UPDATES ON R&D OF NONDESTRUCTIVE INSPECTION SYSTEMS FOR SRF CAVITIES

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Abstract

We are developing high resolution eddy current scan and high density T-map and X-map instruments. The high resolution eddy current scan recognizes a 100 µm diameter hole with 50 µm depth that was drilled on a Nb plate. The surface mount printed circuit technology is applied to the high density T-map and X-map devices, where 1024 T-sensors can be distributed on a cell with ease of installation. In addition, radiography using X-rays and neutrons are also under study.

INTRODUCTION

After the success of the superconducting cavity endoscope[1], nondestructive inspections for sc cavities have been regarded as even more important tools than before. Among many such nondestructive inspection items, we are developing high resolution eddy current scan[2,3] and high density T-map and X-map instruments. The former eddy current scan system inspects Nb sheets before the press and records the data. This enables us to screen out suspicious Nb sheets at the early stage and every completed cavity will have their histories on the material, which should help to raise the production yield at high field gradient. The latter T-map and X-map are used in vertical tests, which will enable us to locate defects by detecting heat spot positions and/or high radiation areas with high spatial resolution. In addition to these items, radiography techniques using X-ray and neutrons are also under study.

EDDY CURRENT SCAN

Fig. 1 shows the completed eddy scan table. While the turn table rotates the Nb sheet on it, the probe head moves from outside to inside. The path is a spiral with 100 µm spacing from radial position of 135mm to 25mm. The relative speed is 1m/s and the sampling spacing is kept less than 50 µm while the timing is given by a rotary encoder installed on the table shaft. By keeping the velocity constant, the rotation speed goes up during a scan (about 5 times). A differential probe is used to detect the signal, using a pair of 0.3 × 0.25mm ferrite needles with sharpened tips and each needle having a pickup coil to detect the signal (see Fig. 2). The set of the needles is wound with an excitation coil whose frequency is a range of 1kHz to 2MHz. The excitation current and the signal processing are provided by ASWAN JSAID-3X200 (ASWAN E.S. Co.,Ltd). Both I and Q signals are recorded through 16-bit ADC (AIO-163202FX-USB), whose acquisition rate is up to 500 ksps. A test Nb sheet with 19 drilled holes was prepared to evaluate the resolution (see Fig. 3). The diameters of the holes are 500, 300, 200, 100 and 50 µm. The depths are 500, 300,

Figure 1: Eddy Current Scanner.

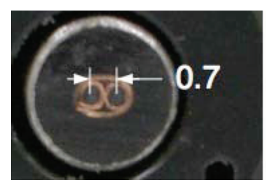

Figure 2: Eddy current probe sensor head. Differential sensor has two pickup coils wound on an excitation coil.

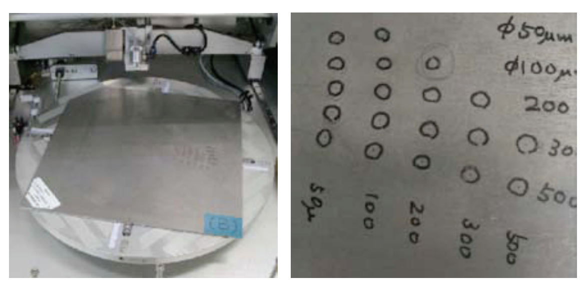

Figure 3: Nb test sheet.

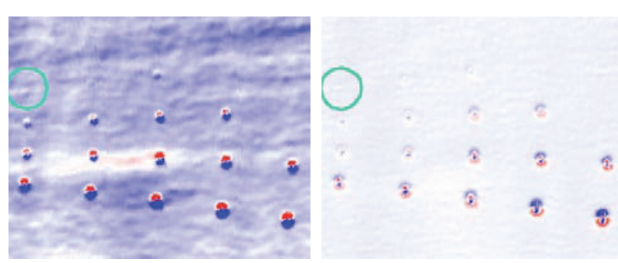

Figure 4: I-Q signals at the drilled holes area. ø100μm x 50 μm depth is barely detected in this run (marked by the circle).

200, 100 and 50 μm. The depths of the fine holes are limited because of the technical limitation. We could observe ø100μm x 50μm depth hole in the current setup (see Fig. 4).

Our ambition is to find a small void just under the surface, which may appear after surface treatments such as electropolishing (EP).

HIGH RESOLUTION XT-MAPPING

Temperature mappings have been a powerful tool to locate the defects that emit heat as hot spots during the vertical test. Higher spatial resolution will help to locate the position precisely. Because the carbon resistors that have been used for the cryogenic temperature sensors had been discontinued at Allen-Bradley, other sensors that can be used for this purpose were searched. Among such devices, we chose surface mount chip resistors made of RuO_2 as the sensors. The best candidate that we found was KTR18 made by ROHM Co., Ltd.(see Fig. 5) The resistance was determined by the sensitivity and time response. The cost of the device is very low and the size is also very small, which eases the design of the system.

