PROGRESS ON DIAGNOSTIC TOOLS FOR SUPERCONDUCTING HIGH-GRADIENT CAVITIES*

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Abstract

Superconducting RF (SRF) cavities have long been used in particle accelerators. The 1.3 GHz niobium cavities developed in the TESLA collaboration will be the basis of the European XFEL [1] and are the cavity of choice for the International Linear Collider (ILC) [2]. The fabrication process of the cavities has been developed and optimised over the past 15 years and will now be applied in large scale industrial production of the 800 cavities foreseen for the XFEL. The DESY ILC group is developing tools to monitor those aspects of the production that affect the gradient of these cavities. To date the main obstacle in achieving a gradient exceeding 30 MV/m is the quench induced in surface structures in the niobium, while field emission is still under investigation. Such features are explored in an optical inspection of the 9-cell cavity structures and supplemented by temperature mapping [3] and measurements of the Second Sound [4] that originates from the phase transition of the liquid helium at the position of the local thermal breakdown ("quench") in superfluid helium. Oscillating Superleak Transducers (OST) are used to record the signal of the Second Sound. The Second Sound measurements are thought to replace the time consuming temperature mapping on the outer cavity surface with a resistor system [3].

QUENCH DETECTION

While the occurrence of a quench in an SRF cavity is quickly evident from the RF operating parameters it is more cumbersome to locate the origin of the quench on the surface. A long established system at DESY consists in harnessing the outer cavity surface by a series of resistors and to measure the change of resistance introduces by the heat deposited at the origin of the quench. Rather newer at DESY is the introduction of the Second Sound measurement capability which registers the phase transition He II to He I induced by the heat deposited.

Temperature Mapping

The most extensive temperature mapping system at DESY senses the surface temperature on all 9 cells of a complete cavity simultaneously at a cryogenic RF test at 2 K. Two arms with 116 carbon resistors in total are mounted on the cavity surface and can be rotated 360° azimuthally around the cavity, as shown in Fig. 1. An overview of the various types of temperature mapping (T-Map) systems in use at DESY is given in [3].

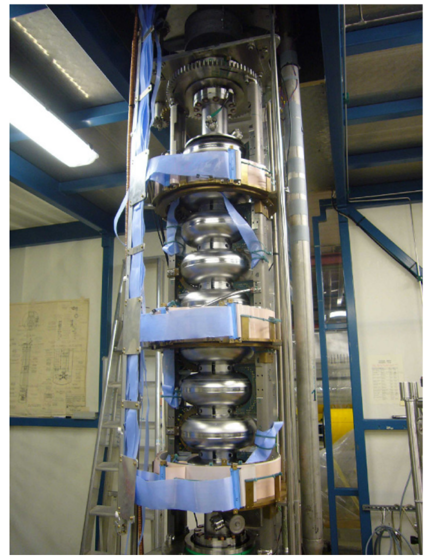

Figure 1: Rotating T-Map system used at DESY

Second Sound

The cryogenic measurements on 1.3 GHz SRF cavities take place at $\leq$ 2 K in liquid Helium below the λ-point. This leads to a mixture of He I and superfluid Helium (He II) inside the cryostat. If energy is deposited in the helium vessel, e.g. by a quench, the phase transition of He II to He I propagates as an entropy wave, the so-called Second Sound. The amplitude of the Second Sound signal and the propagation velocity of the Second Sound depend on the temperature of the helium bath. This wave can be observed with Oscillating Superleak Transducers that operate like condenser microphones with a porous membrane to allow He II flow while He I will be blocked because of its viscosity. With a DC voltage of 120 V applied to the transducers, special safety requirements had to be taken into account, such as special cabling and shielding of the amplifier electronics. With a set of eight OSTs, as shown in Fig. 2, one can cover the entire surface of a cavity and measure the propagation times. With the known propagation velocity v in a range of 16 - 20 m/s at 1.4 - 2 K at least three measured signals are needed to do triangulation. Measurement errors usually lead to a quench position not located on the surface of the cavity which is compensated with a constraint fit on the cavity surface. The resolution of this method is estimated to be around 1 mm, which is a large improvement compared to temperature mapping (about 1 cm).

