# CAVITY INSPECTION AND REPAIR TECHNIQUES

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*Abstract*

To develop cavity inspection and repair techniques is important for quality control of the superconducting rf cavity to get more better yield for high accelerating gradient. A high-resolution camera system was developed as a tool of optical inspection in 2008. It enables 2-D surface analysis on a defect of cavity inner surface by using striped illumination and image processing. For more detailed surface analysis, a replica technique was applied to cavity surface. By connecting defect information with quench location information, the cause of the performance limitation can be categorized by a geometrical defect or by issue of surface treatment and assembly work. By applying optical inspection at each step of the treatment, we can also obtain an information of defect appearance and development. The cavities that quenched at low field by one or few geometrical defects can be improved by removing a geometrical defect at quench location. A local grinding machine was developed for this purpose. This repair method was applied on the 9-cell cavities, and we succeeded to improve the cavity performance by the combination of local grinding and light electro-polish (EP). The method and results of the cavity inspection including the replica techniques and local grinding repair are presented in this paper.

## INTRODUCTION

The inspection and repair techniques have been developed to understand the cause of performance limitation of the cavity in detail at labs around world for 1.3 GHz L-band 9-cell SC cavities [1][2][3][4][5]. Since the quality of the surface treatment and assembly work are greatly improved in these days, the cavity performance tends to be determined by the surface quality of the cavity. A major consensus is that quench limit at low gradient of 9-cell cavities is caused by highly localized defect at or near the EBW seam of equator, iris and cell-end. The size of there geometrical defects is around sub-mm (pit or bump). If there is a defect on near the equator, then quench occurs at low field by magnetic field enhancement or contamination in defect. In case of defect on iris or cell-end, the heavy field emission turns on at low field without recovery during test, once the quench happen at rather high field. These events were observed in some cavities which have a geometrical defect in them. Of cause, it depends on the size and shape of the defect whether these events occur or not. Nevertheless, the development of the geometrical defect removing method is important in order to raise the cavity performance yield better.

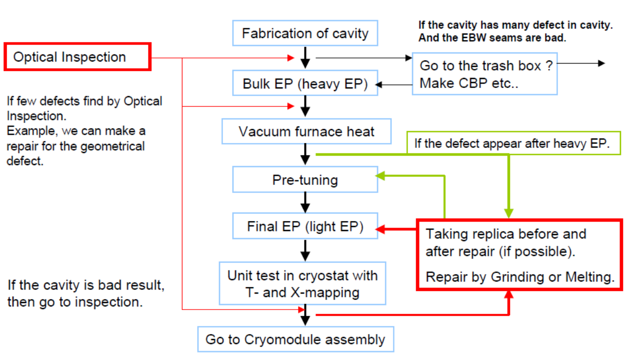


Figure 1: Repair process inclusion for the cavity treatment flow.

Figure 1 shows the example of inclusion of the defect repair process into the cavity treatment flow. We use the repair with combination of local grinding and light EP, in order to avoid the heavy EP, the vacuum furnace heating and the pre-tuning. The repair methods are under development at labs around the world. They are the local grinding, local re-melting by electron beam or laser and the tumbling. We can choose a method from them according to the type and the number of defects. It should be noted that the electro-polishing also change defect shapes.

## TOOLS FOR INSPECTION AND REPAIR

### *Optical Inspection*

Two types of CMOS cameras are used for optical inspection. For normal inspection, Toshiba Teli (CSF5M7C3L18NR. CMOS) camera is used, because this camera has quick response at maximum resolution (1400 x 1000, resolution is 10µm per pixel). Another camera is ARTCAM-900SS-OP (Artray co.). It can take higher-resolution image (3488 x 2618, resolution is 4µm per pixel), while, the response is slow due to the big amount of data to be transmitted though the limited speed of the computer interface. The 2D analysis can be made to measure the wall gradient of inner surface of the cavity by the special striped illumination and the image processing. The measurable wall gradient is ±20 deg at the equator [6].

### *Replica Method*

In case of deeper or higher defect, the 2D profile can not be applied because of the limited measurable gradient range. The replica technique is a useful method to extend the range and to get 3D profile with high precision. The 3D information is important to calculate the magnetic field enhancement [7][8].

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The replica can be taken from all the cell equators by the special tool. The beam tube and the tapered wall area of cell #1, #2, #8, #9 can be replicated by masking and picking by hand with cavity tilt respectively (see Fig 2). The special tool for the cell equators was developed in Feb 2010. The replica material is a silicon rubber.

