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SRF ACCELERATING MODULES REPAIR AT DESY

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Abstract

Eight SRF cavities assembled in an accelerating module represent a building block of the particle linear accelerator based on TESLA SRF technology. DESY has two machines, European XFEL and FLASH. Both use almost same module and cavity types. During the module assembly many factors can deteriorate the cavity performance and cause a need for a repair action. Currently two European XFEL modules and two FLASH ones underwent reassembly procedures. The repair was not immediately successful on every of these modules and re-iterations did follow. The degradation causes were investigated. SRF modules were tested on both test-stands at DESY: AMTF and CMTB. The results of the described actions are presented and discussed.

INTRODUCTION

The European XFEL [1, 2] and FLASH [3] linacs are based on the TESLA SRF technology and are built with accelerating Cryo-Modules (CM) having 8 SRF cavities each. Currently 97 CM are installed in the XFEL and 7 CM in FLASH. Before the XFEL CM assembly SRF cavities were tested in the Vertical Cryostat Test (VT) in the Accelerating Module Test Facility (AMTF) at DESY [4]. After the assembly at CEA (Saclay, France) each CM was tested in AMTF [5, 6]. Two XFEL CMs XM50 and XM46 were re-assembled because of out of specs performances. During the FLASH upgrade in 2022 [7] two CMs presently under assembly and test will replace older CMs.

MODULES FOR EUROPEAN XFEL

CM XM50 was repaired [8] two years ago and re-assembled to XM50.1. The successful CM test in AMTF was reported during SRF2019 [9]. Subsequently CM was installed and tested on Cryo Module Test Bench (CMTB) with a CW test [10, 11] as a main goal. Cavities 1 and 2 did slightly degrade: cavity 1 with high Field Emission (FE) and cavity 2 with earlier breakdown – 20.5 MV/m in CMTB instead of 24.4 MV/m before in AMTF. Even with the first two cavities degraded CM XM50.1 was successfully tested in CW mode and is in specs for the SRF linac.

CM XM46 was delivered to DESY in Sep. 2015 after the assembly at CEA (Saclay). The first test of CM XM46 in Oct. 2015 showed a degradation of the cavity performance with high FE (Table 2 and Fig. 2). At that time the decision was taken not to install the CM in the XFEL linac and re-assemble it after cavities' re-treatment.

After disassembly all XM46 cavities underwent a re-treatment: High Pressure Rinsing (HPR) at DESY [8]. After a successful VT 7 out of 8 cavities were accepted for XM46.1 assembly. Cavities positions were changed and one cavity replaced (Table 1).

After reassembly CM XM46.1 (Fig.1) was tested on both module test-stands at DESY: AMTF (Sep. 2020, Table 3 and Fig. 3) and CMTB (May 2021), a successful CM repair is confirmed on both with a very close test results. Currently a CW CM test on CMTB is ongoing [10, 11].

