EXPERIENCES ON RETREATMENT OF EU-XFEL SERIES CAVITIES AT DESY

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Abstract

For the European XFEL, two industrial companies are responsible for the manufacture and surface preparation of the eight hundred superconducting cavities. The companies had to follow strictly the XFEL specification and to document all production and preparation steps. No performance guaranties were required. Each cavity delivered by industry to DESY is tested in a vertical test at 2K. Resonators not reaching the performances defined for application at the XFEL linear accelerator modules or showing leakage during cold RF tests have undergone a subsequent retreatment at DESY. Nearly 20% of the cavity production required retreatment, most of them by an additional High Pressure Rinsing. Some cavities received additional BCP flash chemical treatment when the initial HPR did not cure the problem. The analysis of retreatments and quality control data available from the retreatment sequences and the workflow of retreatment will be presented.

INTRODUCTION

The two companies, E. Zanon SpA (Italy) and Research Instruments (Germany), were contracted to build accelerator structures for the EU-XFEL accelerator. Each company had to manufacture 412 super conducting (s.c.) cavities by following strictly the procedures for cavity manufacturing and surface treatment as given in the document "Series surface and acceptance test preparation of superconducting cavities for the European EU-XFL (XFEL/A - D), revision B / JUNE 30, 2009 [1]. Handover of these cavities to DESY for acceptance test had to be in status "integrated to Helium tank (HT) and ready for acceptance test".

No performance guaranty was requested when companies could show that they strictly followed the specification. In case specified procedures are followed and cavities did not fulfill the criteria for module assembly, the retreatment for performance improvement had to be done at DESY.

Until May 2014 permission for installation to modules was given, when usable gradient [2] above 26 MV/m was reached. After analysis of data on retreatments the acceptance level was reduced to usable gradients [3] above 20 MV/m.

Until August 2015 more than 90% of the EU-XFEL resonator were manufactured and handed out for acceptance test. About 20 % failed the acceptance criteria for module assembly or showed leaks during test at 2K were retreated at DESY [2].

RESPONSIBILITIES AND WARRANTIES

The fact that EU-XFEL production is the first time that the complete surface treatment is done at industry, no performance guaranty is asked for. The specification and the criteria for quality control (QC) defined in there [1] had to be followed strictly by industry. In case no deviations from specification are found, but cavities do not match performance, the retreatment is done by DESY.

It was agreed that the specification and the parameters specified there may not cover all conditions and unpredictable situations of a serial production. When problems showed up and were not covered by the specification a solution was found in close collaboration between companies and DESY.

In case of non-conformances at a late phase of production or for deviation of process data like TOC value of the ultra-pure water (UPW) or sulfur accumulation in vacuum systems [4] or only limited data from preparation phase of the EU-XFEL were on hand, a so called "limited acceptance" for handout of cavities to DESY was given. In this case companies did not stop processing of the cavities and took the responsibility for that. Cavities holding limited acceptance were recalled for retreatment by the companies, when the cavities failed the vertical acceptance test.

Leak tightness of the cavities is controlled at room temperature at the companies and at DESY during incoming inspection. Accessories like antennas or valves [1] are provided by DESY and responsibility for leak tightness or functionality of these components is at DESY.

In case leaks or suspect of leaks during cold test were detected at 2K but not detectable at room temperature, repair and retreatment was done at DESY. Leaks reproducible detected after cold test at a gasket or flange area were on the responsibly of the companies and cavities were send back for retreatment and control of gaskets and sealing surfaces.

RETREATMENT PASSES AT DESY

The general retreatment sequence (RP) for cavities to be retreated at DESY consist of four processing levels (table 1 to 4), which based on the experiences gained during preparation phase for the XFEL project [3].

The standard retreatment in first pass (RP1) was done by six times high pressure rinsing (HPR) at 100 bar of the inner surface. In case cavities not recovered in performance in first reprocessing the second retreatment pass (RP2) with removal of the Niobium surface by buffered chemical polishing (BCP) is executed. Cavities showing leaks or suspicion of leaks are retreated by processing according to pass RP3.