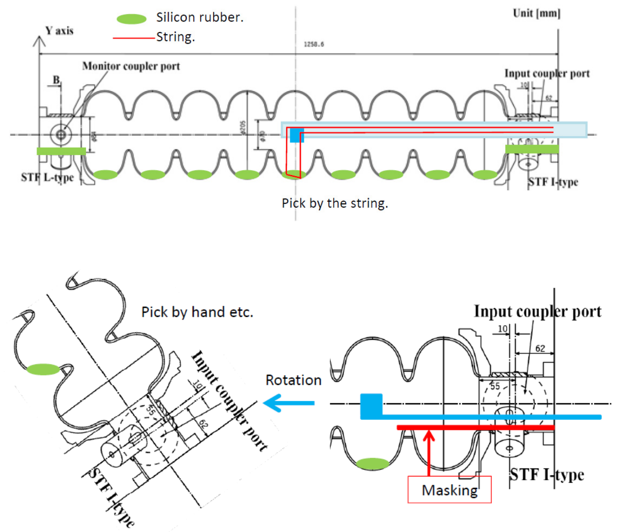


Figure 2: Several method to take replica.

## *Grinding Machine*

Two types of grinders were developed to remove defects on an equator, an iris, a beam tube and a tapered area of a cell (See Fig 3). The grinder #1 can treat a plane parallel to the beam axis. The grinder #3 treats backside of stiffener ring and a tapered wall of the cell. The small USB camera with LED light is equipped on the grinder head. The diamond sheet or 3M Scotch Brite are used for grinding and polishing the inner surface of the cavity.


Figure 3: Grinding machines and grinding area. Grinder #1 is for red area, and grinder #3 is for green area.

## REPAIR OF THE CAVITY

Figure 4 shows several examples of geometrical defects found by the optical inspection. They are the targets for the repair. Table 1 and 2 show the summary of repaired cavities, the results of vertical tests and their current status.

## *AES-03*

The AES-03 was tested at FNAL and JLAB. The cavity performance was up to 20 MV/m by quench at cell #4. After testing at FNAL and JLAB, the cavity was moved to LANL to test new T-mapping system. The last test was resulted at 10 MV/m with heavy field emission.

The cavity was sent to KEK for the repair work by local grinding at June 2009. The optical inspection was made for “as received to KEK”. Figure 5 and 6 show the result of optical inspection. The cavity has three bumps near the equator and many heavy scratches on iris.

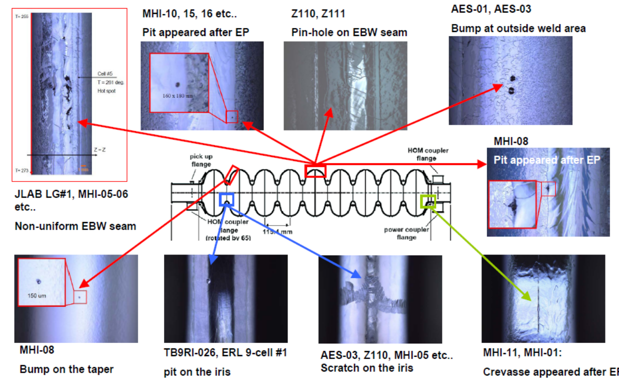


Figure 4: Found geometrical defects by optical inspection.

The targets of grinding are three bumps near equator and 20 heavy scratches on iris. The electro-polishing was expected to repair the small scratches on iris. The surfaces on the equator and the iris after local grinding and 50 µm EP are shown in Figure 7 and 8. The defects were removed very well. The degreasing and HPR were applied before back to FNAL.

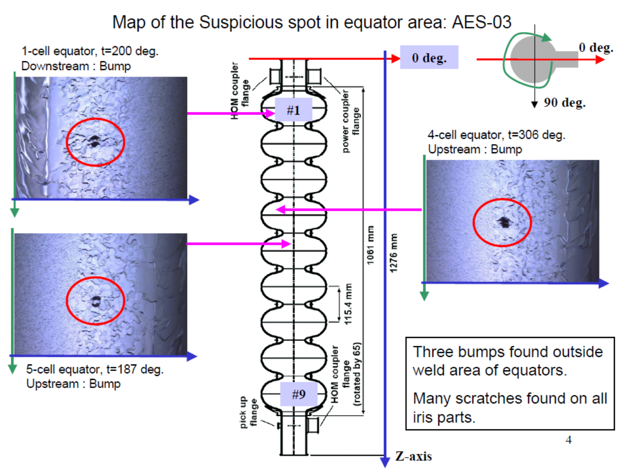


Figure 5: Result of optical inspection of AES-03 at equator.

