DEVELOPMENT OF INSPECTION SYSTEMS FOR SUPERCONDUCTING CAVITIES

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Abstract

Development of inspection systems including high resolution camera for inner cavity surface, thermometry system for a cavity outer surface, and Eddy current scan for bare Nb plates are described. The cavity camera system revealed undiscovered defects at the inner sides of the locations predicted by passband-mode and thermometry measurements. A thermometry measurement system and an eddy current scan system are under development.

INTRODUCTION

Inspections of superconducting (SC) RF cavities seem essential in achieving high accelerating gradient. The inspection of the interior surface with high enough resolution to find defects more than several tens microns is achieved by our high-resolution camera system. This system revealed undiscovered defects at the inner sides of the locations predicted by passband-mode and thermometry measurements (see Fig. 1)[1]. This system will help to improve cavity fabrication processes and their yield. We are planning to widen our activity in this field: developments of a new thermometry system with easy installation and less cabling, and high sensitivity eddy current surface inspection system for bare Nb sheets. The detailed systems and some preliminary data obtained from the systems are presented.

HIGH RESOLUTION CAMERA

This high-resolution camera system is developed to search the defects and measure the shape of them for better yield of accelerating gradient of SC 9-cell cavities. As shown in Fig. 2, a black cylinder with EL (ElectroLuminescence) sheet as an illuminator on it having a camera inside is inserted into a cavity. The camera directs to the cylinder head and looks a reflected image of the cavity wall on a mirror installed in front of the camera [1]. The improvement of this system has been performed for the industrialization toward worldwide delivery. Figures 2-6

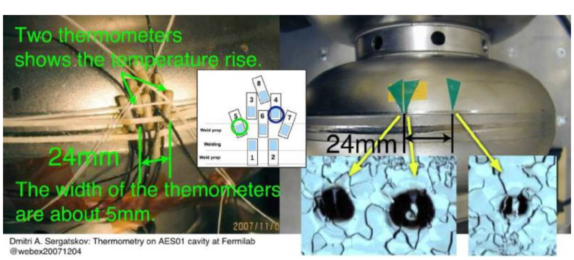

Figure 1: Positions of the two hot spots found at FNAL (left) and those found at Kyoto (right). The inset of left figure shows the location of the thermometers. The two thermometers (#4 and #5) that showed abnormal temperature rise are marked. (Courtesy of FNAL/JLAB.)

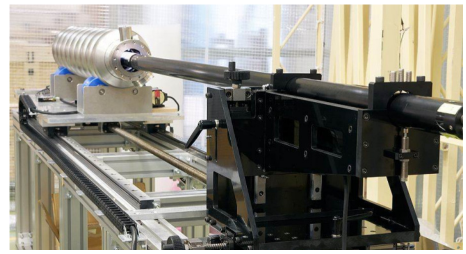

Figure 2: Production model of the inspection system.

show the production model of our inspection system. The improvement points are listed as follows:

1) The width of EL strip illumination is reduced from 10 mm to 7 mm for a better resolution in the shape measurement (see Fig. 3).
2) The EL illuminator is separated from the pipe unit, and all the electric wirings from the module are though two connectors for an easy replacement; its life may be up to a few thousand hours.
3) The EL illuminator unit slides with the mirror angle to keep the peephole on the sight line of the camera (see Fig. 4).
4) The half mirror for the coaxially illuminating LED is located before the tilting mirror to keep the illuminating direction and the sight line of the camera the same at any tilting angle.
5) The head assembly including the EL illuminator and mirror units is demountable from the camera cylinder. This modular structure also helps its maintenance. (see Fig. 5)
6) The camera lens is accessible by removing the head assembly and sending the camera all the way out. The magnification or even the lens itself can be changed at this position.
7) The damper against the vibration of the camera cylinder is installed on the cylinder support.
8) Better interface for the lighting control: each EL strip can be independently turned on/off. Any lighting pattern can be rotated right and left at a rate of about 2 Hz (see Fig.6).
9) The cavity table is retractable for easy shipping.

Figure 3: New EL stripe illuminator. The strip width is reduced from 10 mm to 7 mm; hence, the number of strips increases from 14 to 20. The camera looks through a peephole located at the center of strips.

