OPTICAL OBSERVATION OF GEOMETRICAL FEATURES AND CORRELATION WITH RF TEST RESULTS*

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Abstract:

Three kinds of geometrical feature analysis techniques were adopted in association with cavity gradient R&D at the Jefferson Lab: (1) feature shape analysis by Kyoto camera system; (2) 3D profile analysis using the KH-7700 high resolution digital-video microscopy system (HIROX); and (3) replica technique plus surface profiler for profile measurement of geometrical features. These three profile measurement methods have been applied to three nine-cell SRF cavities: PKU2, TB9RI019 and TB9NR001. The shape analysis of geometrical features and correlation with RF test results of these cavities will be presented here.

INTRODUCTION

The superconducting radio frequency (SRF) cavity has been widely used for many large accelerator projects such as international linear collider (ILC) [1] and the Relativistic Heavy Ion Collider (eRHIC) [2]. For example, 90% of the over 16000 cavities required for ILC program must achieve an accelerating gradient of 35MV/m. However, there are still some limiting factors which result in low production yield of the SRF cavity. The 4th update of the global database of ILC cavity production yield show that recent production yield of nine-cell cavities with gradient over 35MV/m is still at the range of 50~60% [3].

For SRF cavity, the limiting factors which influence the reproducibility of cavity performance mainly include quench and field emission; both of these two limiting factors have strong relationship with the condition of the cavity inner surface. Collecting and categorizing the defects on the inner surface of the cavity and establishing relationship between these defects and RF performance may help to further understand the cavity limiting mechanism and provide guidance to improve technical procedures of cavity fabrication and chemical treatment, so as to improve cavity gradient and yield. Recently, three kinds of optical inspection methods (replica-profilometer [4, 5], HIROX and Koto camera optical inspection system) have been adopted at Jefferson Lab to characterize the defects inside the cavity. Characterization of mechanical features and building correlation with the cavity RF performance using these three inspection methods are the main focus of this paper.

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DEFECT CHARACTERIZATION METHODS

The Kyoto camera (Figure 1) is the most frequently used inspection tool at Jefferson Lab because it can be put into the cavity to inspect the inner surface without cutting samples from the cavity [6]. The system consists of a high resolution CMOS camera and a lighting system which consists of 21 lights built inside a 50mm diameter cylinder. When needed, the cylinder is inserted into the cavity and images are taken of the interested area. The images can be analyzed by two kinds of software (OpenCV and ActivePerl) to generate a 3D profile of the features. The resolution of this system is estimated to 6μm.

Figure 1: Kyoto camera optical inspection system.

To obtain an accurate characterization of defect profile, replica-profilometer technology provides a good choice for measurement. The replica material used at Jefferson Lab is WACKER dental ADS 931 A & B. These two compounds are mixed in the weight ratio of 1:1. The mixture is then poured onto the interested area of the cavity to duplicate the surface details. After one hour of curing at room temperature, the mixture is drawn out of the cavity. It is important to note that this cured mixture only reflects the reverse information of the inspected area. In order to reflect the positive defect detail, two other compounds (STYCAST 2850 FT BLACK and CATALYST 9, manufactured by Henkel corporation) are mixed in the weight ration 100: (4~6) to generate a mixture which is poured onto the reverse replica to form a positive sty-cast replica for the defect. The mixture needs 20 hours at room temperature to cure the positive sty-cast replica. The KLA-Tencor Profilometer was selected to analyze the positive replica. The resolution of this replica-profilometer technology is ~ 1 μm.

The KLA-Tencor profilometer at Jefferson Lab is limited to inspections of defect depths smaller than 326μm. For large and deep defects, the profilometer technology has its own limitations. The HIROX system at the applied research center of the College of William & Marry was chosen to analyze large-size defects. This system consists of a digital camera, a light source, a LCD monitor, and a computer with related software. It uses the multi-focus technique to take a few images of the feature from the feature bottom to the feature top. Subsequently, these images are integrated as a 3D profile for the inspected feature.