By installing 1024 temperature sensors in a cell we need 9216 sensors for a 9-cell cavity, while the end cells may not allow us to cover all the surface. In order for us to transfer and record the detected signal from the cryogenic area to the room temperature area, these signals are analog-multiplexed to reduce the number of signal lines. The sensors are mounted on a flexible printed circuit sheet, which makes the installation easy (see Fig. 6). X-ray sensors are also mounted on the same printed circuit sheet. Photo diode (OSRAM BPW34FSR18R) is chosen as the X-ray sensor considering the size and sensitivity (see Fig. 7), while the sensitivity should be proportional to the silicon chip volume. The numbers of sensors on a leaf for T-map and X-map are 64 and 32, respectively. A couple of the leaves are connected and controlled together at the base. A block diagram of the T-map part is shown in Fig. 8, while the X-map is similar to this except that there is no current feed line and the signals are integrated to collect charges during the sampling period (see Fig. 9).

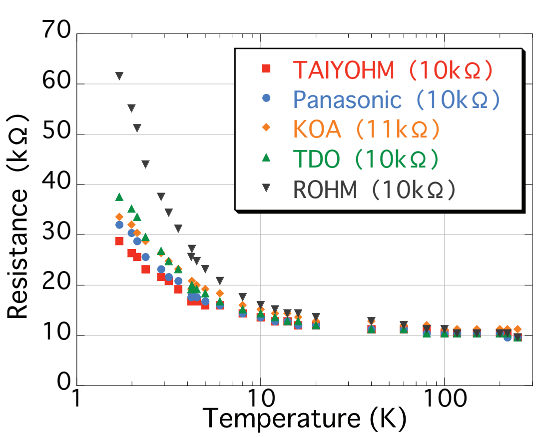

Figure 5: Resistances as functions of temperature.

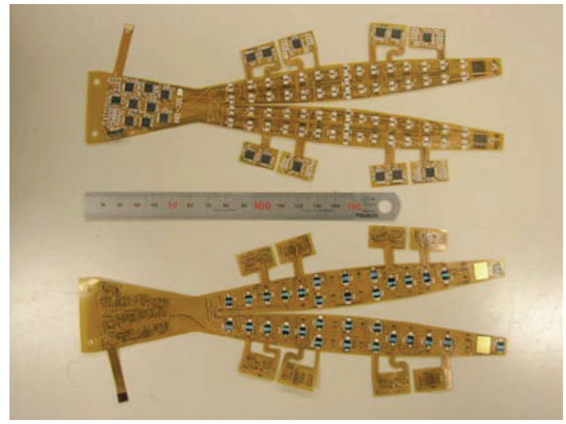

Figure 6: Sensors mounted on a flexible printed circuit. Top: Temperature sensors. Bottom: Photo diodes for X-ray sensors.

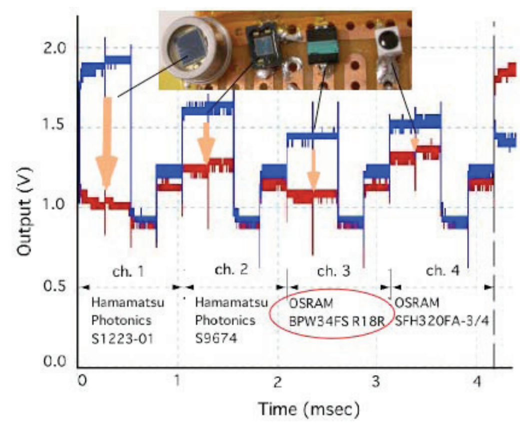

Figure 7: Response of X-sensors during field emission in a vertical test.

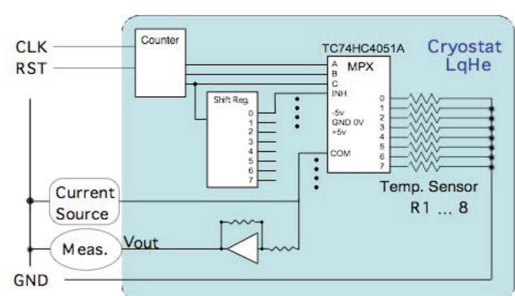

Figure 8: Block diagram of T-map part.

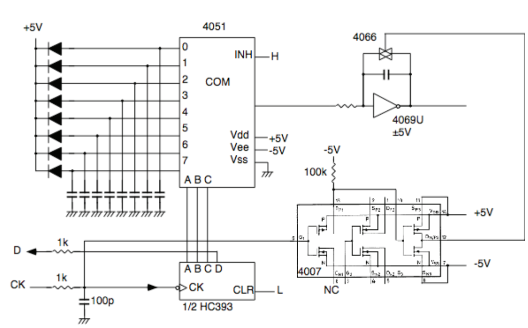

Figure 9: Test Integration circuit for X-sensors.

The current design has ten lines for a cell: three lines for power supply, two lines for clock and reset signal, current feed line, T-sense line and X-sense line, where two ground lines are added to form twist pairs for fast timing signals. With these ten lines, signals from 1024 T-sensors and 512 X-sensors are handled. Because the power lines and digital lines are common to all cells, less than 30 lines are enough for measurement of a 9-cell cavity. The current clock rate is 1kHz and the total scan rate is 1Hz.