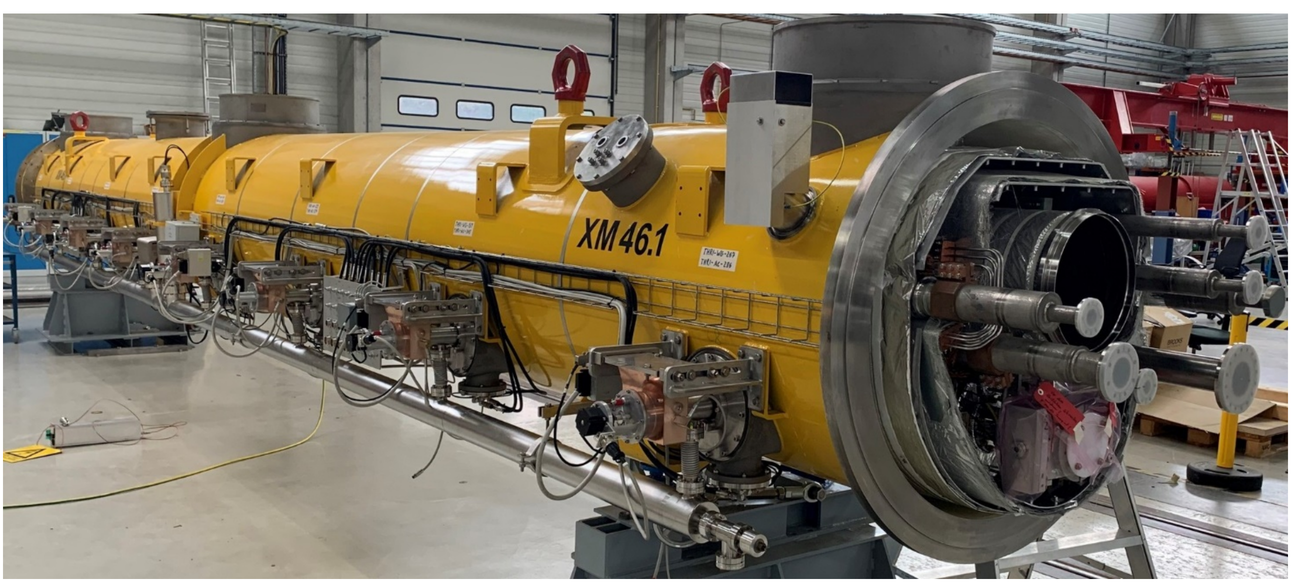

Figure 1: Module XM46.1 in AMTF.

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Table 1: Modules XM46 and XM46.1 SRF Cavities

position	XM46 cavity	XM46.1 cavity
1	CAV00831	CAV00860
2	CAV00869	CAV00818
3	CAV00051	CAV00261
4	CAV00860	CAV00354
5	CAV00279	CAV00279
6	CAV00261	CAV00850
7	CAV00850	CAV00869
8	CAV00818	CAV00051

During the CM tests the operational gradient limit on individual cavities was in general limited by either thermal or magnetic breakdown (quench, BD), field emission FE (measured x-rays above the threshold of 10^{-2} mGy/min measured at one of the CM ends) or to 31 MV/m (PWR, administrative power limit).

Table 2: CM Test Data After First Assembly (XM46)

#	$E_{acc.max}$ [MV/m]	limit	$E_{acc.oper}$ [MV/m]	limit	X_{gun} [mGy/min]	X_{dmp} [mGy/min]
1	18.8	BD	17.4	FE	0.05	1E-4
2	18.1	BD	17.6	BD	5E-4	3E-4
3	21.0	BD	20.5	BD	1E-4	2E-4
4	28.0	BD	24.3	FE	6E-3	0.09
5	28.5	BD	24.5	FE	5E-3	0.13
6	31.0	PWR	19.7	FE	2.70	0.97
7	19.6	BD	15.2	FE	8E-3	0.40
8	22.1	BD	16.7	FE	0.01	0.39

Table 3: CM Test Data After Re-Assembly (XM46.1)

#	$E_{acc.max}$ [MV/m]	limit	$E_{acc.oper}$ [MV/m]	limit	X_{gun} [mGy/min]	X_{dmp} [mGy/min]
1	28.3	BD	27.8	BD	6E-3	3E-4
2	28.7	BD	28.2	BD	1E-3	0.00
3	31.0	PWR	27.1	FE	0.06	4E-3
4	31.0	PWR	29.6	FE	0.03	1E-3
5	31.0	PWR	31.0	PWR	3E-3	9E-4
6	29.8	BD	29.3	BD	7E-3	2E-5
7	31.0	PWR	31.0	PWR	2E-4	8E-4
8	26.3	BD	25.3	FE	0.03	8E-3

Tables 2 and 3 are summarizing the XM46 and XM46.1 CM test results – accelerating gradients and gamma radiation data together with single cavities limits. Figure 2 presents the results of the XM46 gamma radiation and dark current (DC) measurements with a Faraday Cup setup. These measurements were done with all 8 cavities tuned to the resonance and operated at shown average gradient E_{acc}. A very high x-ray level coupled with corresponding high dark current (~260 nA) was detected at a gradient of 19 MV/m. Thus, operating the CM at the XFEL specified average gradient of 23.6 MV/m was not possible and an operation at a lower gradient is not effective in the machine operation. In Figure 3 the operational gradients are compared between the VT and CM tests.

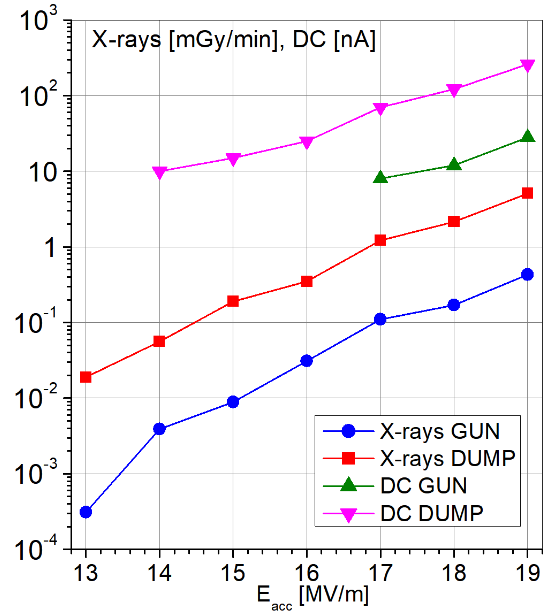

Figure 2: CM XM46 X-rays and DC measurements.

