CAVITY DIAGNOSTIC SYSTEM FOR THE VERTICAL TEST OF THE BASELINE SC CAVITY IN KEK-STF

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Abstract

Four STF-Baseline superconducting cavities were fabricated from 2005 to 2006. They were named BL1, 2, 3 and 4. The feature is that these cavities have the stiffer structure than TESLA cavity. From Feb/2006 to Feb/2007, the vertical tests were done totally 14 times at KEK. These cavities were re-processed and measured repeatedly. The surface treatment processes are composed of Centrifugal Barrel Polish (CBP), Electro-Polish (EP) and High Pressure Rinsing (HPR). And, HF or H_2O_2 rinsing were added as the additional process later.

In the vertical tests, a monitoring system was introduced to search the heating spot on the equator and to check the radiation level around the cavity. It is composed of the carbon resistors and the PIN photo diodes. They were attached on the equator of each cell every 90˚, a few resistors around the HOM couplers and a few diodes on the top and bottom flanges of the cavity. MX-100 (YOKOGAWA) for the carbon resistors and NR-1000 (KEYENCE) for the PIN photo diodes are used as the data logger. The sampling time is 100 or 200msec. The heating spot was successfully observed during the test. The appearance of that on the equator was coincident with the quench of the cavity. On the other hand, the diodes were useful for checking the presence or absence of the field emission and they also were useful for monitoring the radiation level during the RF processing. The mapping display was introduced to identify the location. Consequently, it is conceivable that the quality of the electron beam welding was somewhat poor, when the dumbbells were connected.

INTRODUCTION

Four 9-cell cavities for STF (Superconducting RF Test Facility) were designed and fabricated [1-8], as shown in Figure 1. The surface treatment process including EP follows the traditional way in KEK. After the first EP, a pre-tuning of a cavity and HOM measurement are carried out at STF. And, an annealing is done in KEK workshop. After the final EP and HPR, the cavity is assembled for the vertical test in a clean-room at KEK.

After these processes, the cavities are measured in the vertical cryostat. In the vertical tests, a monitoring system was introduced to search the heating spot and check the radiation level during the test. The four resistors and diodes at each cell were attached every 90˚. An additional resistor was attached at cell #1, 2, 8 and 9. They were fixed at one point. The DAQ system is composed of the two PCs and two data loggers. Although the sampling time was originally 200msec, it was changed to 100msec later. The faster sampling time is crucial to detect the heating spot, because the appearance of the heating spot on the equator was coincident with the quench of the cavity. When the cavity is quenched, the field is damped within 1sec at 2K. And, the heating spot also disappears within 1sec. Therefore, it is necessary that the sampling time is below 1sec.

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VERTICAL TESTS

Four STF-Baseline cavities were repeatedly re-processed and measured in the vertical cryostat. Although an original goal field was 25MV/m, it was not easily accomplished. Therefore, these cavities were experienced CBP twice and EP+HPR many times. After the re-processes, the achieved field of each cell was gradually increased. It was identified by measuring the seven pass-band modes from $3\pi/9$ to π mode. Each cell has the different field in the other pass-band except π mode. It took normally two days to measure these modes and carry out the RF processing. This pass-band mode measurement is a strong technique for identifying the limiting cell, same as the T-mapping.

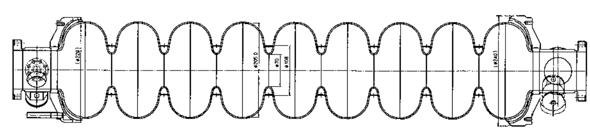

Figure 1: The STF Baseline 9-cell Cavity.

MONITORING SYSTEM

To search the heating spot on the equator and to check the radiation level during the vertical test, a monitoring system was introduced. The monitoring system is shown in Table 1 and Figure 2. Two data loggers and two PC's are used. MX-100 (YOKOGAWA) for the carbon resistors and NR-1000 (KEYENCE) for the PIN photo diodes are used as the data loggers. An amplifier circuits are used for the signals from the PIN photo diodes, because of the small output.

Table 1: Monitoring system.

