High Gradient SRF Research at DESY

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Gradients exceeding 40MV/m have been multiply demonstrated in 9-cell SRF cavities that are foreseen for the International Linear Collider. The mass production of such cavities however remains a challenge. A new, in situ method for optical inspection, developed at KEK/Kyoto University allows to correlate surface features with e.g. quench locations. This and other tools are presented that enable a systematic approach to understanding the gradient limiting features in SRF cavities. Results from the large sample investigated at DESY are shown.

1 Reaching high accelerating gradients

One of the core parts of linear accelerators such as the European XFEL and the planned International Linear Collider (ILC) are the accelerating structures, in this case 9-cell RF resonators (cavities) made from Niobium and operated at 1.3 GHz. The design operating gradient for the ILC has been ambitiously chosen to be 31.5 MV/m [1].To reach high accelerating gradients, one has to demand high standards of the quality of the cavity's inner surface with respect to smoothness and cleanliness. In order to attain these conditions, about 200 μm of the surface material are removed by (electro-)chemical means. Before the test or assembly to an accelerator module the cavities are cleaned and handled in a clean room. The cavity preparation process is described in detail in [2] and [3]. Over the past 20 years, the maximum accelerating gradient of SRF cavities has been significantly improved. Several of the cavities that have been processed and tested at DESY have reached accelerating gradients higher than 35 MV/m in vertical test. A detailed analysis of recent nine-cell cavity results can be found in [4]. Even though high gradients are reached in many cases, the spread in the production is large with some cavities limited around 20 MV/m and below, so that series production with high yield needs a good understanding of the limiting effects. One feature limiting the gradient may be geometrical defects on the inner surface, like defects in the welding seams. Such defects can be detected via optical inspection of the inner surface of a cavity.

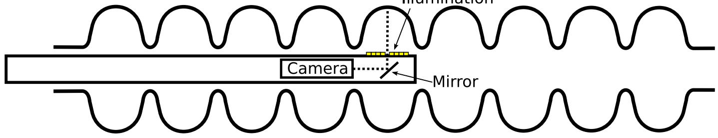

Figure 1: Schematic overview of optical inspection setup

2 Optical inspection of the inner surface of cavities

The properties of the Niobium make the optical inspection of the inner surface of SRF cavities very demanding. The smoothness of the surface after chemical treatment leads to bright reflections and low contrast. Since end of 2008 the prototype of an optical system, developed at KEK and Kyoto University [5], is available at DESY. It has been adapted to the situation inside a cavity and allows the inspection of the inner surface in situ. It consists of a high resolution digital camera in combination with a special lighting system. A schematic overview of the setup is shown in Fig. 1. The camera is situated inside a cylinder, looking to the inner cavity surface via a mirror. Illumination is done by a LED and 20 electroluminescent stripes. The stripes can be turned on and off individually to light the surface under different angles and thereby guarantee appropriate lighting for different structures on the surface.

2.1 Comparison between optical inspection and temperature mapping

During the RF measurement in the vertical test the surface temperature of the cavity can be monitored by an array of thermo-sensors (T-map) [6]. In case of a local breakdown of superconductivity (quench) the position can be identified by the increase in temperature at the outer surface. In several cases subsequent optical inspection of the corresponding areas on the inner surface revealed visible defects, e.g. in the welding seam. One example for such a correlation is shown in Fig. 2. The cavity Z130 was limited at 17.3 MV/m by quench in the first vertical test and was cut out of its He-vessel for further investigation. The second test was donet with T-map. The $3\pi/9$–mode was limited at 22 MV/m and heating of the quench was observed on the equator of cell 5 (left part of Fig. 2). Optical inspection of the corresponding area revealed a circular pit of about 700 μm diameter on the edge of the welding seam (right part of Fig. 2).

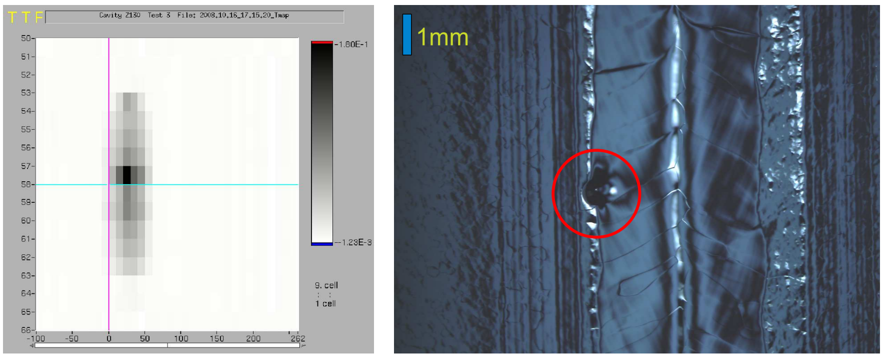

Figure 2: Heating of quench detected by T-map in Z130 (left) and defect in optical inspection picture of corresponding area (right)

2.2 Inspection in different stages of preparation

Optical inspections in consecutive stages of the surface treatment process allow the study of formation and evolution of surface defects. The series of pictures in Fig. 3 shows the evolution of an area on the equator of cell 1 in the cavity Z137. The left picture is taken after welding before any further chemical treatment of the surface. The welding seam looks normal and similar to all the other eight welding seams. After the main surface removal of 108 μm by electro-polishing (EP) (center picture) rough areas and steep edges at the grain boundaries are visible on the equator and in the heat affected zone of cell 1, in contrast to the other eight cells. The final EP has smoothened out the edges a bit (right picture) and the equator is shinier, but the steep grain boundaries remain. The accelerating gradient of Z137 was limited by quench at 25.2 MV/m in the vertical test. Heating of the quench was located by T-map next to the equator of cell 1. It is not yet understood why cell 1 reacted differently under EP.

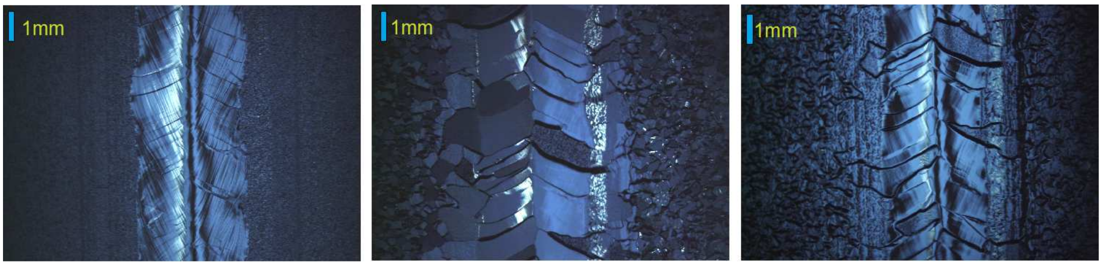

Figure 3: Equatorial welding seam of cell 1 in Z137: before EP (left), after main-EP (center) and after final-EP (right)

3 Summary

SRF cavities already exceed the specifications for future accelerator projects, but production suffers from a scatter in accelerating gradient. One reason for limitation of a cavity at lower gradients are geometrical defects on the inner surface that can be detected by optical inspection. Correlations between heating at the quench location found by T-map and visible defects in the optical inspection were found in several cases. Studies on the evolution of defects during the different stages of surface preparation are carried out. The goal is to categorize structures on the inner surface, in order to understand, which defects keep a cavity from reaching high accelerating gradients. The ability to detect and remove such limiting features in early stages of the processing may help to improve the yield in a large scale production.

References

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