

Quality Assessment for Industrially Produced High-Gradient Superconducting Cavities*

F. Schländer[#], S. Aderhold, E. Elsen, D. Reschke, M. Wenskat, DESY, 22603 Hamburg, Germany

Abstract

A series of 800 industrially produced superconducting 1.3 GHz cavities (3D model see Fig. 1) will be delivered to DESY starting in 2012. Although a considerably smaller gradient satisfies the needs for the European XFEL [1] the electro-polished cavities (50% of the delivery) are deemed to be suitable for gradients in excess of 35 MV/m, the performance goal of the International Linear Collider (ILC) [2].

Specifically, 24 cavities will be supplied without helium tank to enable further investigations as part of the ILC-HiGrade [3] project. The results may serve to improve overall performance; limitations such as field emission and thermal breakdown of superconductivity (“quench”) are still under investigation. For this matter the DESY ILC group has developed tools to monitor obstacles for the cavity performance caused by the cavity fabrication and preparation.

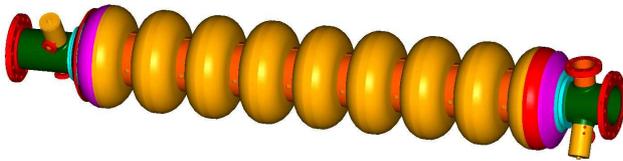


Figure 1: 3D model of the 9-cell 1.3 GHz European XFEL- design cavity

CAVITY MONITORING TOOLS

To establish high gradients reliably it is inevitable to understand the obstacles, especially the local thermal breakdown “quench”, which prevents high yield. This analysis includes the localisation of the quench position during a cavity performance test using temperature mapping [4] or second sound [5]. Another tool is the optical inspection [6,7] of the inner cavity surface to locate features that may cause field emission or quench in advance, but is also used to validate the quench locations found during the performance test. Since the full optical mapping entails many photographs it is necessary to identify such features with an automated image evaluation.

QUENCH LOCALISATION AT DESY

At DESY three different systems for temperature mapping (T-Map) during a cold performance test are available [4]:

- 9-cell rotating T-Map (as shown in Fig. 2)
- Single cell fixed T-Map
- “Quick T-Map” to be attached to one equator of a multi-cell cavity

In addition the second sound in HeII induced by heat deposition during the quench can be detected, as has been first demonstrated at Cornell University [8]. This technology is also in use at DESY since mid 2010 [5,9]. The locations of the condenser microphone-like detectors (Oscillating Superleak Transducers, OSTs) are shown schematically in Fig. 2. Recent tests showed a significant improvement of sensitivity by smoothing the electrode surface [10]. The second sound system is attached to the supporting frame of the cryostat insert and does not have to be removed with every cavity exchange, while the temperature mapping systems are attached to the cavity, thus have to be reassembled for every performance test.

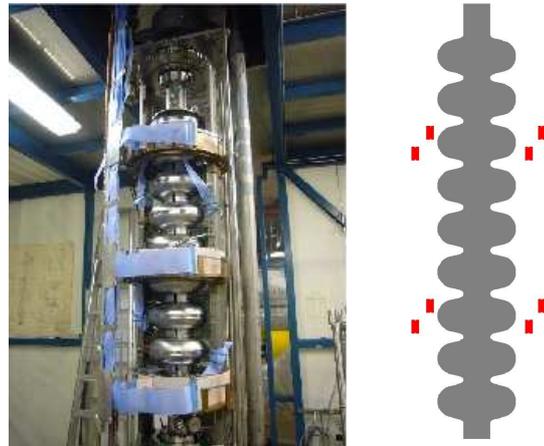


Figure 2: Rotating temperature mapping system used at DESY (left); schematic drawing of the OST locations around a cavity during a performance test at DESY (right)

OPTICAL INSPECTION SYSTEM

The optical inspection of the inner cavity surface is a challenging process, since the aperture of the cavity limits the possibilities for placing a camera inside. In a collaboration between Kyoto University and KEK the Kyoto camera system has been developed [11], a schematic overview can be seen in Fig. 3.

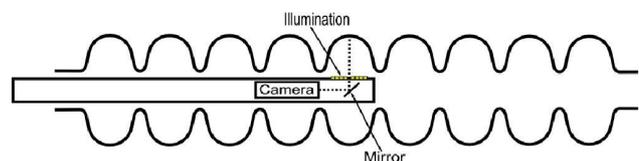


Figure 3: Schematic overview of the Kyoto camera

*This work is supported by the Commission of the European Communities under the 7th Framework Programme “Construction of New Infrastructures – Preparatory Phase”, contract number 206711.