Fig. 10 shows the installed sensors on a cell. Since the sensors are mounted on flexible printed circuit sheet, the installation is not difficult even for such thousands of sensors.

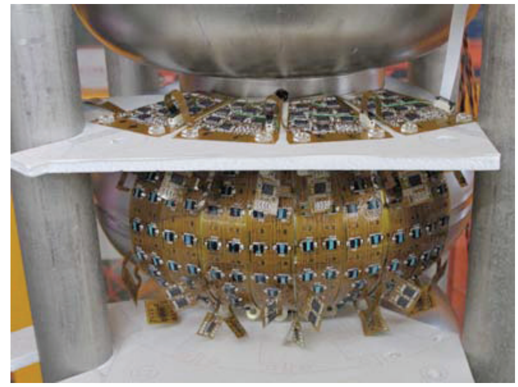

Figure 10: Installed XT-map sensors.

X-RAY AND NEUTRON RADIOGRAPHY

An EBW seam test piece that has sub-millimeter sputter balls was inspected by an X-ray radiography. A double focus X-ray source was used at 120kV, 300µA in large focus mode. A collimator with 24mm x 6mm was located at 670mm from the source. The test piece was put on the 2D detector which was located 540mm from the collimator. Sputter balls with sub-millimeter size were successfully detected in the experiment (see Fig. 11). Because the transmission of X-rays generated by the 120kV source is rather small, the exposure time was 600 s long.

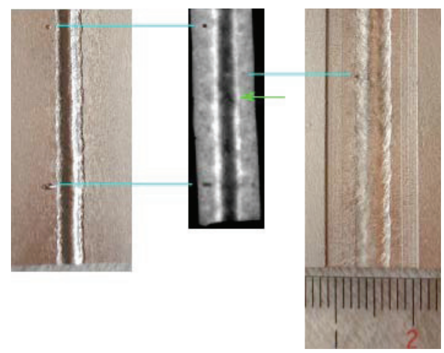

Figure 11: Observed sputter balls on the Nb test piece.

Another test at higher energy was performed by 450keV X-ray CT (Y.CT COMPACT 450kV XL). As expected the transmission even through two of 2.8 mm Nb walls were enough to inspect the two cell cavity(see Fig. 12). The resolution, however, was not enough to inspect the sun-millimeter sized sputter balls. The source size tends to increase with X-ray energy, while a collimation is difficult for high energy X-rays. There should be an optimum point between 120kV and 450kV for both transmission and resolution.

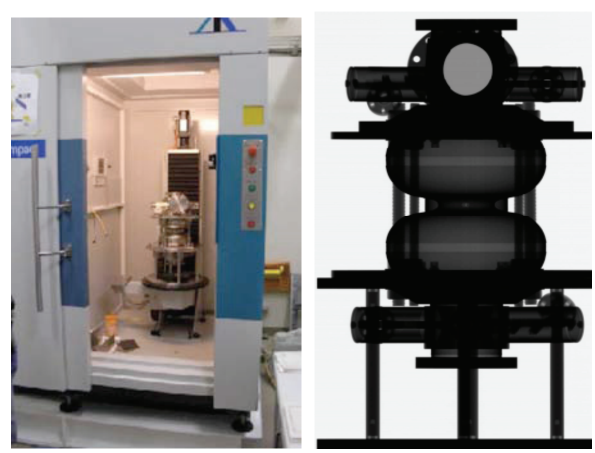

Figure 12 Left: 450kV CT. Right: Inspected 2-cell cavity.

Since neutron penetration power can be better than X-ray, a triangular plate that has a ø1.5 hole and buried ø0.5 tungsten carbide tips was CT scanned (see Fig. 13) at MUSASI beamline of JRR3. Since the neutron absorption of W is close to Ta, which is higher than Nb, n-CT may be effective for Ta detection in the Nb.

More possibilities are under investigation.

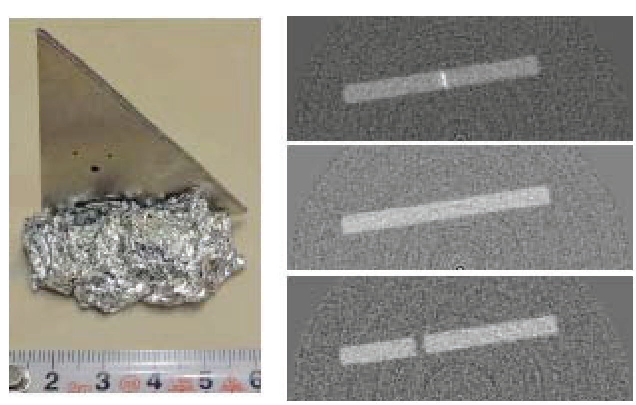

Figure 13 Left: the sample. Right: tomograms at buried ø0.5 WC tip(top), no defect(middle), ø1.5 hole(bottom).

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[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.