# REPAIR TECHNIQUES OF SUPERCONDUCTING CAVITY FOR IMPROVEMENT CAVITY PERFORMANCE AT KEK-STF

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*Abstract*

The repair technique of the superconducting cavity is important to obtain better yield of accelerating gradient of superconducting 1.3 GHz 9-cell cavities for International Linear Collider (ILC) project. The techniques for repair of the cavity are combination of the optical inspection, make a replica of defect, the local grinding and the result of vertical test with temperature mapping.

The pit type defect (size: 0.7 mm x 0.5 mm, depth: about 115 um) was found by optical inspection at the quench location of MHI-08 cavity at 16 MV/m after 1st vertical test at June 2009. The location of defect was boundary between EBW seam and heat affected zone at 172 degree of 2-cell equator. If a cause of field limitation is really this pit type defect, then the cavity can repair to remove the defect by mechanical grinding method. This defect was removed completely by the special grinding machine. After mechanical grinding, electric polishing process and optical inspection were carried out to check the surface condition at grinding area. The 2nd vertical test of MHI-08 was carried out at October 2009. The accelerating gradient was improved from 16 MV/m to 27 MV/m. The gradient was limited by quench due to defect at other location. The bump type defect found after 2nd vertical test at outside weld area from 40 mm away from joint point of 2-cell equator (the angle is 86 degree). The cavity performance was reached at 38 MV/m in 4th vertical test. The recent result of the cavity repair of MHI-08 by a series of techniques of Kyoto-camera, replica and grinding will be reported in this paper.

## INTRODUCTION

The repair technique of the superconducting cavity is important to understand a quality and obtain better yield of accelerating gradient for ILC [1]. The labs are under studying several techniques to remove the defect for cavity repair [2],[3],[4]. There are the repair techniques that the mechanical grinding (Local grind and tumble) method and the melting method by laser and EBW. These methods were applied from long time ago for cavity repair. In recent year, the optical inspection system with high-resolution camera and the special strip-line illuminator was developed to optimize 1.3 GHz 9-cell SC cavities by Kyoto-university and KEK collaboration [5]. To use this strip-line illuminator, the 2D profile of geometrical defect can measure non-destructive at inner surface of the cavity. Therefore, it became possible that the detailed information for geometrical defect in real cavity were taken with the advance of optical inspection technology. The point of the replica method is that 3D profile of the defect can record and measure more high precision than Kyoto camera system at "before and after removed defect". The pit type defect was found in MHI-08 after 1st vertical test, it was a very deep pit. The cavity repair of MHI-08 was tried using by a series of optical inspection, replica and grinding. The recent result of repair of MHI-08 will be reported.

## THE TOOLS FOR CAVITY REPAIR

Three tools for cavity repair introduces in this section. The stage and tools for repair at KEK-STF shows in Figure 1. Two holders are mounted on the stage to change easily the cylinders by slider.

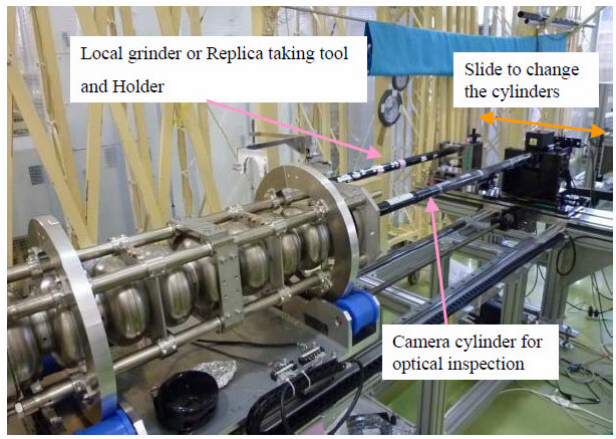


Figure 1: Stage to mount the cavity and the repair tools.

### *Optical Inspection System*

Kyoto camera system is used for optical inspection [5]. The resolution of image is 10 μm / pixel (1400 x 1000, Toshiba Teli, CSF5M7C3L18NR.CMOS), it is dependent on the real pixel size and zoom. Kyoto camera system has a special strip-line illuminator to measure the wall gradient of each pixel on the inner surface of the cavity. The 2D profile of the defect can estimate by measured wall gradient. Measureable maximum wall gradient is +- 20 degree.

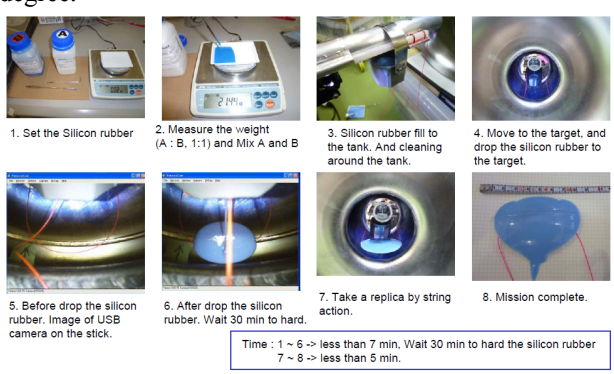


Figure 2: Tool and flow to take a replica.

