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RETREATMENT OF EUROPEAN XFEL SERIES CAVITIES AT DESY AS PART OF THE REPAIR OF EUROPEAN XFEL ACCELERATING MODULES

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Abstract

For the European XFEL 102 accelerating modules were built and tested. Several accelerating modules had to be reworked due to different kinds of non-conformities. The extent of this rework varied greatly. At the end of production four accelerating modules could not be qualified in time before the tunnel installation was to be finished in September 2016. Meanwhile the cavity strings of two of these accelerating modules have been disassembled in the DESY clean room. The cavities have been retreated at DESY either by additional high pressure water rinsing or BCP flash chemical treatment. All cavities were vertically tested and 15 out of 16 were qualified for the reassembly of the cavity strings. One accelerating module will be reassembled completely and tested until the end of 2018; the other will follow in the first half of 2019. We report on retreatment procedures and performance of these cavities.

INTRODUCTION

The European XFEL was built in a European Collaboration [1] and is located at DESY in Hamburg. The superconducting cavities have been built in industry in Italy [2] and Germany [3] and tested at DESY. From there the cavities were brought to CEA Saclay, France for accelerating module assembly [4,5]. After assembly the accelerating modules were shipped back to DESY for test and tunnel installation.

On 61 of the 102 accelerating modules for the European XFEL, repair actions of different extent have been performed to qualify them for tunnel installation. Four of these accelerating modules did not qualify for tunnel installation in time and had to be further investigated. These accelerating modules (XM8, XM46, XM50 and XM99) are being reworked at DESY in Hamburg [6].

Already during the production phase of the European XFEL, cavities that did not match the acceptance criteria were retreated mostly at DESY [7]. In the same way the cavities of the XFEL accelerating modules XM46 and XM50 have been treated.

RETREATMENT PASSES

For the retreatment of superconducting European XFEL series cavities that did not achieve the approval for string installation, different retreatment passes were specified [8]. During the repair of the accelerating modules XM46 and XM50 only the retreatment passes RP1 and RP2 were applied. The retreatment pass RP1 is mainly an additional high pressure rinsing (HPR), while RP2 is an additional chemical polishing (BCP). The complete retreatment cycles are described in Table 1 and Table 2.

After the retreatment all cavities are vertically tested to determine their usable gradient in the vertical cryostats at the Accelerator Module Test Facility AMTF [9] at DESY.

Table 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 Nitrogen gas flow rate
Dismounting of beam tube flange short side
Six times high pressure rinsing and drying for 12 hours in ISO 4 cleanroom area
Assembly of beam tube flange
Pump down, leak check with standard turbo molecular pumping unit

Table 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 Nitrogen 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 cleanroom area
Assembly of accessories and beam tube flanges to cavity, leak check
Dismounting of beam tube flange short side
Six times high pressure rinsing and drying for 12 hours in ISO 4 cleanroom area
Assembly of beam tube flange
Pump down, leak check and residual gas analysis (RGA) with standard standard turbo molecular pumping unit
120°C baking

REWORKED MODULES

On seven accelerating modules beam vacuum leaks were found after the assembly or appeared during the module tests at AMTF. These leaks may affect the cavities directly.

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Four leaks could be sealed using a local cleanroom environment either at CEA Saclay for accelerating module XM54 [10] or at DESY for the accelerating modules XM22, XM24 and XM91 [11]. The accelerating modules XM46, XM50 and XM99 are still being reworked at DESY. XM8 had a vacuum leak in the 2K area, which could not be verified in an intensive investigation in 2018. The accelerating module was reassembled without touching the cavity string.

XM46

The accelerating module XM46 was equipped with well performing cavities with usable gradients of approximately 30 MV/m in vertical test. The accelerating module had a first beam vacuum leak already detected after string assembly inside the cleanroom at CEA Saclay. It was sealed by re-tightening the leaky connection. A second beam vacuum leak was discovered at the end of the accelerating module assembly. Tightening of the cold coupler connection at cavity #4 sealed the leak.

XM46 had strong degradation of the cavities between vertical test and module test. It failed the module acceptance test due to the low average usable gradient of 19.7 MV/m and strong dark current. One explanation for the degradation could be beam vacuum leaks; another explanation could be that the cleanroom at CEA Saclay, where the accelerating modules were assembled, had still not fully recovered from a power break that occurred during the previous module assembly.

In February 2018 the cavity string of XM46 was disassembled in the DESY cleanroom and all eight cavities were retreated by six times HPR according to the retreatment pass RP1. The usable gradient of six of the eight cavities was recovered or even enhanced by this retreatment. Only CAV00831 and CAV00869 achieved usable gradients of only about 20 MV/m after RP1, so that an additional RP2 was decided. After 10 µm BCP flash chemical treatment, CAV00869 recovered and its usable gradient surpassed even the value from the vertical test before accelerating module assembly. It was accepted for accelerating module assembly again. CAV00831 is still limited to a usable gradient of 19 MV/m and is not qualified so far. It will be retreated again or replaced for the cavity string assembly of XM46.1 in February 2019.

The usable gradients in MV/m of the cavities from XM46 in the vertical test before accelerating module assembly (UGV1), in the module test (UGM) and after the retreatment (UGV2) together with the retreatment procedure are given in Table 3. The constraint which limits the usable gradient of the cavities is given in brackets. UGV2 for the cavities CAV00831 and CAV00869 were measured after the BCP treatment.

XM50

The accelerating module XM50 was equipped with very well performing cavities with usable gradients in the range from 36 up to 41 MV/m in vertical test.