FEATURE CHARACTERIZATION AND ASSOCIATED CORRELATION WITH RF PERFORMANCE OF A FEW OF 9-CELL CAVITIES

The pit-type defect with a specific topographical structure exists in both the fine grain and large grain cavity defects

Three nine-cell cavities were inspected by the above three characterization methods: two fine grain cavities (TB9RI019, TB9NR001) and one large grain cavity PKU2.

By using the Kyoto camera inspection system, 305 large defects were detected in the large grain cavity PKU2. The defect size is at the range of 800~2000 μm; almost all of them have a same topographical structure.

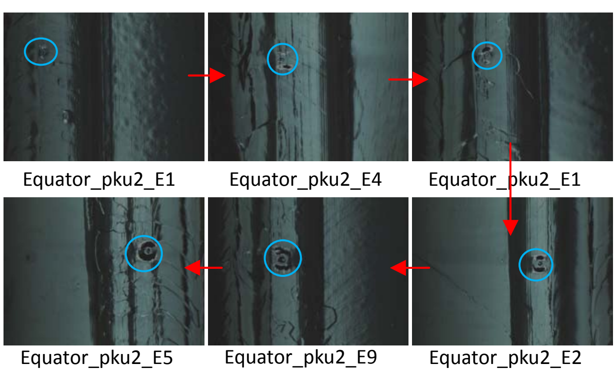
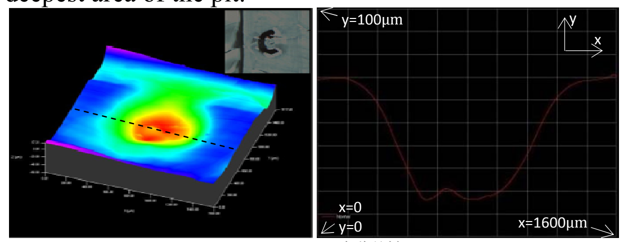


Figure 2: The topographical structure of the defects in a large grain cavity PKU2.

Six defects were selected to present different formation levels but the same topographical characteristics from all 305 defect features found in this cavity, as shown in Figure 2. The topographical characteristics of these features are as follows: there is always an island in the defect center and it is surrounded by a circle-like dark area. The dark area always appears at the top-bottom side (along the equatorial direction).

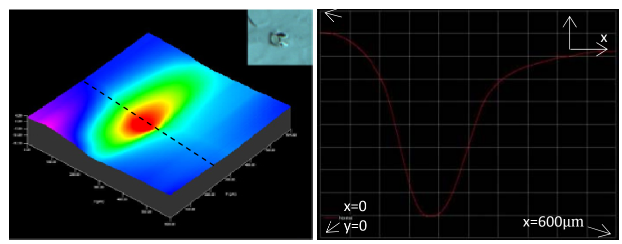
One of the 305 defects was selected to research the profile of this kind of topographical structure (Figure 3). The 3D image and associated profile information provided by replica-profilometer shows that this kind of topographical structure has a pit shape, see Figure 3 (b). The middle island of the defect shows a little bump at the center of the pit and the dark area corresponds to the deepest area of the pit.



(a) (b)

Figure 3: Profile measurement of one of the 305 defects found in PKU2: (a) 3D image of the defect performed by replica-profilometer technology; (b) defect profile measured by profilometer along a straight line through the defect center.

It's worth mentioning that this kind of pit type topographical structure defect also appears at fine grain cavity TB9NR001 (see Figure 4&5).

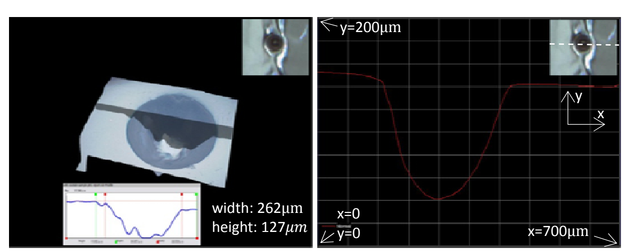


(a) (b)

Figure 4: Profile measurement of one defect in cell#7 of 9-cell cavity TB9NR001: (a) 3D image of the defect performed by replica-profilometer technology; (b) the defect profile measured by profilometer along a straight line through the defect center.

