R&D OF NONDESTRUCTIVE INSPECTION SYSTEMS FOR SRF CAVITIES

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Abstract

Further improvements on KYOTO camera are performed. High density T-map and X-map will be achieved by surface mount print circuit technology. Preliminary test on eddy current scan showed promising results; real stand is under design. We are trying to measure the EBW seam height with a line laser projector and the camera system.

INTRODUCTION

Non-destructive surface inspections are important method to improve yields of super conducting cavities. Starting from the development of the high resolution optical inspection system, temperature mapping system, X-ray mapping system, eddy current inspection system for bare Nb plates are under investigation. Investigation of an auto-focus capability on the camera, automatic defect detection system and EBW bead height measurement are started.

IMPROVEMENTS ON KYOTO CAMERA

After successful observations of the defects with the first model (see Fig.1) [1], it has been improved from many aspects. The recent modifications include following items.

(1) Strip illumination system with LEDs.

More than ten times brighter and long lived compared with the former one that uses EL sheets. The direct illumination, so called the center LED, is moved behind the mirror, which reduces the dead space between the lens head to the object. The reduced minimum working distance can raise the magnification and resolution.

(2) Lens with large aperture

Since the resolution is limited by the lens aperture, working distance and wavelength of the light, a lens with a larger aperture gives better resolution. The new lens has about 50% more aperture.

(3) New C-MOS 9Mpix camera sensor.

The more pixels enable us to observe small objects clearly. It, however, takes longer time to transfer the data from camera and the resulted file sizes are large. Sub-sampling is useful technique in browsing the area. Transferring only selected area speeds up focus adjustments. The differences are listed in Table 1. Fig.2 shows images obtained from the two systems.

(4) Cylinder rotation mechanism

Cavities with cryo-jackets cannot be rotated. The aluminum cylinder with camera installed now has a capability to rotate up to ±185° to inspect them.

(5) Rotating laser pointer around the cylinder

Camera cylinder axis has to match with the cavity axis. A laser pointer is installed on the cylinder surface and parallel to the axis. It can be rotating around the cylinder and makes a light cylinder around the camera cylinder. It hits obstacles, if any, and can identify it easily. This eases the adjustments at the beginning of the inspection.

Some other minor improvements have been performed on the camera such as for the easy maintenance, operation, etc. Fig. 2 Shows the Kyoto Camera of the latest version.

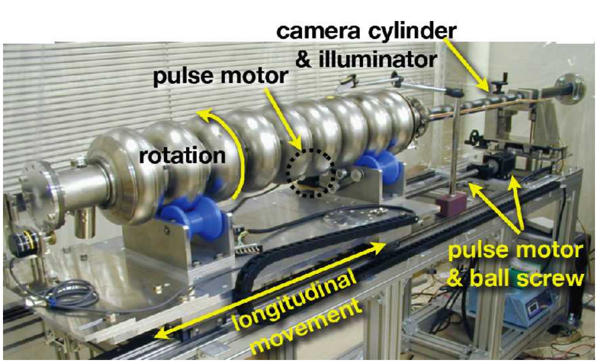

Figure 1: The first Kyoto Camera.

Table 1: Differences of the camera sensor

	Former system	New system
Sensor	3 layer CMOS	CMOS Bayer
Size	1/1.8”	1/2.3”
Pixels	1400 x 1000	3488 x 2616
Pixel Size	5 x 5 µm	1.75 x 1.75 µm
Magnification at 13 x 9 mm	9.3µm/pix	3.7µm/pix

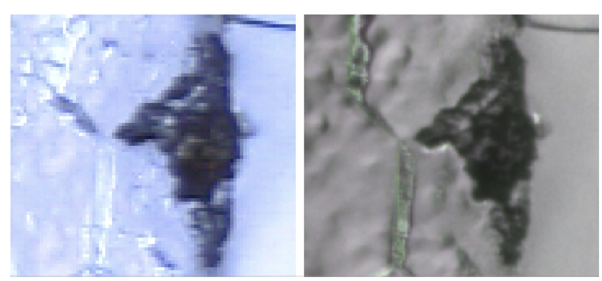

Figure 2: Pictures with the old system and new one.

Figure 3: The latest Kyoto Camera.

T-MAP SYSTEM

A high-density temperature mapping system is under development. Commercially available chip resisters (RuO_2) are found to be good temperature sensors at below 4K as shown in Fig. 4. The coefficient decreases with the test current, maybe because of the self heating. Although the sensitivity is not high compared with the ordinary carbonresisters, the chip resisters can be sufficiently supplied now. They will be placed on the cavity surface 1 cm apart, which will result the number of sensors is in the order of 10^4.

