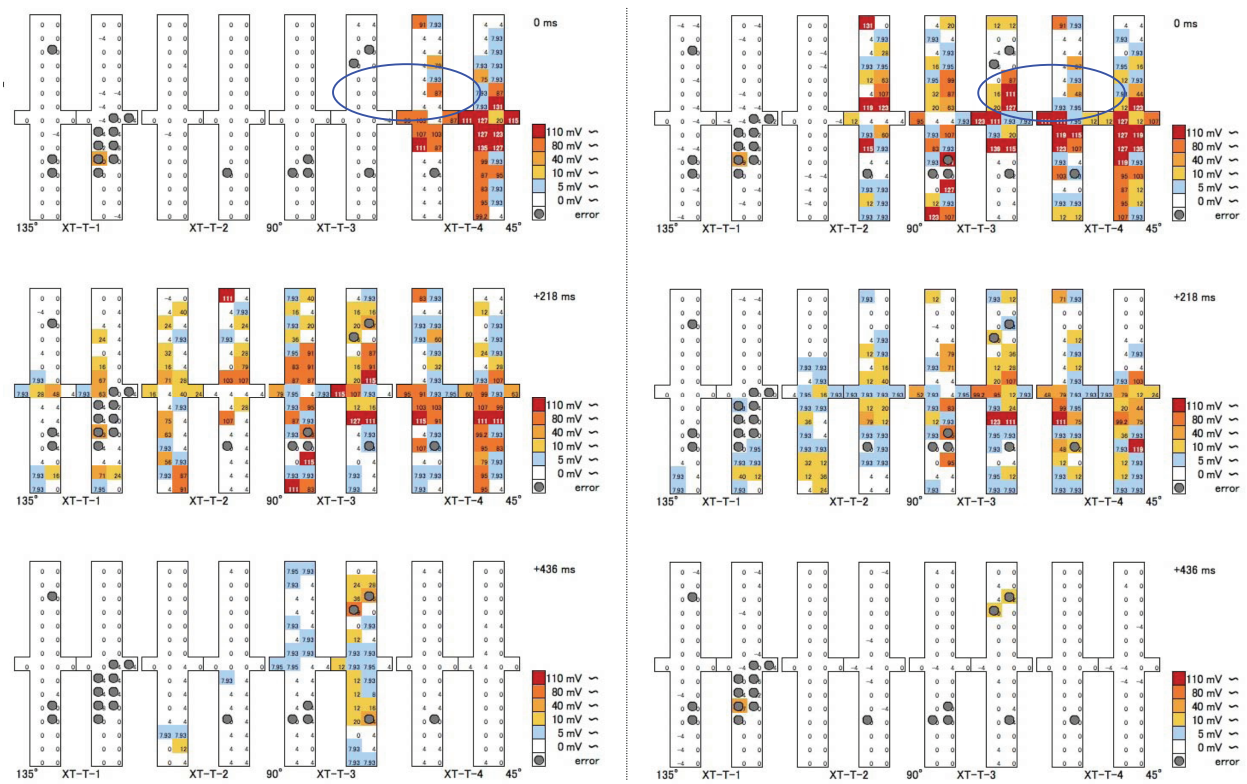

Figure 9: Typical two measurement results of the quench detection test of XT-map during the vertical test. The circles are quench location previously observed by KEK T-map. The temperature rise time is estimated about 0.5sec, because the scan cycle is about 0.216 sec.

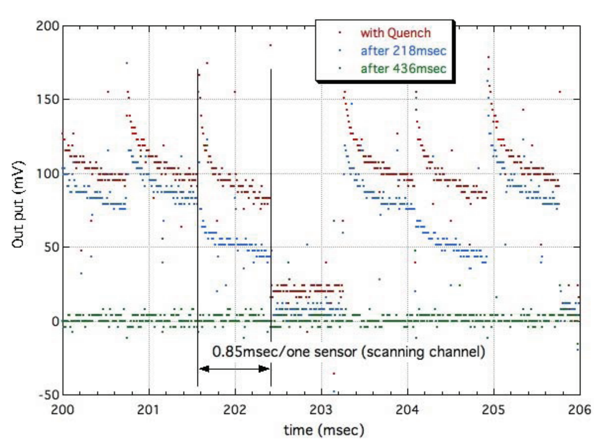

Figure 10: Raw output signals of T-map during quench. Signals from several T-map sensors around a quench event can be seen.

REFERENCES

[1] Y. Iwashita, Y. Tajima, H. Hayano, Development of High Resolution Camera for Observations of Superconducting Cavities, Phys. Rev. ST Accel. Beams, 11, [093501-1]-[093501-6], 2008.

[2] Y. Yamamoto, H. Hayano, E. Kako, S. Noguchi, T. Shishido, K. Watanabe, PROGRESS OF HIGH GRADIENT PERFORMANCE IN STF 9-CELL, Proc. IPAC2012, 2233-2235, 2012.

[3] K. Watanabe, H. Hayano Y. Iwashita, CAVITY INSPECTION AND REPAIR TECHNIQUES, Proc. SRF2011, 598-602, 2011.

[4] Balle, Ch., Casas-Cubillos, J. et al, “Influence of Thermal Cycling on Cryogenics Thermometers” Advances in Cryogenic Engineering 45B, Plenum, 1999, pp. 1817.

[5] H. Tongu, et al., “UPDATE ON SC CAVITY INSPECTION”, Proc. LINAC10, 836-838, 2010.