	T-Mapping	X-ray Mapping
Sensor	Carbon Resistor (51Ω)	PIN Photo Diode (S1223-01)
Manufacturer	Allen-Bradley	HAMAMATSU
Data Logger	MX-100 (YOKOGAWA)	NR-1000 (KEYENCE)
Number	44	40
Attachment Position	Equator HOM coupler	Equator Beam axis
Sampling time	100 or 200msec	100 or 200msec

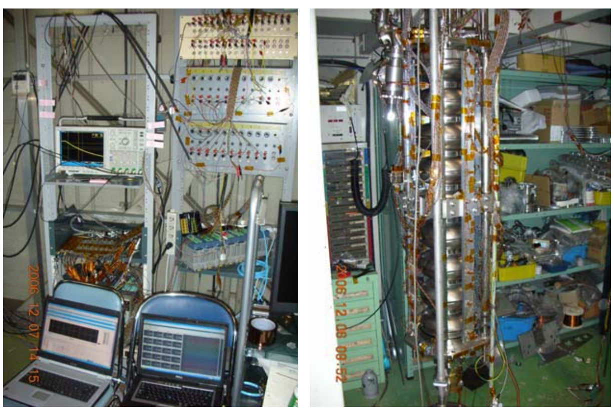

Figure 2: The monitoring system.

The resistors and diodes are attached on the equator of the cavity every 90°, as shown in Figure 3. A few resistors are attached around the HOM couplers and a few diodes are attached on the top and bottom flanges of the cavity. When the x-ray emission occurs, there is a correlation between the radiation level from the radiation monitor at the top flange of the cryostat and the signal from the PIN photo diodes at the top flange of the cavity. And, it is possible to observe more certainly the emission, because there are a few diodes on the bottom flange of the cavity. Although the signal is normally low around the equator compared to the beam axis, it is possible to observe the signal caused by multipacting around the equator and the electron bombardment by the field emission. The temperature of the liquid helium was measured to plot the temperature difference between the liquid helium and the heating spot by using a few resistors.

Figure 3: Attachment to the cavity.

Figure 4: Installation into the cryostat and the inside of the pit.

After the attachment to the cavity, it is installed into the vertical cryostat, as shown in Figure 4. It is carefully put inside the cryostat, because of the narrow space. The cables are guided from inside to outside through the feed-through at the top flange of the cryostat.

DATA ACQUSITION & ANALYSIS

The Data Acquisition System is simple, easy and fast. Once the loggers start running before the test, it is not necessary to stop them to the end of it. This system enables us to concentrate on the measurement of the pass-band mode and the RF processing. The sampling time is 100 or 200msec and it takes 2 days for the test. About 500 thousand events are eventually accumulated in one vertical test. PAW (Physics Analysis Workstation) is used for the data analysis. It is a strong analysis tool, which is included in CERN Library.

The value from the carbon resistor must be calibrated every one measurement due to the poor reproducibility. It is strongly dependent on the helium temperature around itself. It is possible to estimate the helium temperature from the helium pressure under the saturated vapour pressure. It is possible to obtain a calibration curve by fitting the correlation between the helium temperature and the resistor value using an appropriate function. The calibration curves are different between all the resistors. Therefore, the fitting functions for all the resistors must be obtained. After the process, the calibrated temperature is obtained.

Example #1 (EXP #12)

In Figure 5, a status in EXP #12 is shown. The blue line, red line and purple line show the accelerated field, the temperature and the signal from the PIN photo diodes, respectively. Seven pass-band modes are normally measured during the vertical test from 3π/9 to π mode. The measurement was carried out in π, 8π/9, 4π/9, 3π/9 and π mode, in that order.

In π mode, the cell #2 had the heating spot and ΔT was 0.3K. ΔT means the temperature difference between the liquid helium and the heating around the equator. Cell #2 was eventually a limiting cell, as shown in Figure 6. The heating at cell #9 in 8π/9 mode was observed. In this mode, cell #9 achieved at 22.7MV/m, while cell #2 at 20.2MV/m. Although there were many heating at cell #1, 2 and 9 in 4π/9 mode, they were eventually processed out.