Already during string assembly at CEA Saclay a leak at the angle valve caused a delay in the assembly of this accelerating module. The final leak check after complete assembly showed a beam vacuum leak again. The accelerating module was disassembled to uncover the cold mass with the cavity string and a detailed leak check took place. At that time no leak could be detected and the accelerating module was reassembled again. At the module tests in AMTF the cavities showed strong degradation and a huge dark current. No other explanation than the beam vacuum leaks could be found to explain the degradation. During warm up after AMTF test a new beam vacuum leak appeared. The accelerating module was not accepted for tunnel installation.

In October 2017 the cavity string of XM50 was disassembled in the DESY cleanroom and the cavities were retreated by six times HPR according to the Retreatment Pass RP1. In vertical test all the cavities met the acceptance criteria of European XFEL serial production phase and qualified for the reassembly of the cavity string.

The string was reassembled as XM50.1 with all the cavities in the same position as in XM50 in May and June 2018. Table 4 lists the usable gradients of the cavities from XM50 according to the description given for XM46.

Table 3: Usable Gradients of the Cavities from Accelerating Module XM46 before and after Retreatment *CAV00831 is not qualified for accelerating module assembly yet. **Sum of the 7 qualified cavities

Position	Cavity-No	UGV1 in MV/m (limitation)	UGM in MV/m (limitation)	Retreatment Procedure	UGV2 in MV/m (limitation)
C1	CAV00831	30 (Q_0)	17,4 (Xray)	BCP	19 (BD)*
C2	CAV00869	30 (Q_0)	17,6 (BD)	BCP	32 (Q_0)
C3	CAV00051	30 (Q_0)	20,7 (BD)	HPR	31 (BD)
C4	CAV00860	30 (Q_0)	24,5 (Xray)	HPR	30 (Q_0)
C5	CAV00279	30 (Xray)	24,9 (Xray)	HPR	36 (BD)
C6	CAV00261	29 (Q_0)	19,8 (Xray)	HPR	27 (Xray)
C7	CAV00850	29 (Q_0)	17,1 (Xray)	HPR	34 (BD)
C8	CAV00818	30 (Emax)	15,3 (Xray)	HPR	33 (BD)
Sum		238	157,3		223**

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Table 4: Usable Gradients of the Cavities from Accelerating Module XM50 before and after Retreatment

Position	Cavity-No	UGV1 in MV/m (limitation)	UGM in MV/m (limitation)	Retreatment Procedure	UGV2 in MV/m (limitation)
C1	CAV00207	36 (Emax)	20 (Xrays)	HPR	31 (Q_0)
C2	CAV00789	38 (Q_0)	16.4 (Xrays)	HPR	36 (Q_0)
C3	CAV00253	41 (Emax)	29.1 (BD)	HPR	30 (Q_0)
C4	CAV00256	38 (Emax)	31 (PWR)	HPR	34 (Emax)
C5	CAV00257	40 (Emax)	31 (Xrays)	HPR	33 (Emax)
C6	CAV00260	40 (Emax)	25.6 (Xrays)	HPR	39 (FE)
C7	CAV00265	36 (FE)	23.1 (Xrays)	HPR	37 (Q_0)
C8	CAV00267	37 (Q_0)	20.3 (BD)	HPR	32 (FE)
Sum		306	196,5		272

XM99

During the cool-down of the accelerating module XM99 at AMTF a beam vacuum leak appeared. The accelerating module could still be tested and the cavities kept their performance with regard to the vertical test result. The average usable gradient was 17.9 MV/m. The vacuum leak investigations indicate the leak in the area between cavity #1 and cavity #2. The disassembly of the accelerating module is scheduled for late 2019 and the reassembly will take place after the retreatment of the cavities according to the retreatment passes RP1 and if necessary RP2 in 2020.

RESULTS

15 of 16 cavities retreated during the repair actions of the accelerating modules XM46 and XM50 met the acceptance criteria of European XFEL serial production phase and qualified for the reassembly of the cavity string. Nevertheless some cavities did not recover their original performance. The difference between the usable gradient in vertical test before accelerating module assembly and after the retreatment in the framework of the accelerating module repair efforts are compiled in Fig.1.

Due to the typical uncertainties of cold rf measurements, a variation of ±10 % of the previous performance is marked as “unchanged”.

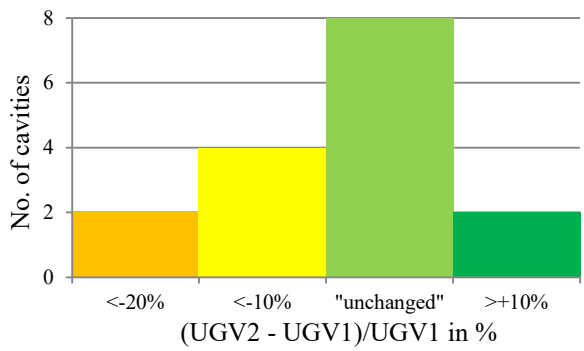

Figure 1: Difference in usable gradient in vertical tests before accelerating module assembly and after retreatment.

SUMMARY AND OUTLOOK

For the repair of the European XFEL accelerating modules XM46 and XM50, 16 SRF cavities have been retreated by DESY according to the retreatment passes already used during the cavity production phase.

All of the cavities passed RP1 and underwent six times HPR. This increased the usable gradient of all the cavities compared to the module test. 14 of them were accepted for accelerating module assembly afterwards. For two cavities an additional BCP flash chemical treatment according to retreatment pass RP2 was performed. One of these cavities achieved a higher usable gradient after this process than in the vertical test prior the accelerating module assembly. One cavity is still not qualified for accelerating module assembly and will be retreated again or replaced.

XM46.1 will be reassembled completely by summer 2019 and tested afterwards.

XM50.1 is being reassembled at the moment and will be tested until the end of 2018.

The repair of XM99 will start late 2019.

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