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PROGRESS OF R&D ON SRF CAVITIES AT DESY TOWARDS THE ILC PERFORMANCE GOAL

A. Navitski[#], DESY, Hamburg, Germany
A. Prudnikava, Y. Tamashevich, University of Hamburg, Hamburg, Germany

Abstract

An extensive R&D programme on cavity investigations and treatments towards ILC performance goal has been established at DESY. Aims and details of the program as well as the detailed results of the optical inspections and replica investigations of the inner cavities surface will be 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 a 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 (EXFEL) [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 EXFEL cavities. In addition to the well-established cavity treatment and inspection techniques, the programme includes also techniques such as centrifugal barrel polishing (CBP) 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 EXFEL cavities. The existence of advanced cavity inspection and treatment techniques allowed feedback to be provided to the cavity fabrication thereby influencing the production of EXFEL cavities. The “European ILC-HiGrade program” was designed to produce better understanding of EXFEL cavity production. All the details of this programme can be found elsewhere [4-6]. 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 EXFEL production process has already provided cavities achieving 35 MV/m and more accelerating gradient in vertical tests [7]. This comfortably exceeds the required 23.6 MV/m for the EXFEL and meets the ILC requirements. These results emphasise the importance of further exploration of new cavity preparation and repair techniques that can achieve high accelerating fields with high fabrication yield.

The following R&D steps are foreseen within the ILC-HiGrade and CRISP [8] programmes as a quality assurance and 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 OBACHT system and replica [6]. 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. This paper is focuses mainly on the results of the optical inspections and replica investigations of the cavities surface.

OPTICAL CAVITY INSPECTION

Optical inspections of the cavities have been performed applying the high-resolution OBACHT system [6].

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[#] aliaksandr.navitski@desy.de

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OBACHT is a semi-automated inspection tool of the inner cavity surface and is based on the Kyoto camera system [9]. 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. The inspection concentrates welding seams at the equator and irises plus the area to the left and right of the equator welding seams.

Based on the optical inspections of over 30 EXFEL series and ILC-HiGrade cavities, the following eight types of the surface defects could be found. These are scratches, defects called "cat eyes", etching pits, pits and foreign inclusions, incomplete welding, welding spatters, and rough polishing. Typical examples of these defects are presented in Fig. 1.

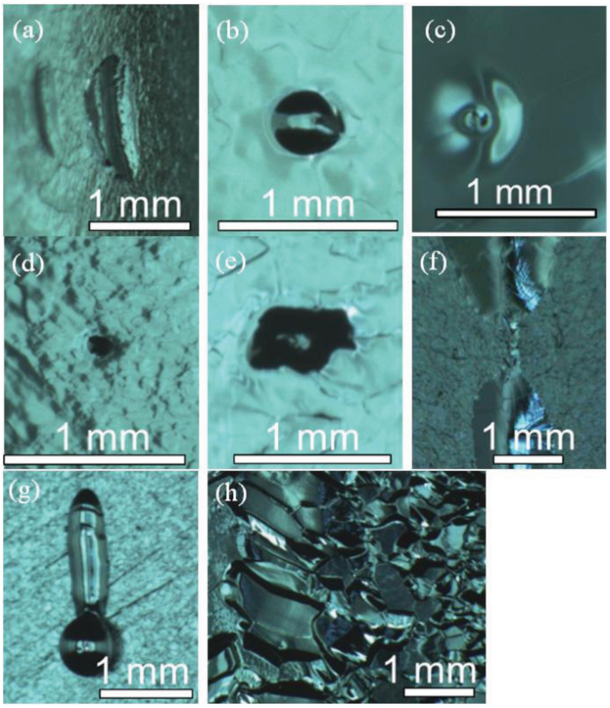

Figure 1: Typical surface defects on series EXFEL and ILC-HiGrade cavities: (a) scratches, (b) "cat eyes", (c) etching pits, (d) pits, (e) foreign inclusions, (f) incomplete welding, (g) welding spatters, and (h) rough polishing.

The scratches on the surface are usually localized only in the iris region and are indications of some mishandling or errors during the production steps leading to contacts or collisions between production tools and the Nb surface thus resulting in mechanical damages of the surface. The main impact of such defects on the cavity performance is a low field x-ray radiation due to the electron field emission enhanced on sharp edges and spikes in the scratched region. The HPR rinsing and in a few cases even a light BCP of around 10 µm followed by the HPR could not cure the field emission load of the cavities with such defects and a more heavy etching is needed. This requires, however, additionally a complete tank removal and retuning of the cavity what still cannot be easy integrated in the mass production flow.

The "cat eyes" are probably the most often appearing defects on the surface. The reason for this is as yet unclear and is the subject of further investigation. Replica studies indicate that these are rounded etching holes as it is shown in Fig. 2. The "cat eyes" and etching pits both are etching artefact. The nature of these artefacts seems to be different since their different geometry and optical appearance. Whereas the etching pits are most probably created due to a sticking of hydrogen bubbles on the surface during the etching process, the "cat eyes" are most probably originated from local material properties like defects or even inclusions. The "etching pits" seems to be harmless in terms of SRF properties since several cavities showed excellent results exceeding ILC specs despite of the observation of many such defects on the surface. The "cat eyes" cannot be yet classified as harmless since high magnetic field enhancement and finally quenches are possible on such defects [10]. Moreover, there are a few cavities with not yet clarified quench reason at a low field and containing some "cat eyes" on the surface.

