

R&D ON CAVITY TREATMENTS AT DESY TOWARDS THE ILC PERFORMANCE GOAL

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Abstract

An extensive R&D programme on cavity investigations and treatments towards ILC performance goal has been established at DESY. A new “ILC-HiGrade Lab” is being commissioned and will house some existing and planned cavity inspection and treatment tools. Aims and details of the program as well as the current status of the facility are reported.

INTRODUCTION

Superconducting radio-frequency (SRF) niobium cavities are a key component of current and future efficient particle accelerators producing high-energy and high-intensity beams. The technology is key to next-generation light sources, accelerator-driven sub-critical nuclear reactors and nuclear-fuel treatment, new accelerators for material science and medical applications etc. The SRF cavities are made from high-purity niobium and undergo a complex multi-step production process to achieve high accelerating gradient, E_{acc} , and a high quality factor, Q_0 . These quantities, together with the manufacturing yield, drive cost and performance factors such as cryogenics, beam energy, machine length etc. The European X-ray Free Electron Laser (XFEL) [1], currently under construction in Hamburg, requires for example 800 Tesla-shape [2] 9-cell 1.3 GHz SRF Nb cavities operating at nominal average gradient E_{acc} of 23.6 MV/m with unloaded quality factor Q_0 of at least 10^{10} . The future International Linear Collider (ILC) [3] would require the production of 16000 such cavities operating at nominal average gradient of 31.5 MV/m with almost the same quality factor Q_0 . With such a quantity of cavities to be fabricated, the manufacturing yield and the possibility of retreatment and repair of the SRF cavities become very important issues.

In order to address the performance, fabrication, and repair issues of cavities, an extensive R&D programme including the commissioning of a new “ILC-HiGrade Lab” is being established at DESY. The programme includes cavity investigations and treatments aimed at achieving the ILC performance goal. It aims at a clear understanding of the limiting factors of the cavities, exploration of reliable methods of cavity treatment, and gaining experience with the mass-production of XFEL cavities. In addition to the well-established cavity treatment and inspection techniques, the programme will also include techniques such as centrifugal barrel polishing (CBP) (see below) and local grinding.

R&D PROGRAM

This R&D programme at DESY continues that of the Global Design Effort for the ILC and is therefore well coordinated with efforts elsewhere. The aim is to gain experience with the industrial mass-production process and have a solid understanding and control of the whole procedure by monitoring the fabrication of 800 XFEL cavities. The existence of advanced cavity inspection and treatment techniques allowed feedback to be provided to the cavity fabrication thereby influencing the production of XFEL cavities. The “European ILC-HiGrade program” was designed to produce better understanding of XFEL cavity production. The details of this programme are given in the following section and can be found elsewhere [4, 5]. The main goal of the R&D is clear identification of the factors limiting the gradient and definition of a cavity treatment providing at least 35 MV/m with a production yield higher than 90%.

The XFEL production process has already provided cavities achieving 35 MV/m accelerating gradient in vertical tests (Fig. 1). This comfortably exceeds the required 23.6 MV/m for the XFEL and meets the ILC requirements. These results emphasise the importance of

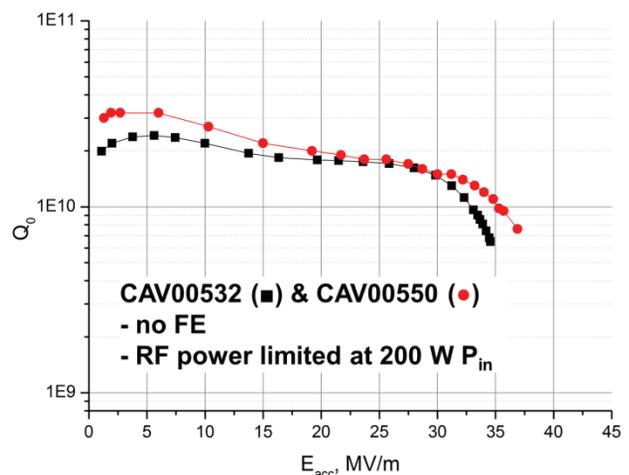


Figure 1: Plot of quality factor against accelerating gradient in cold RF tests of two European XFEL cavities.

further exploration of new cavity preparation and repair techniques that can achieve high accelerating fields with high fabrication yield.