- Pass RP1: Additional high pressure rinsing (HPR)
- Pass RP2: Additional chemical polishing (BCP)
- Pass RP3: Repair of leakage
- Pass RP4: Special investigation

To exclude that there are general problems in production and for investigation on the nature of limitation pass RP 4 was set up. For these investigations Obacht camera system is in use [5,6]. Handling of cavities during pass RP4 and the processing work flow of retreatment on pass RP4 not applied during preparation phase for EU- XFEL were qualified.

Depending on inspection results cavities were retreated by additional HPR, 10µm BCP treatment or even were rejected and send back to the companies.

Cavities not recovering in usable gradient after retreatments by RP1 and RP2 and in addition investigation´s gave no hints on origin of limitation, are collected. They will be installed to special modules at the end of the EU-XFEL Linac [6].

Tables 1 to 4: Workflow on Retreatment Sequences at DESY

1) Retreatment Pass - RP1
Cleaning by ultrasonic cleaning and ultra-pure water rinsing to enter ISO 4 cleanroom
Venting to normal pressure with 3 l/min Argon gas flow rate
Dismounting of beam tube flange short side
Six times high pressure rinsing and drying for 12 hours in ISO 4 area
Assembly of beam tube flange
Pump down, leak check with standard turbo molecular pumping unit

2) Retreatment Pass RP2
Cleaning by ultrasonic cleaning and ultra-pure water rinsing to enter ISO 4 cleanroom
Venting to normal pressure with 3 l/min Argon gas flow rate
Dismounting of all cavity accessories
Chemical treatment of maximum removal of 10 µm by BCP, ultra-pure water rinsing and one time HPR.
Drying for 12 hours in ISO 4 area
Assembly of accessories to cavity beam tube flange and leak check
Six times high pressure rinsing and drying for 12 hours in ISO 4 cleanroom area
Pump down, leak check and residual gas analysis (RGA) with standard TMP pumping unit
120 °C baking

3) Retreatment Pass - RP3
Cleaning by ultrasonic cleaning and ultra-pure water rinsing to enter ISO 4 cleanroom
Intensive leak check to verify leaking components
Venting to normal pressure with 3 l/min Argon gas flow rate
Dismounting of suspect connections /all cavity accessories
Inspection of sealing area / repair if needed
Reassembly /exchange of accessories to cavity and leak check
Six times high pressure rinsing and drying for 12 hours in ISO 4 cleanroom area
Pump down, leak check and RGA control with standard TMP pumping unit

<table>
<tr><th colspan="3">4) Retreatment Pass -RP4
(analysis + investigations)</th></tr>
<tr><td colspan="3">Cleaning by ultrasonic cleaning and ultra- pure water rinsing to enter ISO 4 cleanroom</td></tr>
<tr><td colspan="3">Venting to normal pressure with 3 l/min Argon gas flow rate</td></tr>
<tr><td colspan="3">Handover to Obacht optical inspection area for analysis</td></tr>
<tr><td colspan="3">Open beam tube flanges and inspection</td></tr>
<tr><td colspan="3">Close flanges and hand back for retreatment</td></tr>
<tr><td colspan="3">Decision of processing depending on result</td></tr>
<tr><td>Proceed with pass RP1</td><td>Proceed with pass RP2</td><td>Send back to company for repair</td></tr>
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Verification of Pass RP 4

Most cavities inspected by Obacht in pass RP4 showed surface irregularities and needed a repair at the company.