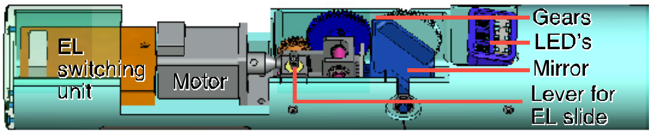

Figure 4: The new head assembly. The mirror is tilted by the pulse motor to change the sight line. Coaxially illuminating LED's located before the mirror enable us to observe a surface normal to the sight line of the camera at any mirror angle, where the EL strip is absent for the peephole. The EL sheet slides with the mirror angle by a lever to keep the peephole on the sight line.

Figure 5: The camera and new head assembly. They can be easily separated and all the electrical connections are through the pins, which makes the assemblage and maintenance easy. Left: Camera cylinder. Right: Head assembly.

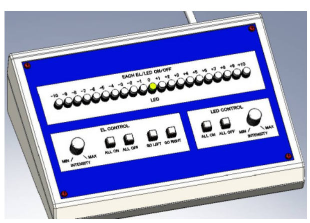

Figure 6: The EL controller box.

We are trying to track the cavity surfaces throughout the surface processes at STF with this camera to evaluate the correlation between the surface conditions and the hot spots quenching during vertical tests. This information will help to screen out bad cavities at early stages of the production line of the cavity. Figure 7 shows typical pictures of inner surface of before and after the electro-polishing (EP) process taken by this camera system. It shows that the grain boundary becomes eminent with the EP process. Measurement of the shape of bosses or pits with the stripe illumination is not available before the first EP because the surfaces are not shiny. Preliminary results for AES001 and Zanon111 show bosses or pits of a few hundreds µm in diameter and a few tens µm around the hot spots at low accelerating gradients (Fig. 1). Further observations of many cavities will increase the statistics and clarify the correlation.

THERMOMETRY SYSTEM

A thermometry measurement is a good tool for finding defects on the insides of superconducting cavities. It measures a temperature map of outer surfaces of the cavity under application of RF power during the horizontal

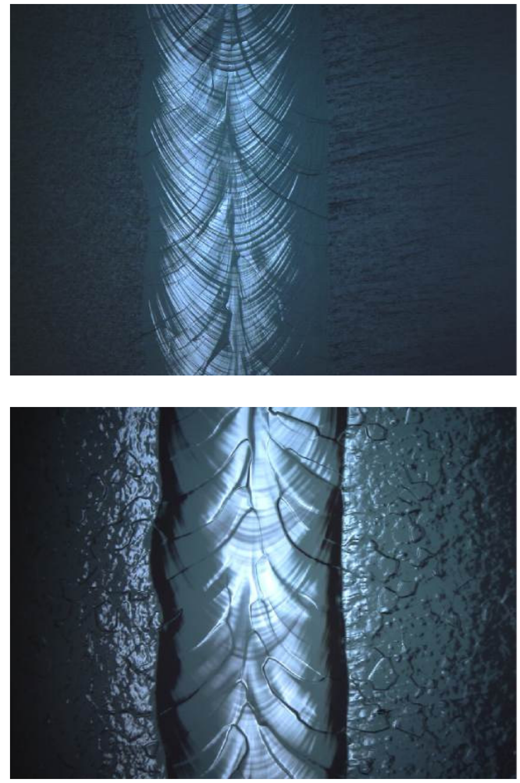

Figure 7: The inner surface (EBW seam) of SC cavity before (top) and after EP process (bottom, 125 µm removed.). The picture size is 13 mm x 9 mm.

test. Suppose that the total surface area is in the order of 1 m^2, and the spacing between the temperature sensors is 1 cm in both longitudinal and azimuthal directions, 10^4 sensors are needed for a system. These massive signals have to be extracted from the cold region. Cabling such signals with separate wires will make the number of wires enormous, which increases the heat intrusion to the cold area and their installation becomes complicated.

The temperature sensors should have high sensitivity at the low temperature. Figure 8 shows a measured result of resistances of typical Ruthenium oxide based thick film resisters at low temperature regions. Although not many data points are available, they show high sensitivity at cryogenic temperature. In this experiment, the 10 kΩ resistor shows higher sensitivity than the 1 kΩ. This kind of device seems promising for the thermometry system because of its availability and low cost [2].

