DEVELOPMENT OF HIGH SENSITIVE X-RAY MAPPING FOR SC CAVITIES

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Abstract

We developed an X-ray mapping system sX-map for superconducting cavities. The sensors are inserted under the stiffener rings between cavity cells, whose locations are close to the iris areas. The whole circuits are immersed in liquid He and the multiplexed signals reduces the number of cables to the room temperature region. sX-map has the advantages in its compact size, low cost and simple setup for nondestructive inspections. The sX-map system detected X-rays from field emissions in vertical RF tests of ILC 9-cell cavities at Jefferson Lab (JLab) and KEK. sX-map showed an excellent performance in the measurement test at JLab, it exhibited a high sensitivity compared with an the fixed diode rings colocated at irises and ion chamber located out side of the vertical test cryostat.

INTRODUCTION

The upper limit of the accelerating gradient of the SC cavities seems to be affected by the condition of the interior surface. One of main cause of this performance deterioration in comparison with the specifications of SC cavity is the quenching phenomena at local heat sources due to defects such as scratches. Another one is the field emission due to dust particles in tens of μm and the roughness of a few hundreds μm. As for the field emission, the Q-factor drops and quenches are seen. Risks of contamination such as the dusts in particular, its risks exist until the last assembling is over. Therefore the non-destructive inspection is important and necessary for the spatial high-resolution survey of the interior surface on R and D of SC cavity.

Among varieties of nondestructive inspections for the superconducting (SC) cavity, 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 and dust locations during the vertical RF tests. A mapping system under is development in collaboration between Kyoto University and KEK, which consists of T-map and X-map for the 9-cell niobium cavity of the International Linear Collider (ILC) [1].

The cryogenic performance tests for each component of our mapping system had been carried out at KEK. The preliminary detection test of T-map and X-map with the prototype models was performed on SC cavities that were known to have a quench location by the previous vertical test for SC cavity. Our T-map system got useful results for finding a defect causing a local temperature rise and finally the quench. Then we tried to detect X-rays with our mapping system at Jefferson Lab. The development status of X-map on a laboratory finding in JLab is reported.

MAPPING SYSTEM

The basic design for our mapping system is almost finalized. The schematic drawing of our mapping system is shown in Fig. 1. In comparison with X-map and T-map methods in some other laboratories, our mapping system has the following features, which are still under improvement.

- Use of low-cost components
- High-resolution survey
- Reduction of number of wiring signal cables
- Easy installation

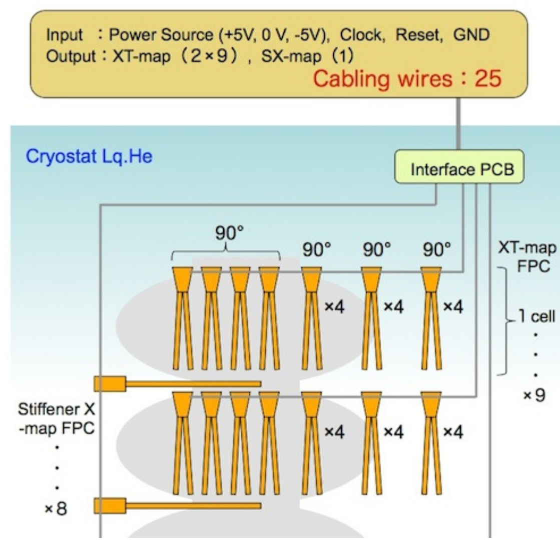

Figure 1: The inter-connection for the XT-map system and Stiffener-X-map in the schematic design.

Only commercially available components are assembled on Flexible Printed Circuits (FPC) sheets for our mapping circuits. Almost all components are low-cost on market. The circuit boards consist of sensors, amplifiers and multiplexers. The huge amount of sensors (T-map:1024/cell, X-map:256/cell, X-map:32/iris) are installed in this system for the high-resolution survey. T-map sensor is Ruthenium oxide (RuO_2) chip resistor and X-ray sensor is PIN photodiode [2]. Both sensors are chosen as our mapping system's sensors in consideration of performance, package size, cost, and availability on market [3]. Although both the sensors adopted have less sensitivity compared with sensors used in other T-map and X-map systems for example carbon resistors, or big sized photodiodes, these sensors have enough sensitivity for our mapping system with the on-board amplifiers.

In the cryogenic area, the reduction of the number of wiring signal cables has been achieved by the daisy chained sensor-circuit boards and the signal multiplexers. The less number of cables brings the low cost and less heat intrusion from the outside of the cryostat. The sequentially scanned signal output through the daisy-chained system has speedy sampling rate faster than 1kHz (a scan of 9-cell cavity takes about 1 sec).

Improvement for stable operation and easily handling have been performed. This mapping system is equipped with two kinds of measurement circuit boards as shown in Fig. 1. Fig. 2 shows the newest prototype (XT-map ver.4 and Stiffer-X-map ver.2). XT-map circuit is the combined system of T-map and X-map and is installed around the equator on exterior of the cavity (Fig.3). Stiffener-X-map strips are installed under the iris stiffener rings between cavity cells (Fig 3, 4). The cabling for the sX-map and the XT-map of each cell are independent each other from the interface PCB as shown in Fig. 1, therefore each installation and operation is possible.