* 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.
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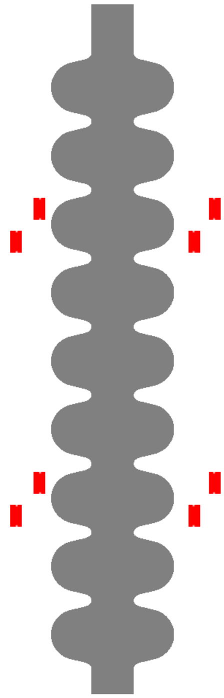

Figure 2: Schematic overview of the OST setup applied at DESY: a 9-cell cavity and 8 OSTs (red)

EXPERIENCE WITH SECOND SOUND

A first test of OSTs assembled at DESY took place in March 2010 with four transducers mounted at one insert with a 9-cell cavity at the vertical cavity test stand. At this first test, only one of the transducers showed a signal, so no quench location could be calculated.

Several tests in the temperature range of 1.4 K to 2.1 K showed the known propagation velocity dependence, but also a temperature dependence of the amplitude on the signal. The largest amplitude has been found at 1.6 K, but as a compromise regarding the pumping time and the provided temperature stability, future Second Sound measurements will be made at 1.8 K. This has several advantages compared to 2 K:

- The signal amplitude is increased due to the larger amount of He-II and the Second Sound signal is carried better in the Helium bath.
- The $\frac{dv}{dT}$-ratio is smaller by a factor of 4 compared to 2 K which results in a better determination of the propagation velocity v.

To date, the measurement is still hampered by electrical noise injected on the the OST channels. Some sources, such as the supply wires acting as antenna, have been eliminated successfully. However, since the vertical test stand shares the same building with the FLASH accelerator at DESY there are more sources of electromagnetic perturbations that cannot be eliminated easily. Future plans are to place one open ended wire inside the cryostat as a noise reference and use this signal for pedestal subtraction. Initial tests showed a significant noise reduction.

OPTICAL INSPECTION

In addition to the described methods for quench localisation a system for the optical inspection of the inner surface of cavities is in use at DESY. The camera system has been developed by KEK and the University of Kyoto [6] and is in use at DESY since 2008 [7]. A schematic overview of the system is depicted in Fig. 3. It consists of a high resolution camera combined with an illumination system that is able to adapt to the topology of the surface. Since the application of this optical inspection, the relevant surface effects can be observed. Currently the inspection of the inner surface is done manually and takes about two days for a full inspection of a 9-cell cavity. An automated setup is under construction and will be brought into service soon.

The comparison of the optical inspection pictures and known quench locations gives information about structures on the inners surface that may cause such a quench. Correlations between defects found in the optical inspection and hotspots from the quench detected by T-Map or Second Sound have been found in several cases [7]. By studying the formation and evolution of defects via optical inspection in-between the different steps of surface treatment the identification of possible limitations of the cavity performance becomes feasible at early stages of the cavity production and preparation process.

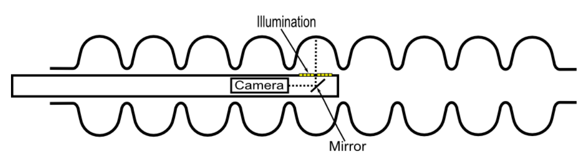

Figure 3: Schematic overview of the Kyoto Camera System

MEASUREMENTS AT CAVITY AC126

One example of the first measurements using the Second Sound system is a test of the superconducting 9-cell 1.3 GHz cavity AC126. It has been tested recently with rotating Temperature Map and a Second Sound setup. The quench locations have been successfully found with both T-Map and Second Sound. In Fig. 4 the temperature map of cell 2 at the quench position in the π-mode is shown.

The red spot on the lower half cell has been identified in this T-Map to be the quench spot. In addition there is another heating source near the equator which also was a hot spot in another measurement. The position calculated with the Oscillating Superleak Transducers shows a position between both located heat spots, but the measured angular position is in very good agreement with the temperature map. The quench locations detected by Second Sound in the other fundamental passband modes have also been verified by the temperature mapping system.