Two vertical tests were performed at FNAL. The HPR was applied again before 1$^{st}$ vertical test, and the cavity showed 30 MV/m in the 1$^{st}$ test. The HPR and baking were applied again before 2$^{nd}$ test. In the 2$^{nd}$ test, the cavity showed 34.6 MV/m [9].

### *TB9RI-026*

The TB9RI-026 was tested at FNAL. Initially, the field reached 28.8 MV/m with several FE burn-off events. The field emission did not reduce well. Final gradient was limited at 19.6 MV/m. A pit type defect found on #8-#9 iris by the optical inspection at FNAL.

The cavity was sent to KEK for the local grinding on the defect. The surface after polishing is shown in Figure 9. After mechanical polishing, 30 μm EP, the degreasing and HPR were made before sent back to FNAL.

Another HPR and baking were made before vertical test. The cavity performed 36.6 MV/m without filed emission. This is successful result [9].

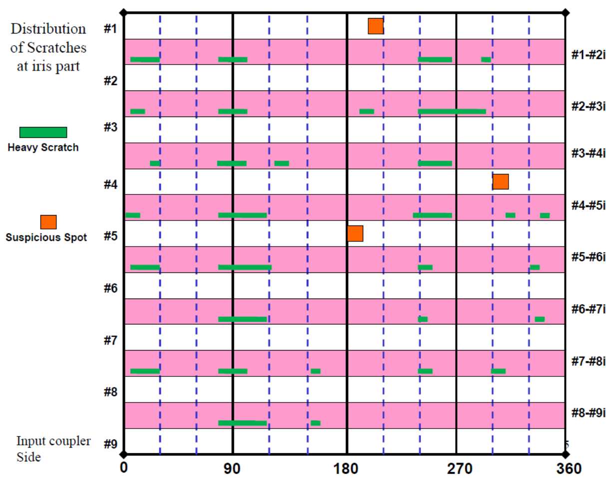


Figure 6: Result of optical inspection of AES-03 at iris.

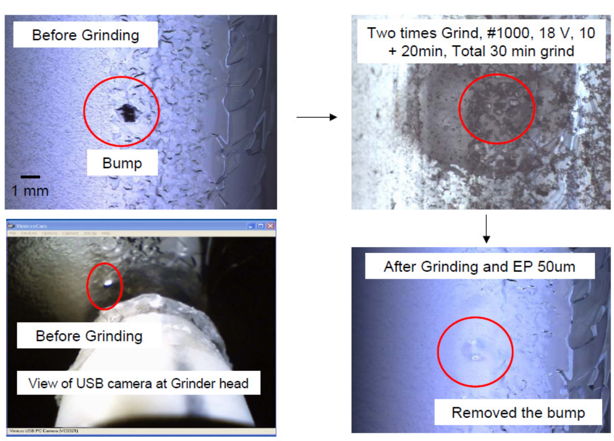


Figure 7: Grind and EP at cell #4 equator.

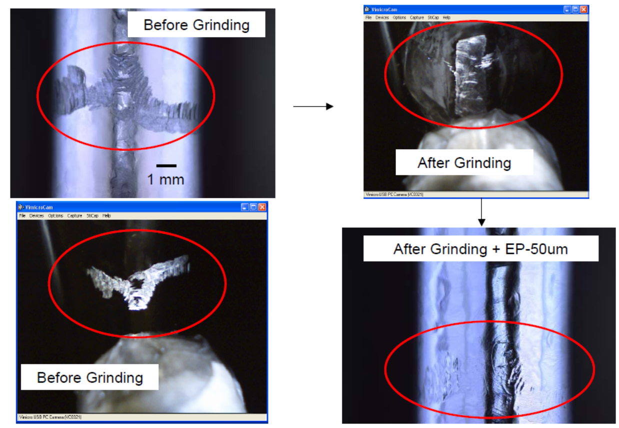


Figure 8: Grind and EP at heavy scratch on iris.