EUROPEAN ILC-HIGRADE PROGRAM

The EXFEL cavity order includes an additional 24 cavities as part of the European ILC-HiGrade programme. Initially, these cavities serve as quality-control (QC) samples extracted from the serial production of EXFEL cavities on average once per month. The first few cavities have been already delivered and passed first cold RF tests. After this normal acceptance test, the cavities are taken out of the production flow and released for further R&D. The QC and quality assurance (QA) have to include all processing steps of the EXFEL cavities. To maximize the data from these so-called QC cavities, a surface-mapping technique (“Second Sound” and temperature mapping (T-mapping)) is applied in a second cold RF test. Therefore the cavities are delivered with the normal full treatment of the inner surface but without a helium tank.

The following R&D steps are foreseen with these cavities within the ILC-HiGrade and CRISP [6] programmes as a feasibility study for the ILC. The “Second sound” and T-mapping techniques are first applied during the second cold RF test in order to localize any quenches. Investigation of the inner cavity surface and detailed analysis of the quenching defects as well as of the surface of “quench-free” cavities is performed by means of the high-resolution optical system OBACHT and replica. Finally, depending on the cold RF result, surface quality, and number of defects, the cavity will be given to a second-pass electropolishing (EP) process, buffer chemical polishing (BCP), and high-pressure ultrapure-water rinsing (HPR) and/or sent for centrifugal barrel polishing (CBP) or local grinding repair.

ILC-HIGRADE LAB AT DESY

Fig. 2 shows the general layout of the ILC-HiGrade Lab. This will house the optical cavity inspection system OBACHT in routine use at DESY as well as the CBP, local grinding machine, and replica. The specially constructed rinsing station and vertical ultrasonic bath are

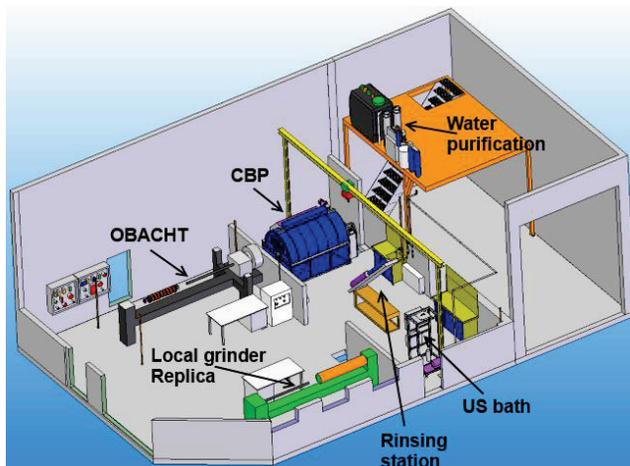


Figure 2: “ILC-HiGrade Lab” layout.

used for extracting polishing residues from the cavities

after every CBP polishing step. The water purification system delivers ultrapure water with conductivity <math><1 \mu\text{S}/\text{cm}</math> for the rinsing station, ultrasonic bath, and for the CBP polishing itself.

DIAGNOSTIC TOOLS

Within the R&D programme, the following methods of non-destructive surface diagnostics will be used.

Optical Cavity Inspection System (OBACHT)

OBACHT (see Fig. 3) is a semi-automated (based on LabView®) optical inspection tool of the inner cavity surface and is based on the Kyoto camera system [7]. It allows inspection of a large number of cavities with and without a He-tank as well as of the components that make up a complete cavity such as “dumbbells” and end groups. For a “standard” cavity inspection the system yields around 3000 pictures in around 8 hours. The inspection concentrates welding seams at the equator and irises plus the area to the left and right of the equator welding seams. The OBACHT pictures cover a cavity area of 12 mm x 9 mm with 2616 x 2488 pixels and around 5 $\mu\text{m}/\text{pixel}$. The position accuracy of a cavity mounted on a movable sled is about 10 μm , whereas the angular camera positioning accuracy is about 0.01°. The possibility of automated image processing and defect recognition is being explored [8].