On the other hand, the radiation level was high during the test. The x-ray emission was observed at every cell by the PIN photo diodes, as shown in the x-ray mapping display. The radiation monitor on the top flange of the cryostat recorded the radiation level of 14mSv/h. The PIN photo diode on the top flange of the cavity observed the maximum level in π mode, while the diode at cell #9 detected the higher radiation level in 3π/9 or 4π/9 mode than π mode.

After the vertical test, BL2 cavity was re-processed by EP2, because the field emission occurred. The result of the fifth test is described in Example #3.

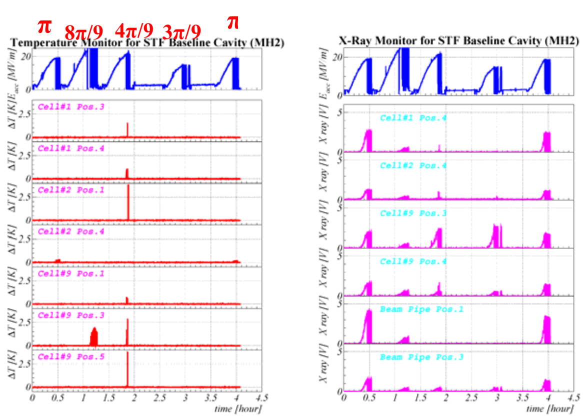

Figure 5: Temperature and x-ray monitoring.

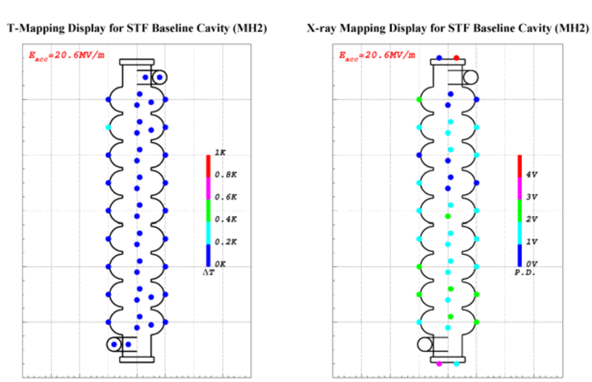

Figure 6: Temperature and x-ray mapping display.

Example #2 (EXP #13)

In EXP #13 for BL4 cavity, cell #1 was the limiting cell, as shown in Figure 7. This cavity was limited at 20.2MV/m. Cell #1 had the heating even in the other modes. The measured pass-band modes were π, 8π/9 and 7π/9 modes. The end cells (#1 and 9) achieved above 20MV/m in these three pass-band modes.

During the RF processing in π mode, the radiation level gradually became lower. The field emission was not observed in this test.

After the measurement of 7π/9 mode, the vacuum leakage trouble occurred. This was the only one trouble of the vacuum leakage due to the "superleak" at 2K. The vacuum leakage was not observed at the room temperature before and after the test. And, this cavity advanced to the next step, which is the assembly to the first Cryo-Module in STF-Phase0.5.

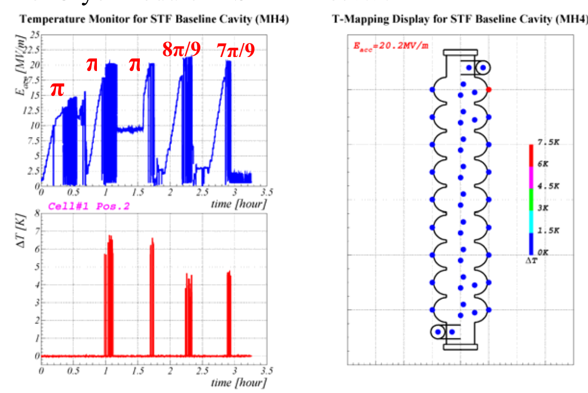

Figure 7: Temperature monitoring and mapping display.