[#]felix.schlnder@desy.de

Since 2008 the camera system is also available at DESY with an upgrade in 2009 [7]. About 70 full manual surface inspections (equator and iris welds) have been done with this system up to now. A manual inspection at DESY takes about two working days, so the development of an automated optical inspection setup is necessary.

OBACHT

The mechanical commissioning of the Optical Bench for Automated Cavity-inspection with High resolution on short Time scales “OBACHT” [12] is almost completed (Fig. 4). Cavities will be mounted on a horizontally moveable sled. The camera tube itself is attached to a torque motor. The steering software for the system is under development and is planned for completion at the beginning of the cavity series delivery.

An advantage compared to the current system used at DESY is the possibility to inspect cavities dressed in their He-vessel, which will be the largest fraction of inspections. The overall inspection time will be reduced to a few hours, so two inspections per day seem feasible.

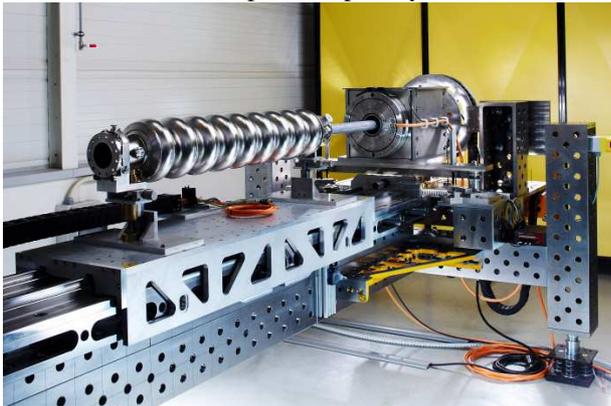


Figure 4: Picture of the mechanical setup of OBACHT

AUTOMATED IMAGE PROCESSING

One full optical inspection of a 9-cell 1.3 GHz cavity produces in the order of 1000 pictures, and since the acquisition of the pictures will be done automatically, there is no reasonable possibility for the OBACHT-operator to examine all pictures simultaneously.

In the order to obtain the information of interest out of the large number of pictures, they have to be processed and evaluated by a self-developed algorithm-based software. An example of image processing is shown in Fig. 5, which shows one picture of a cavity equator. In the centre one recognizes the welding bead which is framed by the welding seam. The welding seam itself has a fishbone-like structure with thin, long lines tilted from the bead. Adjacent the so-called heat affected zone close to the melted area one sees a slightly different surface structure compared to the bulk niobium of the cavity half-cell, since the heat of the welding process is still sufficient to change the grain structure of the niobium. A defect

from the welding process is clearly visible in this picture, included in the white boxed area. This defect has a size of 0.16 mm².

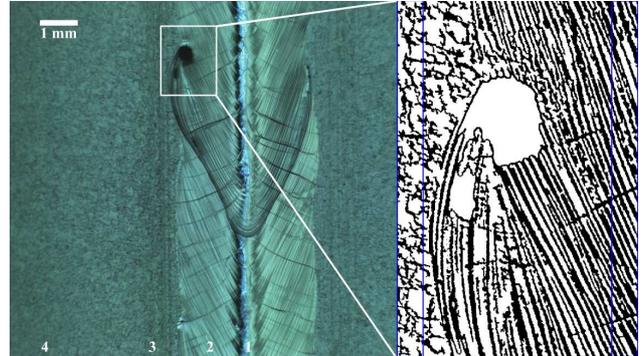


Figure 5: left: Picture of an equator welding seam (2) with a welding bead (1) in the centre, the heat affected zone (3) next to the seam, and the bulk niobium (4) of the cavity half-cell; right: Magnification of the defect (size 0.16 mm²) in the white boxed area as processed black-and-white picture. Blue boxes: areas of coverage calculation.

On the right hand side of Fig. 5 the processed magnification of the white framed area is shown. The previously coloured picture was converted to grey-scale. After further processing and applying a suitable grey-scale threshold one obtains the black-and-white picture, with the defect in the centre visible as a white area. The resulting image exhibits rather homogeneous areas interconnected by lines (ridges). The fishbone-like structure has been well reproduced and results in long thin areas/objects. In contrast to this, in the heat affected zone larger areas have been found which can be explained with the smoothening or remelting of niobium grains during the welding process. The two blue boxes indicate the location where the object coverages (ratio of white pixels to all pixels in the area) were calculated. A large coverage means that there are few, large objects, thus less boundaries (as in the heat affected zone with a coverage of 66%), while a lower coverage indicates lots of smaller objects (welding seam, 44% coverage).