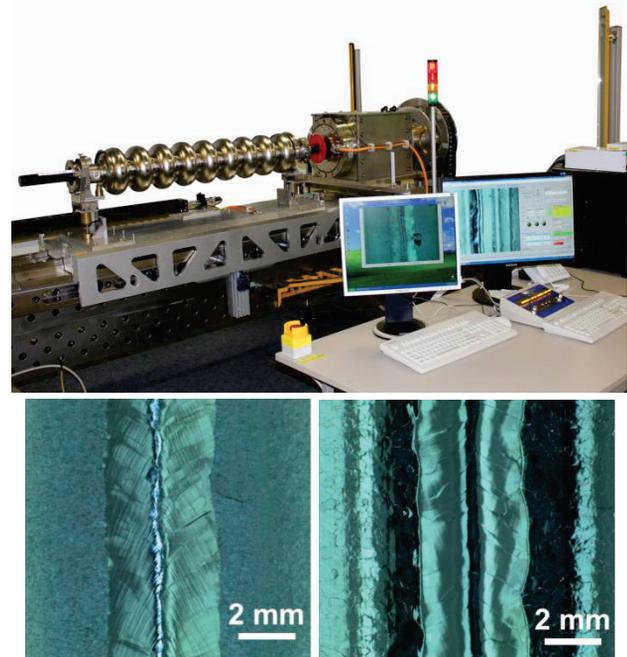


Figure 3: The OBACHT system showing a mounted cavity with the camera inserted into the cavity interior and two examples of images showing the equator welding seam before and after polishing.

Replica

Replica is non-destructive cavity inner-surface study method with resolution down to 1 μm . It copies the

details of the surface by imprinting onto hardened rubber. The footprint is subsequently studied with a microscope or profilometer. An example of the replica test of the 3D surface geometry showing a defect is shown in Fig. 4. It allows better correlation between the topography and 2D images from the OBACHT.

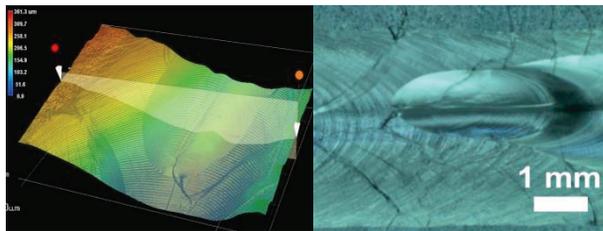


Figure 4: 3D surface defect geometry and correlation with optical image from OBACHT.

“Second Sound” Quench Localization System

The “Second Sound” method is a fast quench-localization system routinely used at DESY. The method utilizes the temperature wave or second sound in the helium bath induced by the heat pulse from a quenching spot. To detect the second sound in helium, Oscillating Superleak Transducers (OSTs) [9] are used. These devices are built analogously to condenser microphones and use a thin porous membrane sputtered with a conductive layer on one side. This membrane is placed on a brass electrode as the second “plate” of the capacitor. The very small distance between membrane and brass electrode changes when the second sound interacts with the membrane, leading to a change in the capacitance which can be measured. Determination of the quench location is done via trilateration. The first setup and first measurements were carried out at Cornell University, USA in 2008 [10].

Although the “Second sound” technique offers a convenient method to locate quenches in SRF cavities during cold RF tests, precise localisation and understanding of local thermal breakdowns or quenches in SRF cavities is still a challenge. Typical resolutions of 1 cm and better have been obtained. The current resolution is limited by details of the heat propagation within the complete vertical test setup. With the upgrade to a highly redundant system at DESY (from 8 to 16 OSTs per insert) such effects can be studied. Comparison between the upgraded “Second Sound” quench detection system and the old setup, as well as with the results of the T-mapping and optical inspection (OBACHT) systems will be performed.