The profile of the defect found in cell #7 of cavity TB9NR001 was measured by profilometer (see Figure 4). This defect also shows the same topographical structure as the 305 defects in large grain cavity PKU2, and the profile measurement result also presents the pit-type shape.

RF test for cavity TB9NR001 indicates another two pit-type defects near the quench site of this cavity (the cavity was quench limited in π mode @ 17 MV/m). The two defects were localized in cell #5 by T-mapping [7].



(a) (b)

Figure 5: Profile measurement of one defect in cell#5 of 9-cell cavity TB9NR001 by two defect characterization methods: (a) HIROX; (b) replica-profilometer.

Figure 5 shows the profile measurement of one of them by two different kinds of defect characterization methods. Both two characterization methods designate that this defect is pit-type shape. For this defect is near the quench site, it demonstrates that this pit-type defect can result in quench initiation.

Defect evolution with chemical treatment

A fine grain 9-cell cavity TB9RI019 was also RF tested at Jefferson Lab recently. Before the first RF test, 120 μm of the surface of this cavity was etched by heavy EP treatment, followed by 2 hours of vacuum furnace heat purification at 800℃. The cavity during first RF test was limited by quench (32 MV/m). The quench site was determined by T-mapping system. The quench source was localized in cell #1 near equator EBW (see Figure 6). Following the first RF test, additional 25 μm light EP was applied. Subsequently, the cavity was re-tested with OST and T-mapping. The cavity was quench limited at 38 MV/m. The quench source was also localized in cell#1 near equator EBW, close to the previously observed quench location.

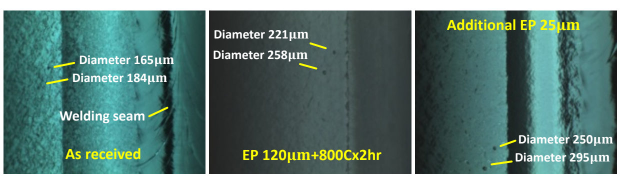


Figure 6: The geometrical evolution of one defect in 9-cell cavity TB9RI019 with chemical treatment in cavity.

During each RF test, associated optical inspection was performed by Kyoto camera to trace the defect size evolution with different chemical treatment for this cavity. Figure 6 shows that how the size of the defects changed with the chemical treatment. After 120μm EP, the defect diameter of TB9RI019 increases ~ 36%; after an additional 25μm EP, the defect size also increases, about 13% (see Figure 6). It is a remarkable fact that the gradient increased from 32MV/m to 38 MV/m when the defect size increased from 221-250μm/258-295μm by an additional 25μm EP.

CONCLUSIONS

Three kinds of geometrical features analysis techniques were adopted to characterize 3 nine-cell cavities. A pit-type defect with the same topology structure was found both in large grain cavity PKU2 and fine grain cavity TB9NR001. Experiments from the RF test of TB9RI019 shows that after chemical treatment, the defect will grow larger and associated gradient would increase.

REFERENCES

[1] http://www.linearcollider.org.
[2] V. Ptitsyn et al., 2009 Particle Accelerator Conference (Vancouver, Canada, 2009).
[3] Akira Yamamoto. Advances in SRF Development for ILC, this meeting.
[4] K.Watanabe et al., Repair techniques of superconducting cavity for improvement cavity performance at KEK-STF, Proceedings of IPAC'10, Kyoto, Japan.
[5] M Ge, G Wu, D Burk, J Ozelis, E Harms, D Sergatskov, D Hicks and L D Cooley, Routine characterization of 3D profiles of SRF cavity defects using replica techniques, Supercond. Sci. Technol. 24(2011)035002.
[6] K. Watanabe, Review of optical inspection methods and results, Proceedings of SRF, 2009, Berlin, Germany.
[7] G. Ciovati, Jlab Technical note TN-05-59.