The readout lines are reduced by multiplexing them at the cryogenics level by CMOS analog multiplexers, where their functionality was also already checked at down to 1.6K. Because the internal resistance of the analog multiplexer was anticipated, two of them are used for current feed and voltage sense as shown in Fig. 5. The number of common lines is five: three power supply lines, one clock signal to run the sequence, and one reset signal to start the sequence. These common lines are distributed to the modules that have three signal lines: the current feeder and voltage sense line and the current-return/voltage-reference line. Shift registers are used to select and scan the multiplexers sequentially. Suppose that 1024 sensors on a cell are multiplexed in a module, nine modules are needed and 27 signal lines are needed besides the five common lines. This number will increase when a quick response is required, which will be discussed later.

The sensors are mounted on a flexible print circuit strip,

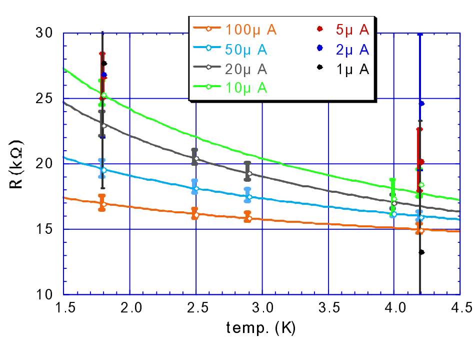

Figure 4: Resistances as a function of temperature.

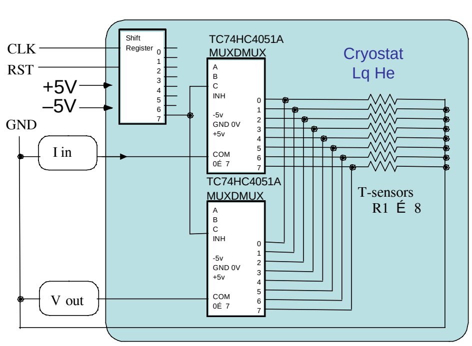

Figure 5: Block diagram of the T-map system. Only five lines are needed for a module that may have 1024 sensors.

where the polyimide strips are flexible even at cryogenic temperature. The strips are stretched on a cell surface by a coil spring at one side and the sensor chips are pushed against the wall by the tensions (see Fig. 6).

Fig.7 shows a typical output from the multiplexers, when the feed current was changed. The measured time response as shown in Fig.8 gives the maximum scan rate of up to 2.5 kHz, although some noise reduction may be needed. 2.5 kHz scan rate results 2.5Hz repetition rate for a cycle. The response may be improved by modifying the layout.

The small number of lines eases the installation of the system and reduces the heat intrusion to the cryogenics temperature region.

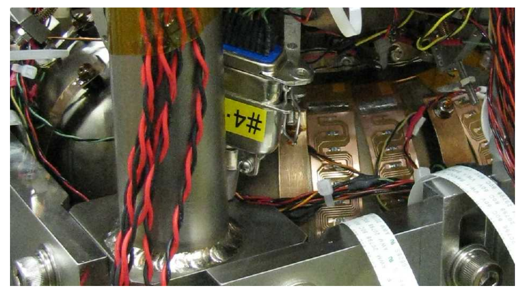

Figure 6: Installed sensor strips. Two sensor strips were installed between the conventional sensor jigs and evaluated during a vertical test.

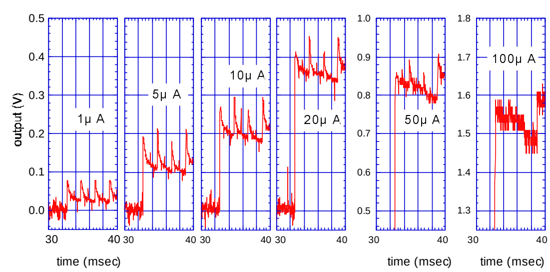

Figure 7: Typical output of the multiplexers at 4K. The sense voltages increase with the current. The switching rate is 500Hz.

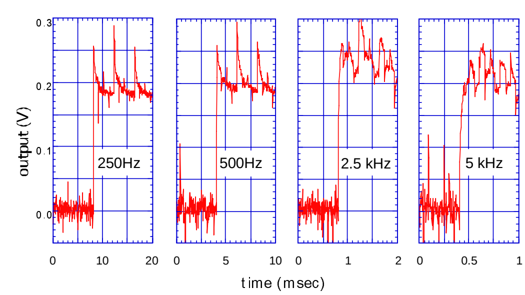

Figure 8: The time response.

