OPTICAL INSPECTION OF SRF CAVITIES AT DESY

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Abstract

The prototype of a camera system developed at KEK/Kyoto University for the optical inspection of the inner surface of cavities is in operation at DESY since September 2008. More than 20 prototype nine-cell cavities for the European XFEL have been inspected. The unique illumination system combined with the optical sensors allows for the in-situ search of surface defects in high resolution. Such defects may limit the gradient when causing a breakdown of the superconducting state (quench). The comparison of features detected in the optical inspection and hotspots from the temperature mapping during RF-measurements give evidence for correlations. Consecutive inspections of cavities in different stages of the surface preparation process monitor the evolution of surface defects. There are examples for defects traced from the untreated surface condition to the RF-test with temperature map, which identify the defect as the quench location.

INTRODUCTION

Since its commissioning at DESY more than 20 nine-cell cavities have been inspected with the Kyoto camera system [1]. The high resolution pictures obtained with the system allow the locating and study of defects on the inner cavity surface in a way that was not possible before without cutting samples from the cavity.

Categorizing these defects and linking the information obtained in optical inspection to the one from temperature mapping during RF-test may help to further understand gradient limiting mechanisms and improve the yield of high gradient cavities.

COMPARISON OF OPTICAL INSPECTION AND T-MAP DATA

The surface temperature of a cavity can be monitored by attaching an array of thermo-sensitive sensors on the outer side of the cavity (T-map). In this way the position of a local thermal breakdown of the superconductivity (quench) can be detected via its increase of temperature during the cold vertical RF-test.

Optical inspection of the inner surface corresponding to these hotspots gives information about the structures that may cause such a quench. In several cases visible defects, e.g. in the welding seams could be correlated with the hotspot area.

An example for the very good agreement between the hotspot and a visible defect in optical inspection is cavity Z130.

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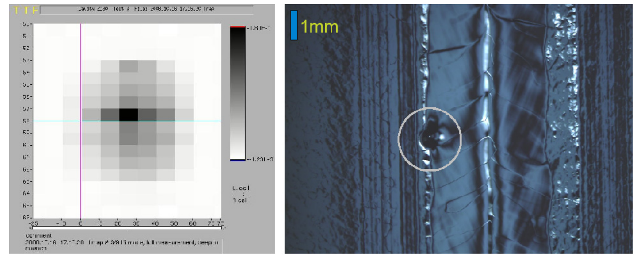

Figure 1: Z130: Hotspot found by T-map during RF-test (left) and defect in optical inspection picture of respective area on inner surface.

In the first vertical RF-test, Z130 was limited by quench at 17.3 MV/m and was therefore cut out of the He-vessel for further investigation. The second test after an additional HPR was carried out with T-map in all nine modes. The π-mode was limited at 16.6 MV/m with quench. The heating spot for the 3/9- and 1/9-π-mode was found on the equator of cell 5 (see left part of figure 1).

Optical inspection was carried out after the second vertical RF-test. A circular pit of about 700 µm was detected at the heating location in cell 5 (right part of figure 1) on the edge of the welding seam.

This defect has been subject to detailed analysis by now. Samples have been cut from Z130 for surface analysis, one of them the above described defect [2]. The profile of the pit shows a difference in height between the highest and the lowest point of more than 150 µm. No foreign material inclusion was detected by EDX measurement.

Cutting the sample with the defect from the cavity also allowed taking SEM-pictures with high magnification, as shown in figure 2. At the edge of the defect with its rather large diameter of 700 µm small, sharp structures of the order of less then 10 µm are visible.

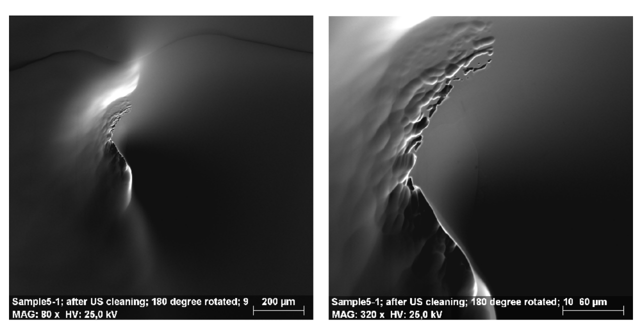

Figure 2: SEM-pictures of the defect in Z130: 80x magnification (left) and 320x magnification (right)

A second, good example for the match between T-map measurement and optical inspection is the cavity Z142. The temperature map recorded during the quench in the π-mode during the first vertical RF-test is depicted in the left part of figure 3.