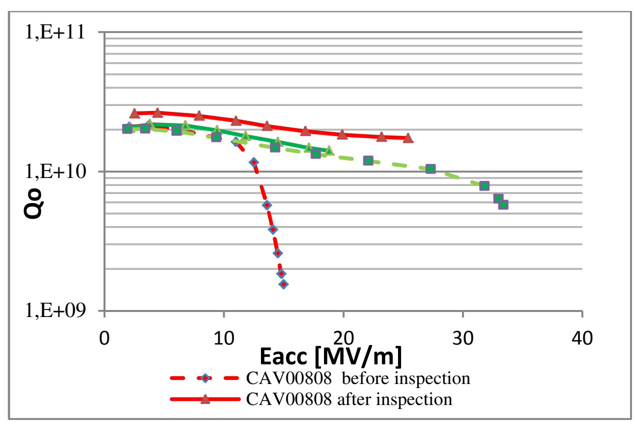

Figure 1: RF test result of qualification retreatment for pass 4 (Obacht optical inspection).

On Cavity CAV00808, limited by field emission loading at 12 MV/m, and Cavity CAV00809, limited by breakdown at 19 MV/m without indication of electron loading, no information of any significant surface problems [7] was found. In addition to the optical inspection a so called replica [7] of the surface was applied for analysis of cavity CAV00809.

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Both cavities completed the pass RP4 and retreatment by HPR (RP1) before second RF test. Performance in test two showed no degradation (Fig. 1). The increase of gradient observed for these two resonators can be explained by removal of origin of limitation by HPR applied at the end of pass RP4. It is unlikely to assume that the limitation is influenced or was removed by the inspection.

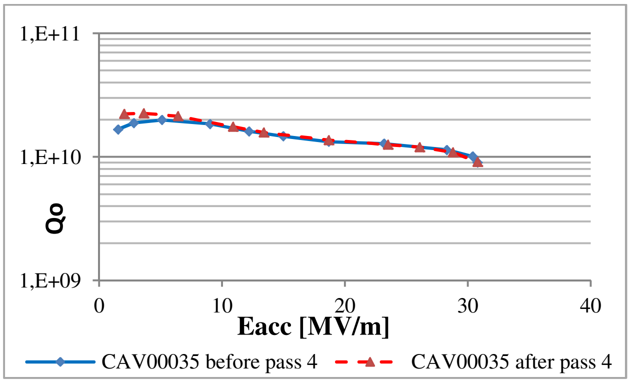

Figure 2: Test results of high grade cavity before and after retreatment by applying pass RP4 processing.

For CAV00035 from the high grade program [8] inspection and replica of iris 2 were done. Also here no degradation of usable gradient of 30 MV/m was observed (Fig. 2).

RESULTS

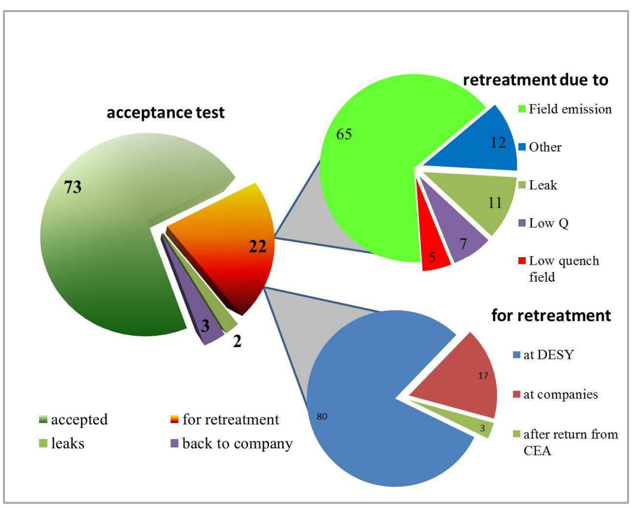

Figure 3: Ratio, given in percent, of 671 resonators tested after delivery that required a retreatment.

From the about 671 cavities, tested as received from industry until July 2015, about 22 % need to be retreated (Fig. 3).

For about 80 % of theses series cavities, failing the test in “as received” status and for cavities handed back from module assembly, retreatment is done at DESY. Retreatment pass RP1 was applied as first retreatment for 95 % of the cavities. The remaining 5 % RF test result indicated that BCP or special investigations should be applied first without doing pass RP1.