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### *Replica Method and Tools*

The 2D profile of the defect can be measured by Kyoto camera system, however measureable axis is Z-axis only. In case of the defect with steep angle, the 2D profile can't be measured by limitation of the measureable wall gradient. The replica method is useful method to cover it.

The special tool and flow to take a replica inside cavity is shown in Fig. 2. This tool is applied for equator region of the multi-cell cavities. The replica materials are used the silicon rubber (Wacker dental ADS931) and Stycast (2850FT). The time to get one replica is about < 1 hour. A made replica by silicon rubber is negative. To obtain the positive geometry, the Stycast used to copy it. The Stycast is very hard material and good reproducing the surface condition. The 3D profile can measure by the laser microscope, 3D digital microscope and the surface roughness measuring machine to use copied replica to Stycast. It also can be used the bench test of local grinding to check the surface condition after grinding and fitting between niobium material and grinder head.

### *Local Grinding Tool*

Developed local grinding machine shows in Fig. 3. This machine can grind a geometrical defect at inside cavity. The cylinder size and head structure is optimized to the 1.3 GHz 9-cell cavity for ILC. The location which can be ground is the equator between ±10mm from joint point and top of the iris. For example, in case of the bump, the defect can be removed easily. The time to remove one bump (Example, defect size is $\phi$ 500 μm with 100 μm height) is < 1 hour. In case of deep pit (depth is about 100 μm), the time to remove one deep pit is about 10 hour. There is under studying to achieve the reduction of hours of grinding.

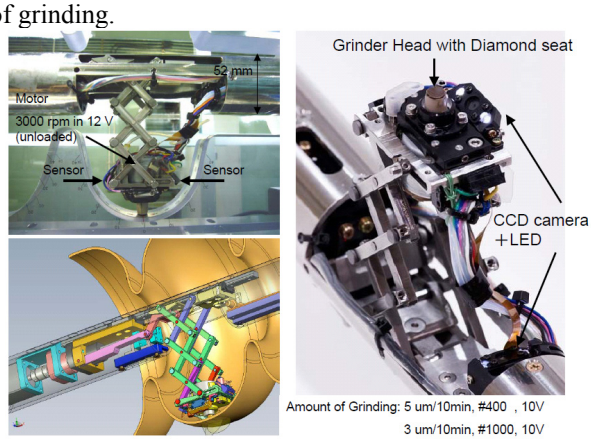


Figure 3: Local grinding machine.

## THE REPAIR OF MHI-08

MHI-08 was fabricated made by MHI at 2009. The cavity was inspected at each treatment from "as built". All EBW seams of equator and iris, and the outside weld area were inspected before 1st EP-2 and vertical test. There was no suspicious defect around equator in this time.

### *ALL Vertical Test and Optical Inspection Result*

Four vertical tests with temperature mapping [6] of MHI-08 were carried out from June 2009 to Feb 2010. The result of four vertical tests shows in Fig. 4 and 5. The gradient was limited by quench at 16 MV/m in pi-mode at 1st test. The T-mapping detected the quench location at 2-cell equator (t=180deg). After vertical test, the defect was found near the quench location. Before final EP and 1st vertical test, there was no defect at quench location (see Fig. 6). The defect was made after final EP. The shape could not measure by Kyoto camera system due to the wall gradient of the defect has steep angle. The replica method used to measure the detailed shape. Fig. 7 is 3D profile of the defect measured by laser microscope. The defect was deep pit. And the size was about 700 x 500 μm, the depth was about 115 μm.

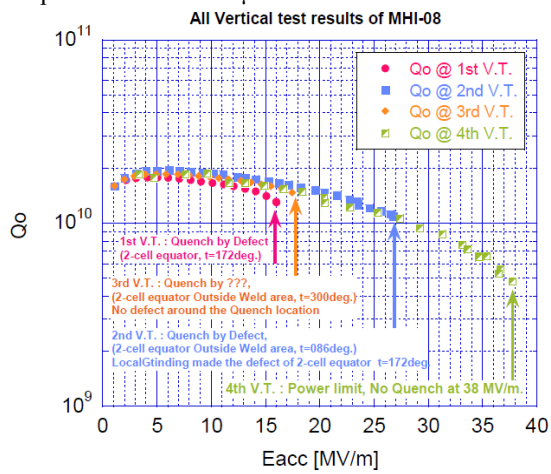


Figure 4: Summary of the vertical tests.

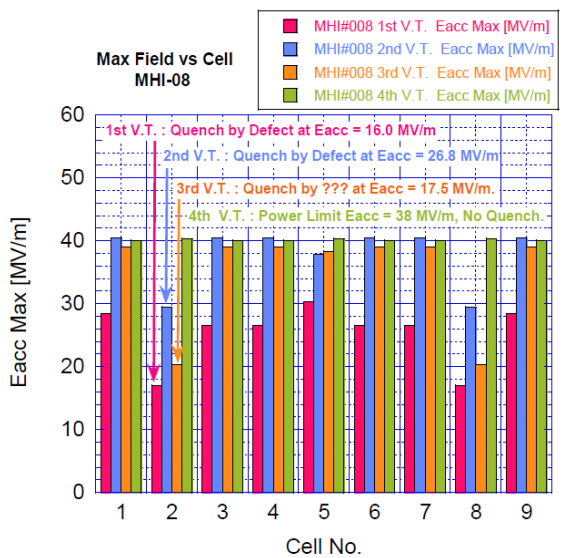


Figure 5: Results of passband measurement and T-map.