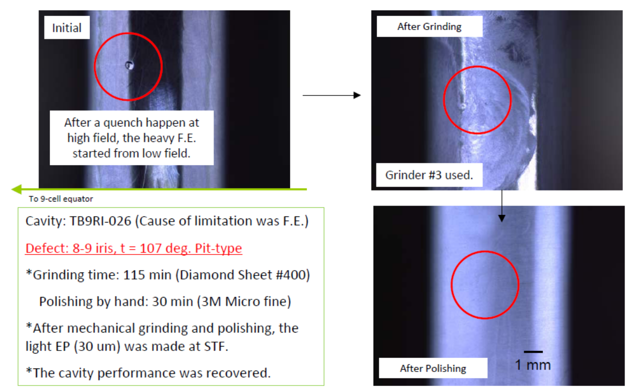


Figure 9: Polishing of pit type defect on the iris.

### *JLAB-LG#1*

This cavity was fabricated JLab in house built as large-grain 9-cell cavity. The cavity performance was limited 30 MV/m at cell #5 before sent to KEK for repair by local grind. Figure 10 shows the result of optical inspection. Three non-uniform EBW seams were found on the hot spot and cell #6 equators. The shape of defect at cell #5 was pit similar to funk hole (depth is about 300 μm). Two times grinding and three times EP were applied to make smooth surfaces for repair. The surfaces after repair are shown in Figure 11. The degreasing and HPR were applied before sent back to JLAB.

The field flatness tuning, HPR and baking were made before vertical test. The performance of cell #5 was improved from 30 MV/m to 43 MV/m in the 1st test. However, it was limited at 21 MV/m by quench at cell #6. The performance of cell #6 was degraded from 30 MV/m to 21 MV/m. Figure 12 shows the images on cell #6 before and after additional EP at KEK-STF. The dark zone in defect grew by additional EP. There is a possibility that the defect shape changed to a deeper pit, and then the quench field degraded. The edges also changed to the sharp edges around dark zone of the defect.

The repair work for cell #6 is planned at August 2011. KEK's grinding machine will be sent to JLab to do repair work at JLab [10].

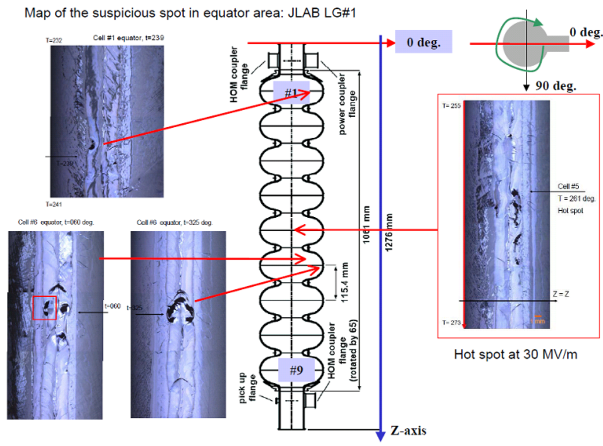


Figure 10: Result of optical inspection of JLAB LG#1.

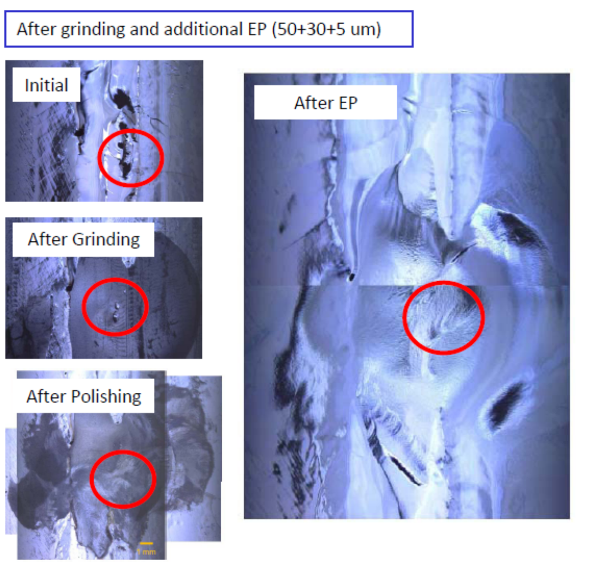


Figure 11: Grinding and EP at JLAB LG#1 cell #5 equator.