Example #3 (EXP #14)

Figure 8 shows the assign of the position for the sensors. Figure 9 and 10 show the results measured in the first day of the fifth vertical test for BL2 cavity. Although the heating normally occurs around the HOM coupler due to the multipacting in the first measurement by π mode, it was easily processed out. In this measurement, both end cells had the heating at every mode except 3π/9 mode. While the heating at cell #1 disappeared in the end, that at cell #9 remained at Pos.1 and 5. This situation was same in the second day of the vertical test. Therefore, the limiting cell was cell #9, when the accelerating field achieved the maximum level of 29.4MV/m. The heating at cell #2 was also observed during 3π/9 and 4π/9 mode in the first day, as not shown in this paper.

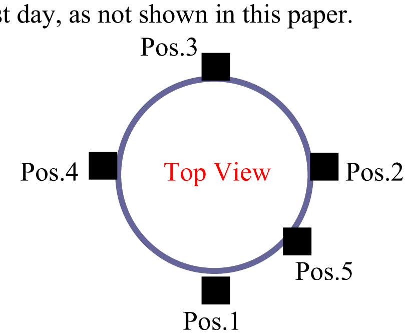

Figure 8: Assign of the position on the equator.

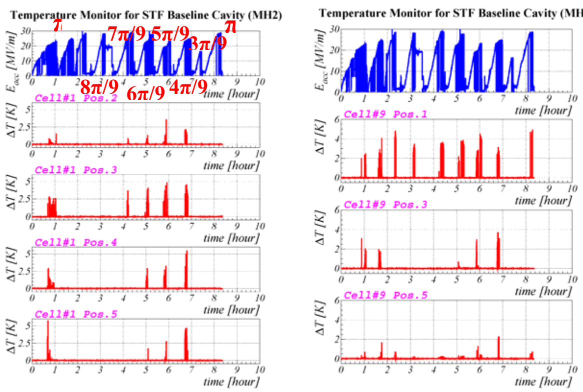

Figure 9: Temperature monitoring.

On the other hand, although the radiation level was low at the beginning of the first day, it became suddenly high in the end, as shown in Figure 11, and it became lower after the RF processing. The green scattered plot shows the exponential growth of the radiation level with the field. In the second day, it gradually became much lower during the RF processing. No field emission was eventually observed. This BL2 cavity had the best performance within four STF-Baseline cavities, as shown in Figure 12.

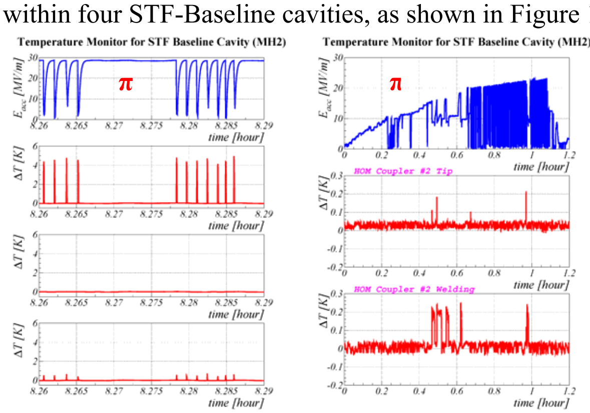

Figure 10: Expanding temperature monitoring around cell and HOM coupler.

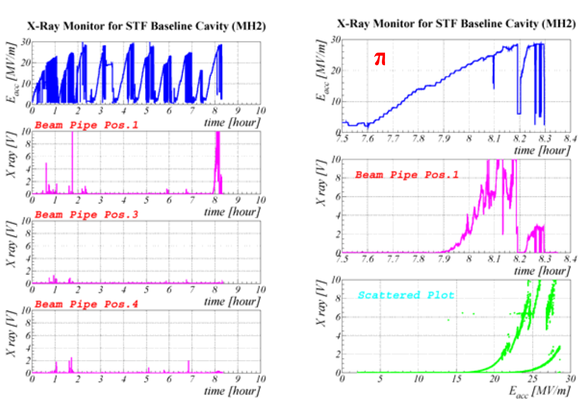

Figure 11: X-ray monitoring and scattered plot.