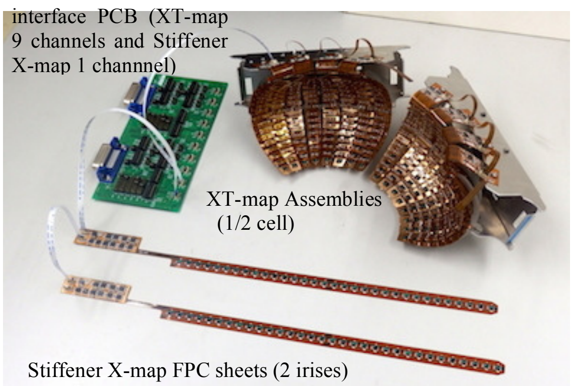

Figure 2: New FPC assemblies for Ver.4 XT-map (1/4 cell) and the Ver.2 Stiffer-X-map (2 iris). These have sensors, amplifiers and multiplexers on FPC sheets (polyimide film with several layers).

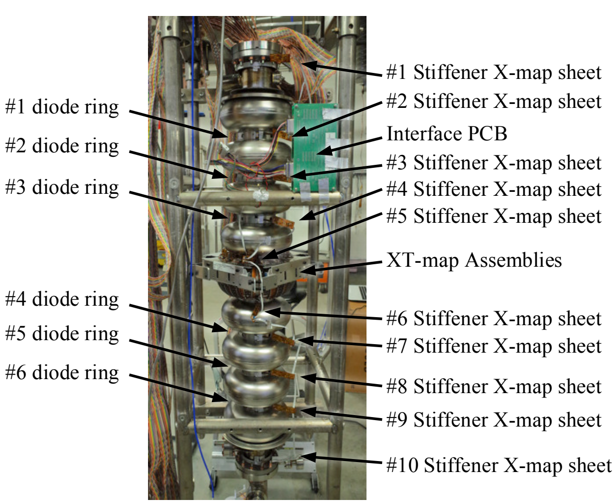

Figure 3: XT-map (1 cell) and Stiffener-X-map (10 strips) test circuits and its installation with vertical test at JLab.

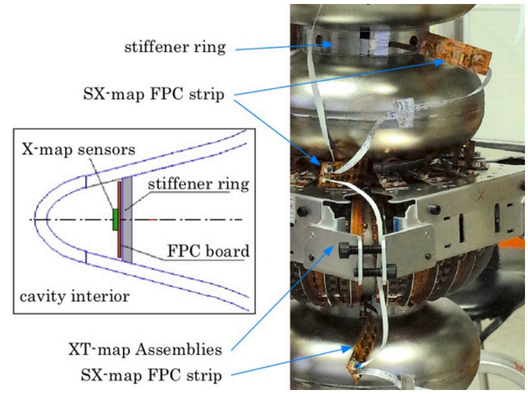

Figure 4: Stiffener-X-map FPC strips are installed under the stiffener rings.

XT-map

In order to cover an exterior surface of a cell with as many dense sensors as possible, the XT-map circuit board has a double-leaf shape. 16 XT-map sheets can cover the whole one-cell and connected by the daisy-chained lines. The T-map sensors have independent springs in order to have sufficient thermal contacts between the T-map sensor and the exterior surface of the cavity.

A preliminary quench detection test using an XT-map ver.3 assembly was performed on an ILC 9-cell cavity which was known to have a quench location by a previous vertical test at KEK [4]. These results showed the feasibility of our T-map system, which consists of the huge amount of sensors and its sequential scan circuit at the cryogenic region.

Stiffener-X-map

Conventional X-ray measurement around the narrow cavity iris zone is interfered by the stiffener ring, because X-map sensors have to detect X-rays through two niobium sheets of a cavity and a stiffener ring as shown in Fig. 3. Therefore a special X-map system (the ribbon shaped Stiffer-X-map) was developed so that X-map sensors can be installed under the stiffener rings. This Stiffener X-map system consists of the eight strips, where each strip has 32 photodiodes with an integrating amplifier. This system is able to the number of SX-map strip circuit. The sX-map strips can be installed at the cavity flanges of the top and bottom in addition to 8 irises totally 10 strip are installed in the configuration of Fig. 5.

The SMD (Surface Mount Device) photodiode has less sensitivity as a X-ray detector because of the smaller sensitive area compared with a big sizes metal-can package device, a brief integrating amplifier in the X-map circuit is installed in each strip. A charge accumulated during the scan interval is collected by the integrating amplifier.

MEASUREMENT RESULTS

A vertical test was carried out at JLab, and field emissions started at about 16 MV/m. In an attempt to enhance field emission, the cavity was cooled down up to 4K with a 10^{-3} mber vacuum.