CAVITY TREATMENTS

Several techniques in addition to the well-established EP and BCP will be used for surface treatment and repair to reach high field gradient and high quality factor. The main ones are local grinding as a cavity repair technique and CBP as both a cavity repair and possibly stand-alone preparation technique.

Centrifugal Barrel Polishing (CBP)

CBP is an acid-free surface polishing technique using abrasive media. It considerably reduces chemical usage, only a final light electropolishing (about 10 μm) step being required [11]. It can achieve 10 times smaller roughness with mirror-like surface compared to chemical treatments [12].

A new CBP machine (Fig. 5) has been purchased by the University of Hamburg and will be used in the ILC-HiGrade Lab for:

- Serial tests of the polishing procedure (partially with ILC-HiGrade cavities) as a feasibility study to meet the ILC performance goal.
- Further optimisation and understanding of the process, addressing such issues as polishing recipes, hydrogen-free polishing, polishing time, etc.
- Study of the CBP as a cavity repair and standalone preparation technique.



Figure 5: Centrifugal Barrel Polishing machine in the ILC-HiGrade Lab.

The machine is being commissioned based on the polishing recipes derived from best FNAL, JLAB, and previous DESY experience. The following full cavity preparation scheme has been considered:

- Step 1 – around 8 hours surface cutting using 9 mm x 9 mm triangle abrasives, soap, and ultrapure water;
- Step 2 – around 15 hours intermediate polishing using RG-22 cones, soap, and ultrapure water;
- Step 3 – around 30 hours intermediate polishing using 15 μm alumina, 5 mm wood blocks, and ultrapure water;
- Step 4 – at least 40 hours final polishing using 40 nm colloidal silica and 5 mm wood blocks;
- Step 5 - ultrasonic degrease/rinse;
- Step 6 - HPR;
- Step 7 - 800 °C baking for 2 hours;
- Step 8 - around 10 μm EP;
- Step 9 - ultrasonic degrease/rinse;

- *Step 10 - HPR;*

A test will then be carried out by slowly pumping the cavity down followed by vertical cold rf testing with mode measurement, “Second sound,” and probably T-mapping.

Depending on the initial surface condition, only a “soft” CBP might be applied skipping e.g. some of the initial steps.

Local Grinding

A local grinder (Fig. 6) produces a mechanical polishing technique and is used for local defect removal. A similar machine will be developed and used in the ILC-HiGrade Lab for serial tests of the repair procedure (partially with the ILC-HiGrade cavities), as a feasibility study for meeting the ILC performance goal and for further optimizations.

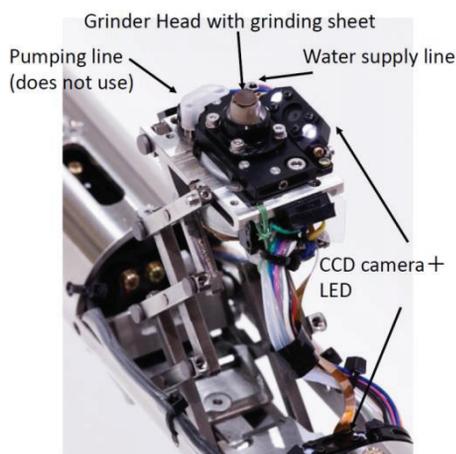


Figure 6: Local grinding tool [13].

CONCLUSIONS

An extensive R&D programme on cavity investigations and treatments aimed at reaching ILC performance goals is being established at DESY. The programme aims at a clear understanding of the cavity limiting factors, elaboration of reliable cavity treatment, and gaining experience via the mass-production of 800 European XFEL cavities. The new ILC-HiGrade Lab is being commissioned and will house OBACHT, replica, local grinder, and CBP techniques.

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