### *Local Grinding and Taking Replica for the Defect*

If a cause of field limitation for MHI-08 is really this pit at 16 MV/m, then the gradient is recover to remove the defect by local grinding method. The local grinding

machine with diamond sheets was used to remove the defect. The process of local grinding is shown in Fig. 8. The location of defect is boundary between EBW seam and heat affected zone (red circle (0) in Fig. 8). To grind the defect in a short time, the diamond sheet #400 was used until removed the defect. The diamond sheet #1000 was used for polishing to make a smooth surface and edges. The field flatness was kept after local grinding and EP. The progress work before 2nd test is summarized following as,

(1) Optical inspection after 1st test with T-mapping result.
(2) Make a replica, measurement of 3D profile.
(3) First grinding for 2-cell equator (172deg.) until remove the defect.
(4) HPR to clean the dust by car washer, EP 20 μm.
(5) Optical inspection and 2nd grinding to make smooth edges around circle of grinding location. The replica made after 2nd grinding to check the shape of edges.
(6) HPR to clean a dust by car washer, EP 30 μm.
(7) Optical inspection and Field flatness measurement.
(8) Final EP 20μm, FM-20 rinsing, Hot bath, HPR, Assembly and Baking.
(9) 2nd Vertical test with T-mapping and X-ray mapping.

2nd test was done at Oct 2009. The gradient was improvement from 16 MV/m to 27 MV/m. The location of local grinding was no heating in vertical test. The reason of limitation was quench by other defect at outside weld area form 40 mm away from joint point of 2-cell equator (86deg.). This defect was bump, the diameter is 150 μm and height is about 20 μm. This defect also had steep wall gradient around edge. Our grinding tool can't apply this location due to the mechanical structure of grinding machine. Fortunately, the type of this defect is bump. It is possible to remove the defect by EP process.

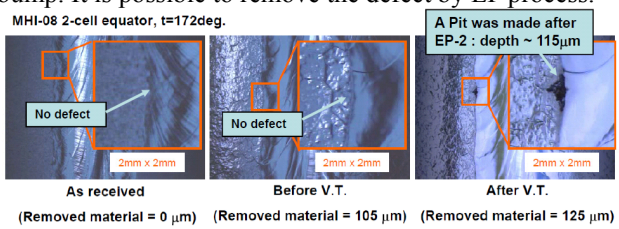


Figure 6: Inspection of after vertical test at hot spot location.

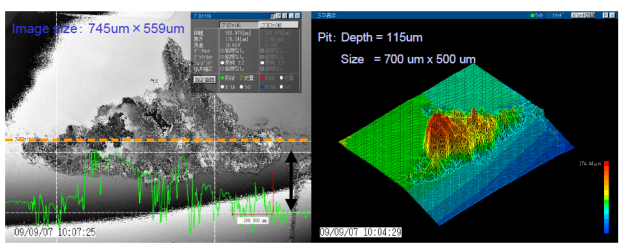


Figure 7: 3D profile of defect at 2-cell equator (172deg.).

3rd test was done at Nov 2009. The gradient was limited at 17 MV/m by quench at outside weld area of 2-cell equator (300deg.). After 3rd test, the optical inspection made, however, there was no defect around quench location. 4th test was done at Feb 2010. The gradient was reached at 38 MV/m in pi-mode. The reason of limitation was power limit by field emission. The optical inspection made after 4th test. The defect at outside weld area of 2-cell equator (86deg.) was removed by EP (the material removed 20 + 20 μm after 2nd test). The shape of defect was changed from bump to flat plane. Total removed material is 235 um. The gradient of all cells was reached > 40 MV/m in passband measurement.


Figure 8: Surface condition after mechanical grinding and electro-polishing at 2-cell equator (172deg.).

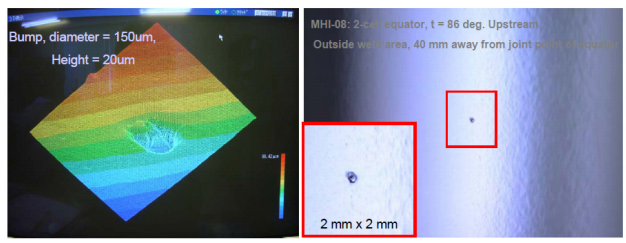


Figure 9: 3D profile of defect at outside weld area of 2-cell equator (86deg.) .

## SUMMAY

Three methods used for cavity repair of 9-cell cavity. The gradient of MHI-08 was improvement from 16 MV/m to 27 MV/m by local grinding method. The electro-polishing is also have a effect to remove the bump type defect. Some time, there is no defect around quench location at low gradient (< 20 MV/m). To understand the reason of quench, the surface study for chemical and contamination is needed to achieve the good repeatability of the surface treatment.

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