The test results of XM46 (Table 2) did show mostly FE related degradation after the CM assembly. CM cavities re-treatment described in details in [8] restored the cavities performance, as is seen from VT results (Fig. 3) before the XM46.1 assembly at DESY. XM46.1 CM test did show almost no gamma radiation and hence no FE related degradation after the re-assembly.

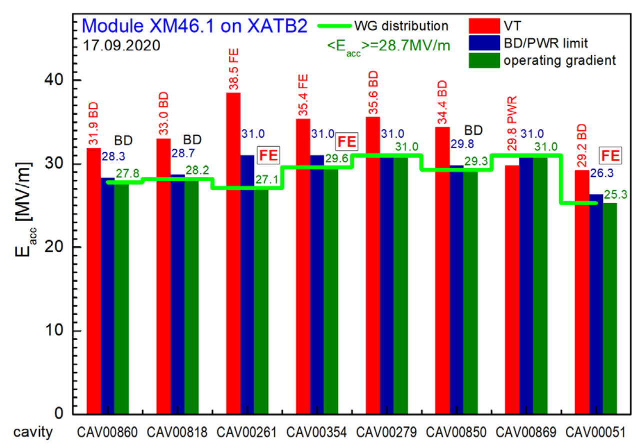

Figure 3: XM46.1 cavities VT (max) and CM tests.

MODULES FOR FLASH

PXM2 and PXM3 CMs are planned for the FLASH [3] linac upgrade in 2022 [7] and will replace two older modules there. Both CMs were assembled at DESY.

Compared to the vertical test results CM PXM2 suffered from cavities 1, 2 and 8 degradation with increased FE (Fig. 4). One of the possible CM degradation causes may be storage and transport under gas pressure (not vacuum).

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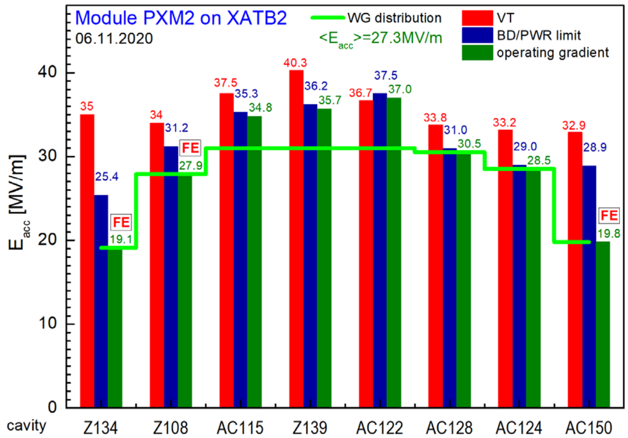

Figure 4: PXM2 cavities VT (max) and CM tests.

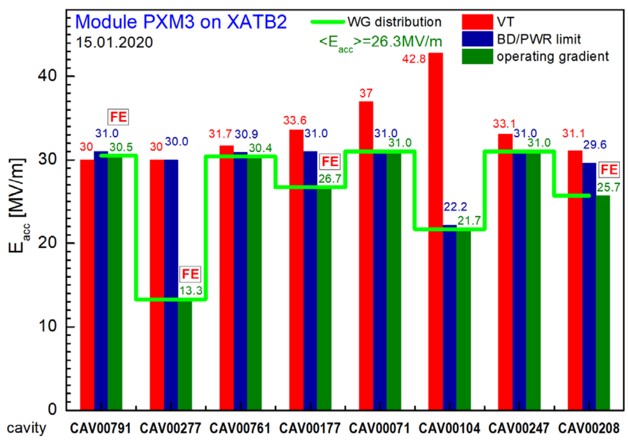

Figure 5: PXM3 cavities VT (max) and CM tests.