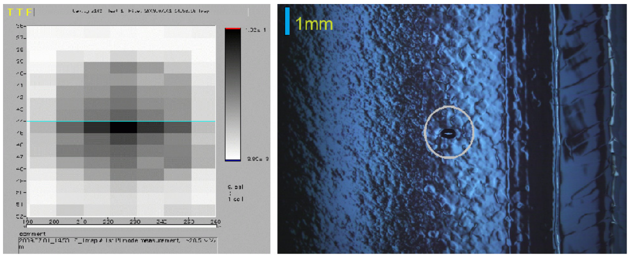

Figure 3: Quench location found by T-map (left) and optical inspection picture of respective area (right) in Z142

In the π-mode Z142 quenched at 20.6 MV/m without measured field emission and heating was observed near the equator of cell 6. Optical inspection of the respective area after the test revealed a defect in the heat affected zone next to the equator welding seam (right part of figure 3). The defect is a pit of elliptical shape with a semi-minor axis of about 300 µm and a semi-major axis of about 500 µm.
This defect is also part of the studies on the evolution of defects described in the next section.

DEFECT EVOLUTION STUDIES

In order to study the formation and evolution of defects, optical inspection is not only done after the finished surface preparation and RF-test, but has also been done in several earlier steps of the cavity preparation cycle for a subset of the inspected cavities.

A batch of 4 cavities (Z134, Z136, Z137 and Z142) from the 6th production series of cavities for TTF/FLASH [3] has been inspected after several major steps of the surface preparation process:

1. before surface preparation ("as received")
2. after main-EP
3. after final EP and RF-test

In the optical inspections before surface preparation and after the main-EP all equator and iris welding seams are inspected. After the RF-test the welding seams are inspected once more. In addition, the areas of heating located by T-map, that may also be situated outside the welding seam areas, are inspected.
In the first inspection step the surface condition after manufacturing of the cavity is documented enabling the comparison of the surface before and after chemical treatment.
The second inspection checks the surface after the bulk surface removal and thereby monitors the evolution of defects that might have been documented already in the first inspection or the formation of new defects.
The third inspection after the final surface treatment and RF-test records the state of the surface as it was during the test and possible quench.
First results from the optical inspection and test with T-map of this batch of four cavities have been presented in [4].
The series of pictures in figure 4 depicts the evolution of the defect in Z142 that was already described in the previous section.

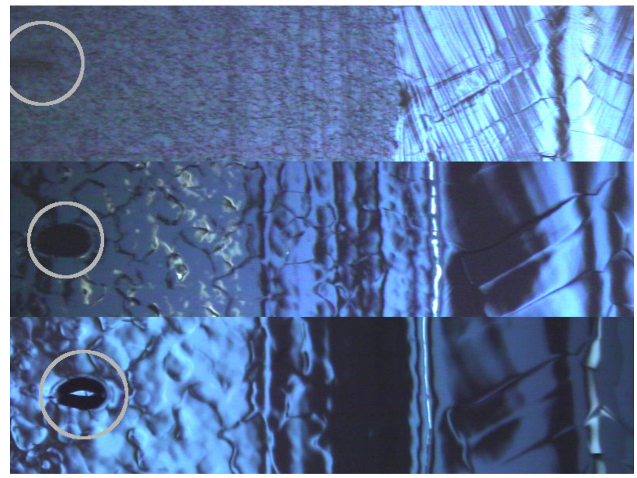

Figure 4: Defect evolution in Z242: Before surface removal (upper part), after main-EP (middle), after final EP and RF-test (lower part)

The upper part of figure 4 shows the surface of Z142 before surface removal directly after the manufacturing. Some millimeters to left of the equator welding seam, one can see a darker spot at the location where the defect is visible later. The middle picture of figure 4 was taken after the bulk surface removal of 108 µm by electro-polishing. Instead of the darker spot an elliptical pit with a semi-minor axis of about 300 µm and a semi-major axis of about 500 µm is clearly visible. The lower picture is the same as in the right part of figure 3, taken after the final EP of 48 µm and the RF-test. The pit has not changed significantly in shape or dimensions with respect to the step before final EP.

SUMMARY AND OUTLOOK

The optical inspection of SRF cavities with the KEK/Kyoto-type camera system proves to be a very valuable tool for investigating the quench spots in-situ. Correlations between the hotspot found by T-map measurement and visible defects in the optical inspection have been found in several cases. Two examples in the cavities Z130 and Z142 have been presented here.
The analysis of the sample with the defect cut from Z130 indicates that the cause for the quench lies in the geometrical nature of the defect.

In Z142 a defect could be traced through all surface preparation steps from the state "as received" until the RF-test with T-map and confirmation of the defect to be the hotspot.

Another batch of eight cavities, made from large-grain Niobium sheets, has been inspected in all surface preparation steps up to now. Their final preparation and RF-tests are scheduled, beginning in the next weeks, so that further analyses of the evolution of defects are awaited for the near future.

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