Standard Retreatments

With first retreatment at DESY by pass RP1 more than 64 % of the cavities could be recovered. 20 % had to be retreatment in a second time, 4 % were send back to company after analysis of limitation and 5 % were dedicated to pass RP4. 7 % of the resonators showed a leak or requested special investigations before further treatment by redoing RP1 again (Fig. 4).

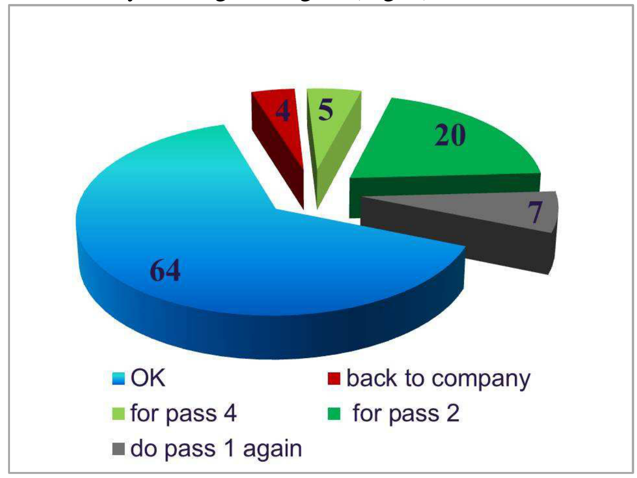

Figure 4: Success rate in percent for 155 cavities after 1st retreatment by RP1.

In average the usable gradient improved by 8 MV/m after 1st retreatment with sequence RP1.

After 2nd retreatment by BCP +120 ^{o}C baking (pass RP2) more than 65 % recovered and were installed to modules (Fig. 5).

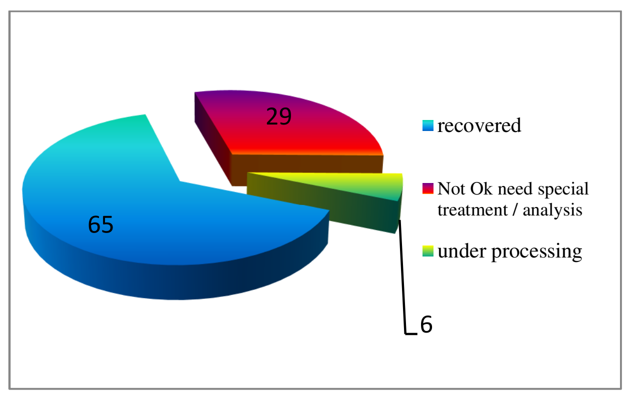

Figure 5: Success rate (displayed in percent) for 17 cavities retreated by pass RP2 at DESY.

Resonators not recovering after pass RP1 and pass RP2 were applied, were inspected by the Obacht optical system in pass RP4. On all of them surface irregularities are found [3]. These cavities were sent back to companies for repair.

FEEDBACK TO PRODUCTION

During the first year of retreatment and test it was found that several cavities showed typical behavior and limitation during test. About 2 % of the cavities tested showed maximum usable gradients below 10 MV/m, independent from manufacturer. After HPR applied to these cavities, nine out of ten cavities with low gradient recovered (Fig. 6) and were acceptable for string installation at CEA Saclay. In average the usable gradient improved by 26 MV/m ranging from 22 to 32 MV/m.

The crosscheck of all processing data and interviews with operators did not give any hint for the low gradients. It was agreed on with industry that a non- detected fatal error might have happened during final treatment for test. Companies mostly accepted that cavities showing very low gradients are sent back to industry for retreatment by HPR.