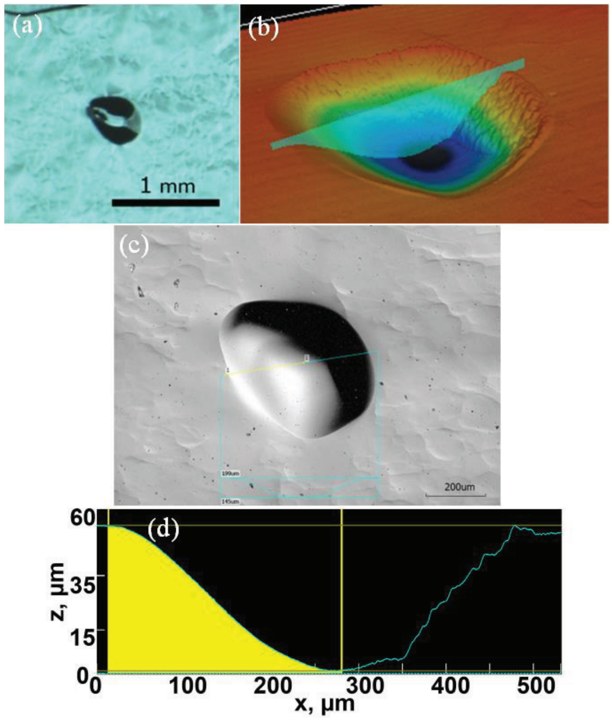

Figure 2: OBACHT and replica investigation of a "cat eye" on the surface of a Nb cavity: (a) OBACHT image and (b) 3D view, (c) topography view, and (d) a profile of the "cat eye" as measured by means of a 3D laser scanning microscope on a replica sample.

The "pits" and foreign inclusions seem to be the most critical defects since a few cavities with such defects were limited by a quench at fields below 20 MV/m. Material analyses in the area of these defects is unfortunately not yet possible without cavity destruction. Replica studies give some hints that these could be foreign material inclusions since the defect area was not affected by the polishing (Fig. 3). Similar etching behaviour has been observed in the past by presence of aluminium flakes on the surface.

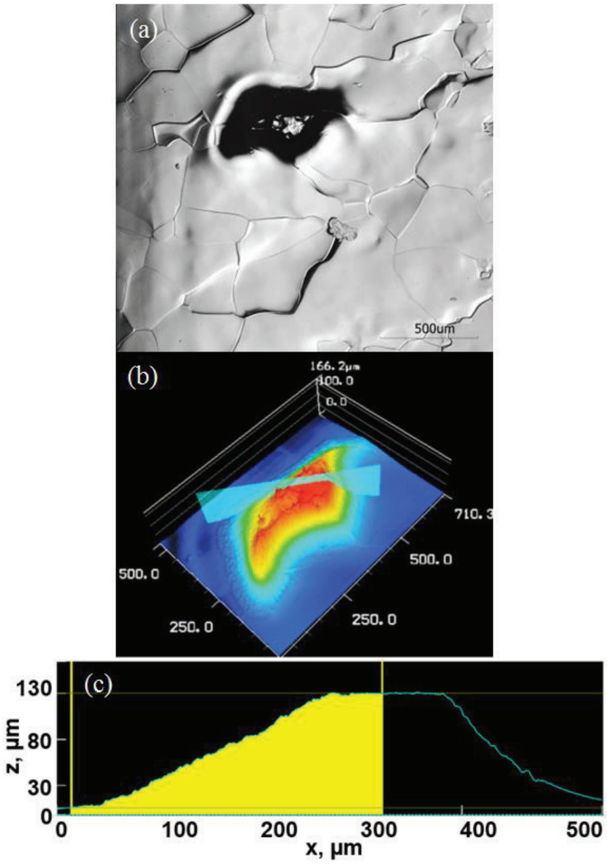

Figure 3: Topography view (a), 3D view (b), and a profile (c) of the defect shown in Fig. 1e as measured by a 3D laser scanning microscope on a replica sample taken in a cavity with 16 MV/m quench field.

An incomplete penetration of the welding seams and strong variation of the seam-width was one of the difficulties that occurred during the ramp-up phase of the EXFEL cavity production. Optical inspections with conventional endoscopes at companies gave some indications of the problem. Detailed analysis of the defects, however, was only possible using the OBACHT system. Meanwhile the problem with the incomplete welding was solved by adapting the welding parameters and only some variation of the seam-width might be observed. The cavities with the incomplete welding have been never cold RF tested since problems with low field quenches and leak tightness were expected.

The ~mm-sized “spatters” are occasionally occurring on the surface during the electron beam welding as observed during the endoscope and OBACHT inspections. There are actually two hypotheses explaining these defects. This might happened due to sparks in the high voltage circuit of the welding machine or due to presence of some dust in the contact of two Nb half-cells. Some dust flakes have been often observed around the “spatters” area, what supports the second idea. The reason for this is as yet unclear and is the subject of further investigation as well. As a consequence, additional local repair of the cavities is required to remove these defects, which are essentially unaffected by the standard polishing techniques. Some local grinding tries are ongoing and an optimum repair procedure is currently under study.

The very rough polishing is an etching artefact which appears very rarely and the reason for this is most probably in the reliability and reproducibility of the etching parameters control. The cavities with such defects show usually a very low quality factor Q_0 and an achievable accelerating gradient E_{acc}.

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.

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