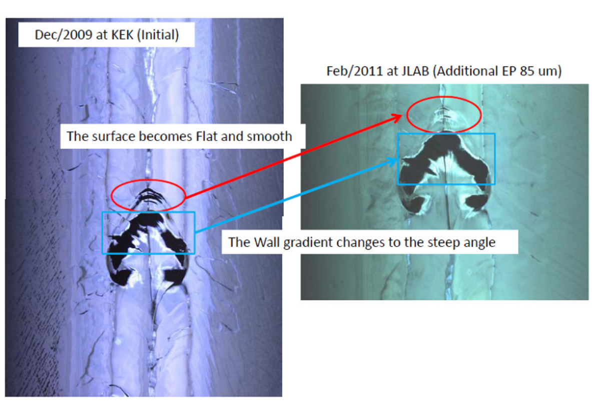


Figure 12: Defect deform by additional EP (85 μm).

Table 1: Summary of repaired cavity

| Cavity | (1) Location of Defect<br>(2) Type of defect<br>(3) Repair method<br>(4) Treatment after repair |
|---|---|
| AC71 | (1) #1-#2 iris, 137 deg.<br>(2) Scratch<br>(3) Local grinding and light EP<br>(4) EP-2 (30μm) -> VT |
| MHI-08 | (1) Cell #2 equator, 172 and 85 deg.<br>(2) Pit (172) appeared after EP, Bump (85) 40mm away from EBW seam.<br>(3) Local grinding and EP<br>(4) G(172deg)->E(20)->G(172deg)->E(30) ->EP-2(20μm)->VT->EP-2(20)->VT ->EP-2(20μm)->VT |
| AES-03 | (1) Cell #4 equator, 306 deg<br>Cell #1 equator, 200 deg<br>Cell #5 equator, 187 deg<br>All iris<br>(2) Bump, 8 mm away from joint (#4, 306)<br>Bump, 8 mm away from joint (#1, 200)<br>Bump, 8 mm away from joint (#5, 187)<br>Heavy scratch on all iris (20 point grind)<br>(3) Local grinding and EP<br>(4) EP-2 (50μm) -> VT |
| JLAB LG#1 | (1) Cell #5 equator, 261 deg.<br>(2) Pit and non-uniform seam<br>(3) Local grind<br>(4) G->E(50)->G->E(30)->EP-2(5μm)->VT |
| TB9RI -026 | (1) #8-#9 iris, 107 deg.<br>(2) Pit<br>(3) Local grinding<br>(4) EP-2 (30 μm) -> VT |
| AES-01 | (1) Cell #3 equator, 169 deg.<br>(2) Two Bumps, 8 mm away from joint<br>(3) Local Grinding<br>(4) EP (30 μm) -> waiting VT |
| MHI-11 | (1) EBW at cell #1 and Beam tube.<br>(2) Crevasse and pits appeared after EP along EBW seam<br>(3) Re-EBW<br>(4) Waiting EP-2 and VT |
| G: Local Grinding, E: electro-polishing after Grinding,<br>EP-2: light EP before VT, VT: Vertical test<br>After EP-2, the rinsing and baking were done before VT. | |

Table 2: Result of VT after repair

| Cavity | Before | After |
|---|---|---|
| AC71 | 26 MV/m | 30 MV/m at DESY [11] |
| MHI-08 | 16 MV/m | 38 MV/m at KEK [12] |
| AES-03 | 20 MV/m | 34.6 MV/m at FNAL |
| JLAB LG#1 | 30 MV/m | Cell #5 performance improved to 43 MV/m at JLAB [10] |
| TB9RI -026 | After quench at 30 MV/m, then F.E. stated from low field. 20 MV/m | 36.6 MV/m without F.E. |
| AES-01 | 22 MV/m | Waiting VT at FNAL |
| MHI-11 | After quench at 24 MV/m, then F.E. stated from low field. 18 MV/m | Waiting EP and VT at KEK |

## SUMMARY

Development of inspection techniques started from 2008. The replica can be taken from all cell equators of 9-cell cavity by special tool for getting 3D information of gometrical defect in precision. The shape after grinding and EP also can be checked by the positive replica.

Six cavities were repaired by combination of local grind and light EP from 2009. The cavity performances were improved for five cavities. It is successfully demonstrated in 9-cell cavities. As to the AES-01, it is wating for the rf test at FNAL. MHI-11 was also repaired at the crevasse around EBW seam of cell end by EBW. It is the melting method. MHI-11 is also wating for the surface treatment and the rf test at KEK.

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