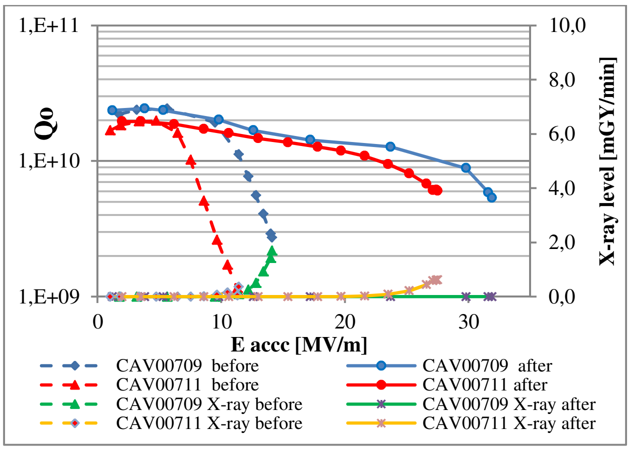

Figure 6: Examples for recovery by HPR of cavities with very low usable acceleration gradient and low gamma loading.

For several cavities not recovering after BCP treatment in pass RP2, inspection by Obacht optical system [9] identified surface irregularities like for instance scratches on the irises (Fig. 7). These types of defects were most probably the reason for the high field emission loading during RF test that could not be cured, even if 10 µm of surface was removed in pass RP2 (Fig. 5). They were sent back to the companies after RP4 (Fig. 8).

To exclude such problems in the future the quality control on last preparation steps has to be reviewed and improved.

The company removed the cavities from the helium tank and repaired these areas [10]. Usable gradients up to 35 MV/m without field emission loading are reached after repair of the defects at the company [10].

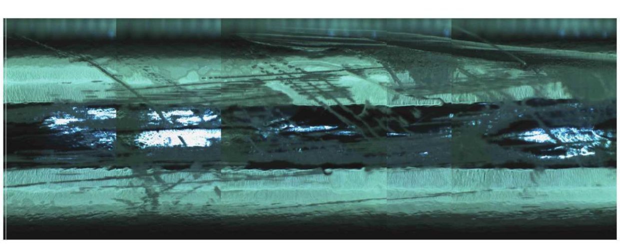

Figure 7: Example for scratches on iris observed by Obacht inspection on Cavity AC 155 – Iris 8 /190°-250 °

The optical inspection system in use at one company did now allow adequate inspection of that area during production. After this feedback of information a new high resolution camera [11] was installed and the problem was solved for the following up part of the production.

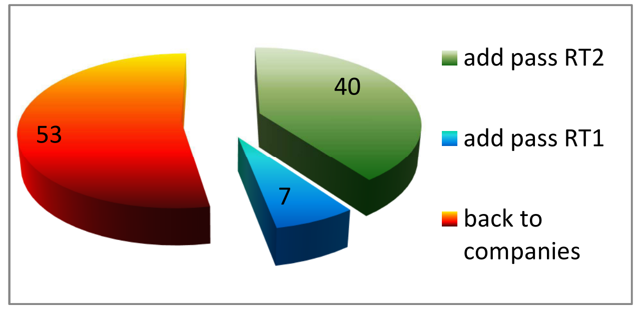

Figure 8: Decisions (displayed in percent) made for the 15 Cavities after pass RP4.

SUMMARY

For the EU-XFEL project cavities with usable gradients below 20 MV/m were not accepted for string installation and were retreated. 22% of EU-XFEL delivered by industry so far, needed to be retreated. More than 80 % of these retreatments were done at DESY. For the retreatment at DESY, 4 retreatment sequences (passes) were set up. More than 60 % of the cavities retreated at DESY, reached acceptance gradient for module installation with one retreatment with high pressure rinse. 60% of the once not acceptable after 1st retreatment recovered after a second retreatment with 10 µm BCP, HPR and 120 ° C baking. Cavities showing leaks or suspects of leaks were leak tight after passing the repair pass RP3.

For analysis of limitation retreatment pass RP4 was set up and qualified. From this analysis a feed back to industry could be given and quality control during production was improved.

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