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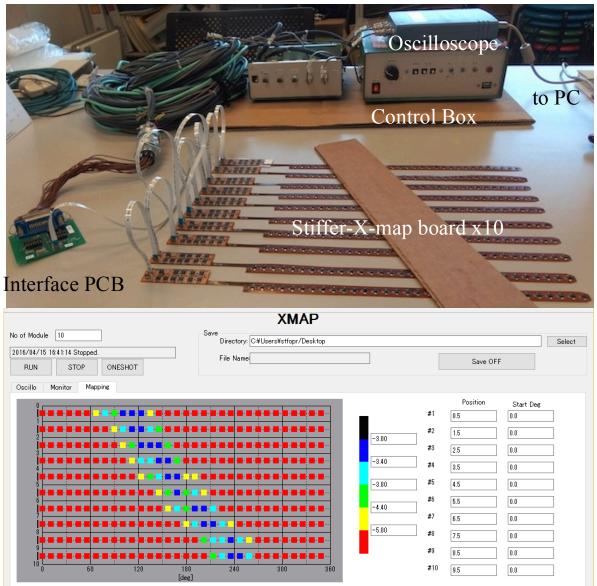

Figure 5: The data acquisition system for SX-map (Ver.2 FPC board). A USB connected PC oscilloscope converts the multiplexed sensor voltage train transmitted through a pair of signal lines together with a clock signal. The acquired data is processed in a notebook-PC. A screen shot of the measurement software is shown in the bottom, where sX-map detects the infrared light from fluorescent room lamps as shown in the photo above. A shade bar was placed on SX-map. The red dots indicate detection of infrared light from fluorescent room lamps.

Our X-map system showed high sensitivity in compared with the JLab X-map system with 16 diode sensors were installed outside of six stiffener rings. The nominal operation of our mapping system is at 1 s/scan. the sensitivity was reduced by raising the scan rate (0.2s/scan : integrating amplifier time is about 20%) as shown in Fig. 6-a. Most of the sensor signals were saturated at the quench (acceleration gradient 18 MV/m with pi mode), sX-map with high-sensitive operation (2.5s/scan : integrating amplifier time is about 250%) was able to detect the low level X-rays (acceleration gradient 10MV/m with pi mode) that was not even detectable by the ionization chamber type survey meter located out side of the vertical test cryostat (Fig. 6-h).

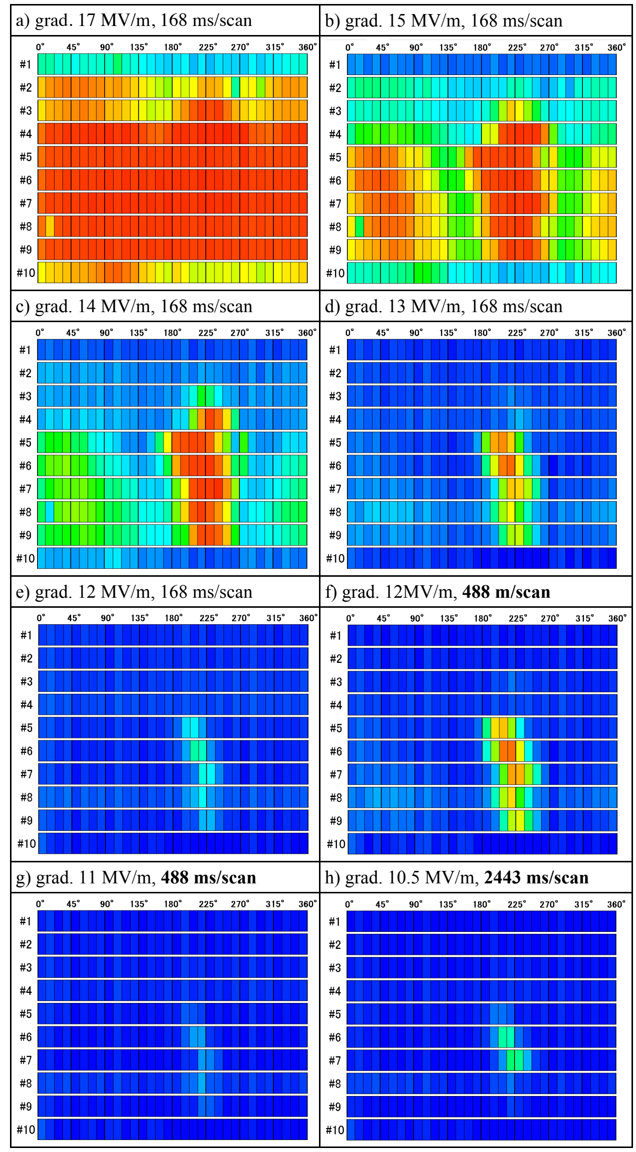

Figure 6: The screen shots of measurement results with Stiffer-X-map. For example, #6 SX-map board is installed at an iris between 5th and 6th-cell from the cavity top. And the locations of #1 and #10 are top and bottom flanges. The horizontal axis is an angle of sensor position on each iris. The signal display becomes close to red so that an output signal is strong.

CONCLUSIONS

sX-map has been proven to have an excellent performance in this measurement test. SX-map realized enough high-speed scanning and high-sensitivity under the downsizing and the low cost.

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