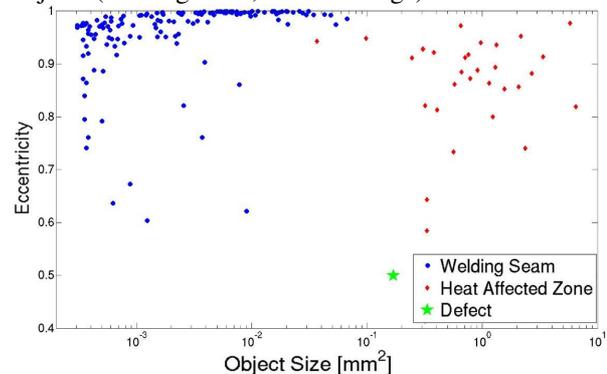


Figure 6: Scatter plot of the size of the objects found vs. their eccentricity in the processed image of Fig. 5. The blue dots are objects found on the welding seam (fishbone structure), while the red diamonds are objects found in the heat affected zone. The defect is marked as green star.

These obvious features are quantified by the pattern recognition algorithm. The defect has been found to be a feature with a relatively low eccentricity and seems to be the “roundest” object detected, while the fishbone structures are reconstructed as objects with small area and large eccentricity (“lines”) in the scatter plot in Fig. 6. The eccentricity is defined as $e=(1-(b/a)^2)^{1/2}$ with a and b being the semi-major and semi-minor axis of the ellipse placed in the objects. The contours in the heat affected zone are somewhat rounder and typically encompass larger areas. Typical numbers of areas and eccentricities in the heat affected zone and the welding seam can be found in Tab. 1.

Table 1: Quantities in the processed image

zone	Feature area (mm ²)	Averaged eccentricity
Welding seam	< 0.1	0.93
Heat affected zone	> 0.1	0.82
Defect	0.16	0.5

The density of objects varies between the regions. The contours of the heat affected zone encircle fairly large areas while the “edges” in the welding seam area typically cover the area densely.

The fairly obvious measures of length, area and eccentricity already provide good means of distinguishing gross features of the image. Other measures can be devised. The algorithm aims for characterising all surface variations automatically and eventually to single out those defects that are detrimental to the cavity performance. The tuning of the algorithm will depend on the feedback arising from the various cavity performance tools.

SUMMARY

DESY is developing and improving sophisticated diagnostic tools for 1.3 GHz superconducting cavities. The tools will be used to examine the cavities for the European XFEL and for ILC-HiGrade. The pattern recognition will classify the images and reveal details of the manufacturing process. Eventually the tools will

hopefully provide the evidence for a good understanding of cavity performance so that the entire efforts forms the basis to ascertain the higher quality demands for the International Linear Collider ILC.

ACKNOWLEDGEMENTS

We wish to thank the staff in the cavity test area in “Hall 3” for all its patience and diligence during the cavity scan and the technical staff involved in the OBACHT construction for help and support.

REFERENCES

- [1] “The European X-ray Free Electron Laser” FEL Technical Design Report, DESY 2006-097, Hamburg, July 2007.
- [2] ILC Technical Design Report, ILC-Report 2007-001, August 2007.
- [3] www.ilc-higrade.eu
- [4] D. Reschke, “Analysis of Quenches using Temperature Mapping in 1.3 GHz SCRF Cavities at DESY”, LINAC '08, Vancouver, Sept. 2008, THP016; <http://www.JACoW.org>.
- [5] F. Schlander et al., “Second Sound as an automated Quench Diagnostic Tool”, SRF 2011, Chicago, July 2011, THPO031, to be published
- [6] S. Aderhold, Dissertation, DESY, Hamburg, 2011 (to be published)
- [7] S. Aderhold, “Optical Inspection of SRF Cavities at DESY”, IPAC '10, Kyoto, May 2010, WEPEC005 <http://www.JACoW.org>
- [8] Z.A. Conway et al., “Oscillating Superleak Transducers for Quench Detection in Superconducting ILC Cavities cooled with He-II”, LINAC '08, Vancouver, September 2008, THP036 <http://www.JACoW.org>
- [9] F. Schlander et al., “Recent Results from Second Sound, T-Mapping and Optical Inspection of 1.3 GHz Cavities at DESY”, SRF 2011, Chicago, July 2011, TUPO066, to be published
- [10] F. Schlander, H. Vennekate, ILC-HiGrade-Report 2011-001-1, 2011 <http://www.ilc-higrade.eu/e83212/>
- [11] Y. Iwashita et al., “Development of High Resolution Camera for Observations of Superconducting Cavities”, Phys. Rev. ST Accel. Beams 11, 093501 (2008)
- [12] S. Aderhold et al., ILC-HiGrade-Report 2010-005, 2010 <http://www.ilc-higrade.eu/e83212/>