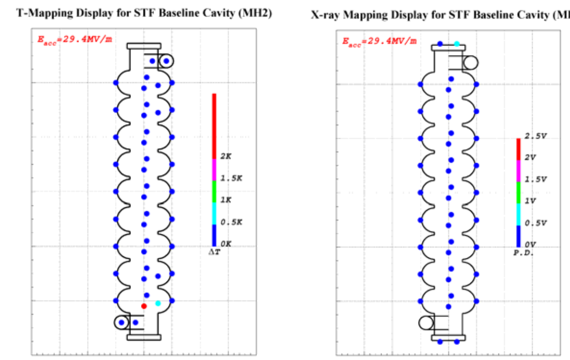

Figure 12: T-mapping and x-ray mapping.

RESULTS & DISCUSSION

Limiting Cell

Figure 13 shows the results of all the vertical tests for STF-Baseline cavities. Totally, 14 tests were done. After Exp #10, four carbon resistors and PIN photo diodes were attached on the equator at each cell every 90° and the limiting cell was identified at 100%. BL2 cavity was measured totally five times and eventually achieved 29.4MV/m. The other cavities (BL1, 3 and 4) were limited around 20MV/m. There was a correlation between the cell with the heating spot and the cell which the maximum field was clear by the pass-band measurement. The distribution of the limiting cell is uniform. It is not correct that the limiting cell is fixed.

Not measured or Unknown

Exp #	Year	Date	Cavity	$E_{acc,max}$★ [MV/m]	Limiting Cell	Radiation Level [mSv/h]†
1	2006	25/Feb	BL1	19.1		>100
2		26~27/Apr	BL2	14.2		0
3		25~26/May	BL1	19.3		3
4		8~9/Jun	BL3	20.3		0.8
5		22~23/Jun	BL2	21.5		0.3
6		6~7/Jul	BL1	19.3		>100
7		24~25/Aug	BL4	17.1	Cell #4	2.5
8		21~22/Sep	BL3	20.5	Cell #5	1.4
9		12~13/Oct	BL2	19.3		26
10		7~8/Dec	BL4	17.1	Cell #4	11
11		21~22/Dec	BL1	20.8	Cell #3	>100
12	2007	18~19/Jan	BL2	20.6	Cell #2	14
13		31/Jan~1/Feb	BL4	20.2	Cell #1	0.4
14		22~23/Feb	BL2	29.4	Cell #9	1.9

★ $E_{acc,max}$ is the value in the final state of the vertical test.
† The radiation level is measured on the top flange of the cryostat.

Figure 13: Summary of the vertical tests.

Although BL2 cavity experienced vertical tests totally five times and the maximum field achieved 29.4MV/m, the heating spot remained in the final state of the vertical test yet. All the cavities eventually had the heating spot on the equator. It is conceivable that the quality of the electron beam welding was somewhat poor, when the dumbbells were connected each other. Next time, the attention should be paid to this point.

The pass-band measurement and the search of the heating spot are the strong techniques in the vertical test for 1.3GHz, 9-cell cavity.

Field Emission and Radiation Level

In Figure 13, the radiation level is also shown. It is measured by the radiation monitor, which was set on the top flange of the cryostat. The radiation level was consistent with the signal from PIN photo diodes set on the top flange of the cavity. BL1 cavity had the strong field emission almost every measurement. Other three cavities had the low radiation level in the final state after the RF processing. The PIN photo diodes were very useful for the presence or absence of the field emission and monitoring the situation of the RF processing. For little field emission, there are several points to which should be paid attention, that is, the cleanness of the clean-room, the careful assembly in the clean-room, the purity of the ultra pure water at HPR and etc.

SUMMARY & FUTURE PLAN

This system worked very well during the vertical tests. It was unexpected that a small number of the carbon resistors enabled us to detect the heating spot on the equator. This may mean that a large number of the resistors are not necessary to search the heating spot. At most 50 or 60 resistors per cell will be sufficient to identify it. At the beginning of 2008, a new vertical test facility will be completed in STF and a new monitoring system will be also introduced. Totally 500 resistors and diodes will be used for the system and attached to the region except the equator of the cavity. It is necessary to investigate the inside of the cavity, if the heating spot is detected. A new investigation system is under study in Kyoto University. And, two new 9-cell cavities are under fabrication. From Feb. in 2008, new vertical tests will be started in STF.

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