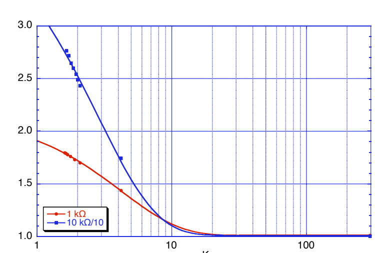

Figure 8: Measured resistances of 1kΩ and 10kΩ chip resisters as a function of temperature. The fitting curves are just guides for eyes.

Although many of circuit components do not work at the 2K regime, digital CMOS circuits such as inverters and analog switches worked fine in a preliminary test [3]. An 8-to-1 analog multiplexer (74HC4051) built from these elements should work at this temperature. Using these devices, we can construct a 512-to-1 multiplexer combining 512-sensor signals into one. The number of wires to be supplied would be eight for this system: three power supply lines, two output lines, two addressing lines and a ground line.

Installation of the sensors would be simplified by a concept shown in Fig. 9. The devices are mounted on a flexible printed circuit board (PCB). The resistive sensors are located on each separated strip (see Fig. 10) while the analog multiplexers are mounted at the common area (see Fig. 11). The sensors are mounted on the facing side of the PCB and pushed against the wall surface by squeezing the strip at the neck (see Figs. 10, 12). Because it was confirmed that the flexible PCB does not loose its flexibility at 77 K, it is supposed to hold the property even at 2 K. Further preliminary tests are under preparation. Since the density of the sensors on the cell is not enough, other PCB layout will be developed later to raise the sensor density.

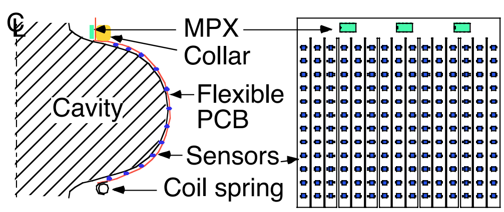

Figure 9: Conceptual sketch of an easy installation of sensors. The sensors are mounted on a flexible PCB that is wrapped around the cavity cell.

EDDY CURRENT SCAN

Screenings of bulk Nb plates at the beginning would help to reduce the defects on the inner surfaces of cavities. This step has to be carried out before making the cups. We are seeking to use a special high-resolution eddy current scan for that purpose [2]. By setting exciting field perpendicular to the detecting coil, a detecting coil does not magnetically couple to it and only the disturbances from defects on the specimen surface are detected. Two excitation coils 90° rotated each other around the normal axis to the specimen surface with 90° excitation current will generate a rotating field and the detecting capability will be raised (see Fig. 13). About 0.1 mm diameter hole with 0.1mm depth can be detected so far.

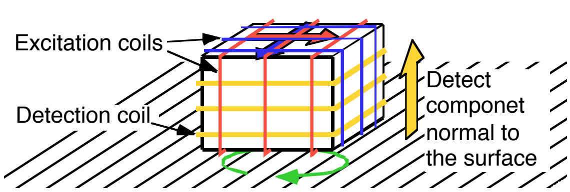

Figure 13: Excitation coil configuration. They generate a rotating magnetic field on the specimen surface.

Figure 10: The flexible PCB

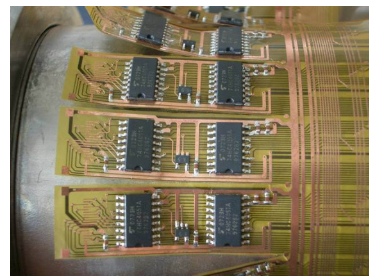

Figure 11: Analog multiplexers mounted on a demonstration setup.

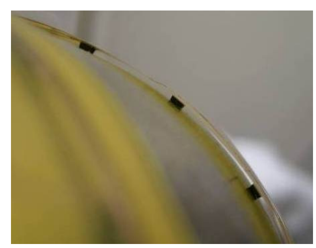

Figure 12: Sensors mounted on a flexible PCB are pushed against the wall surface.

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