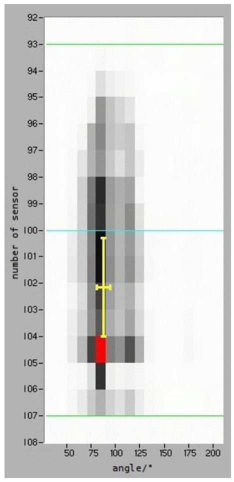

Figure 4: Temperature Map image of cell 2 of cavity AC126 in π-mode with the red hot spot and the quench location by Second Sound marked in yellow

The optical inspection of AC126 after the vertical test showed that the quench location measured in π-mode and the position of the defect found in Fig. 5 agree.

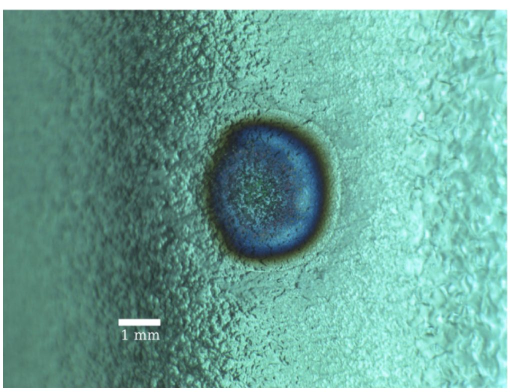

Figure 5: Defect observed in AC126 at measured π-mode quench location

A rainbow colored area has been found at the located quench position. While continuing the inspection of the inner surface, three more of those areas were identified near the equator. This gave evidence that the high pressure rinsing head had been interrupted during a rinsing cycle. Earlier studies [8] showed that high pressure rinsing may oxidize Niobium surfaces. An HPR spraying head with 8 nozzles has been used and all 8 corresponding defect areas have been found inside the cavity. Usually the oxidation due to a HPR interruption is not a cause for a quench at these positions and does not lead to remarkable defects. "Classical" defects are pits or bumps as have been shown in several earlier publications, e.g. [7] and have a span of several hundred microns. Further studies of the quench position and its inner structure will be done as cavity AC126 will be dissected soon and further examined.

SUMMARY AND OUTLOOK

DESY is applying several diagnostic tools for superconducting 9-cell 1.3 GHz cavities for quality assessment following the sophisticated production process:

- Temperature mapping
- Measurement of Second Sound
- Optical inspection of the inner surface of the superconducting cavities is done with the Kyoto camera system

Several simultaneous tests of the Second Sound setup with the established T-Map system showed a good agreement of the quench location in the vertical cavity test. To reduce the current uncertainties of the quench localisation, some more effort like more precise positioning of the OSTs and a better time resolution of the DAQ has to be made to improve the accuracy. Future plans are an automated quench detection using Second Sound to avoid time consuming temperature mapping, which is not practical for a large amount of cavities like for the European XFEL and the ILC-HiGrade programme, combined with an automated optical inspection.

ACKNOWLEDGEMENTS

Special thanks to Z. A. Conway and G. Hoffstaetter (Cornell University) and to all staff working on and around the cavity testing site at DESY.

REFERENCES

[1] XFEL Technical Design Report, DESY 2006-097, Hamburg, July 2007

[2] ILC Technical Design Report, ILC-Report-2007-001, August 2007

[3] D. Reschke, "Analysis of Quenches using Temperature Mapping in 1.3 GHz SCRF Cavities at DESY", LINAC '08, Vancouver, September 2008, THP016 http://www.JACoW.org.

[4] L. Tisza, "Sur la Theorie des Liquides Quantiques. Application a L'Helium Liquide", J. de Physique Radium 5 & 8

[5] 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.

[6] Y. Iwashita et al., "Development of High Resolution Camera for Observations of Superconducting Cavities ", Phys. Rev. ST Accel. Beams 11, 093501 (2008)

[7] S. Aderhold, "Optical Inspection of SRF Cavities at DESY", IPAC '10, Kyoto, May 2010, WEPEC005 http://www.JACoW.org.

[8] J. Knobloch and R. Freyman, "Effect of High-Pressure Rinsing on Niobium", February 1998, SRF Note 980223-01