EDDY CURRENT SCAN TEST

Eddy current scan is planned for Nb plates before the press. Fig.9 shows a Nb sheet sample loaned from FNAL, which has small dimples drilled on it. A scan test was performed by DENSHIJIKI INDUSTRY Co., Ltd. as shown in Fig. 10. EM/C ET5002A with probe: EPT-4 was used. The measured conditions are listed in Table 2. Fig. 11 shows the result of the eddy current scan test. Even the smallest one (0.15mm diameter and 0.6mm depth) was detected in this case.

Based on these results, we are planning to fabricate a scanning table. It turns a Nb sheet and scans a relevant area by moving a probe in radial direction.

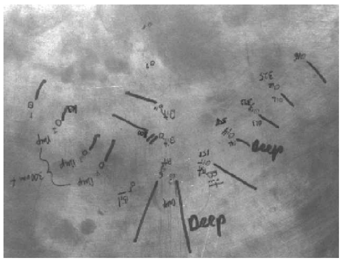

Figure 9: Nb sample sheet. Small dimples are drilled on it.

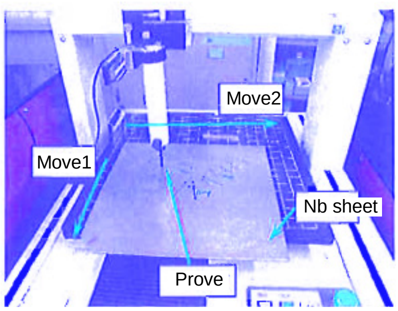

Figure 10: Eddy current scan test bench.

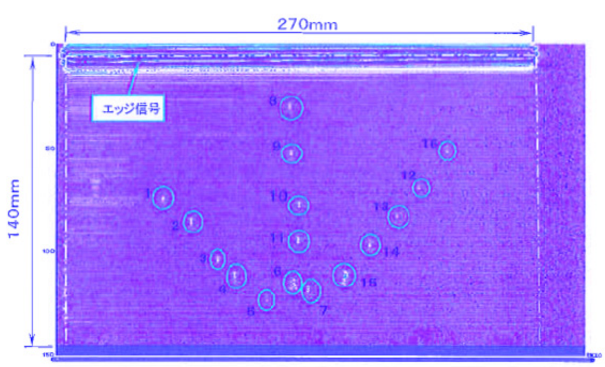

Figure 11: Eddy current scan test result.

Table 2: Eddy current scan conditions

Items	Values
Detecting Unit	ET5002A
Probe	EPT-4
Frequency	512 kHz
Sensitivity	42 dB
Noise Filter	10~220 Hz
Phase angle	63°
Lift Off	0.5 mm
Velocity	20 mm/s
Line space	0.2 mm

EBW SEAM HEIGHT OBSERVATION

We are interested in observing the EBW seam height in a cavity. It will require a resolution of about 10µm, and a laser height meter maybe adequate for this purpose. The minimum aperture of the cavity, however, is so small that we could not find any commercially available unit with such a size. Furthermore, because the surface is very shinny after EP, tested commercial units, which were too large to fit in, did not show successful results even on a test EBW plate in neither right reflection mode nor diffused reflection mode. Thus, we decided to test a combination of discrete devices, such as line laser projector and our camera.

Fig. 12 shows the layout of the test bench we used and the preliminary result. Because the length of the line projected by laser was too short to cover the EBW seam width, we superpose the observed images and the seam shape seems to be observed. We are designing a system based on the result.

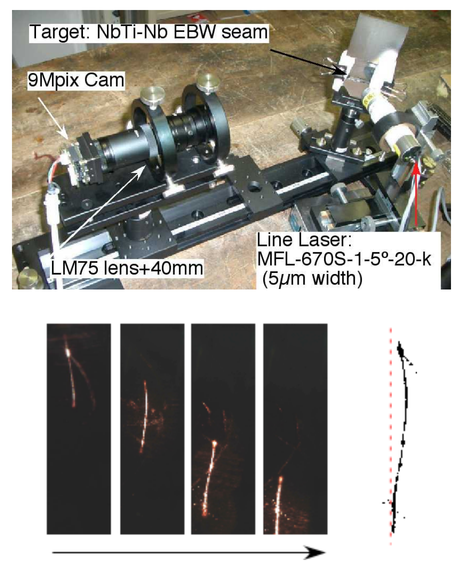

Figure 12: Test bench for the EBW seam measurement and the preliminary result.

CONCLUDING REMARKS

The improvements of Kyoto camera have been successful to adopt wider cases such as for a cavity with jacket on it. High density T-map system should be useful for finding abnormally heating location. High density X-ray mapping is also under consideration. Eddy current scan plan is just started; with a turn-table currently under design, we will test some probes to find out a suitable product to use. The seam height measurement will use the camera system of the Kyoto camera.

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