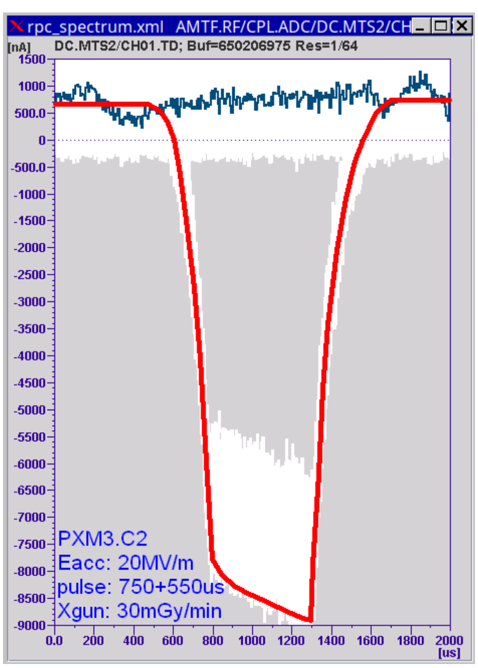

Figure 6: PXM3 cavity 2 DC measurement.

Also for PXM3 (Fig. 5) three cavities degraded in their performance compared to their VT. At cavities 1 and 2 Fundamental Power Coupler (FPC) antennae did touch the cavity inner surface caused by an incident during FPC cold parts bellows adjustment. While cavity 1 showed a higher radiation level, but the gradient is unchanged, cavity 2 degraded significantly limited by a very high FE. The corresponding DC measurement (~9 µA) is shown in Figure 6. Also the gradient of cavity 6 degraded to 22 MV/m limited by breakdown after it FPC cold part had to be exchanged in the clean room because of pre-cleaning water penetration under the cold part protecting cap.

It was decided to re-assemble both modules after re-treatment (HPR) [8] and partial exchange of their cavities.

After retreatment of the PXM3 cavities two cavities had to be replaced before the assembly of PXM3.1. As shown in Figure 7 the test of all cavities in the CM was successful, especially no cavity was limited by FE. Unexpectedly the cold part of the FPC of cavity 6 (CAV00791) degraded during the CM test showing strong RF discharges. An optical inspection showed copper sputtered on the ceramic window, see Fig. 8. The reason is unclear, but as no reliable FPC operation can be assured, it was decided to exchange the cold part. Afterwards the defective cold part will be investigated

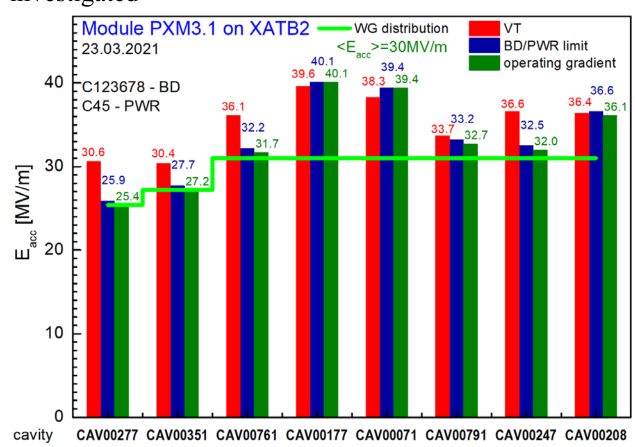

Figure 7: PXM3.1 cavities VT (max) and CM tests.

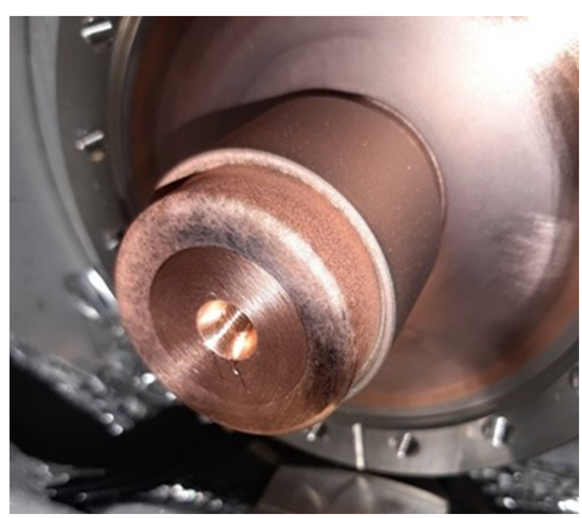

Figure 8: PXM3.1 FPC6 cold part.

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SUMMARY

- Four SRF accelerating modules with degraded cavities performance were disassembled, cavities were re-treated with HPR [8], tested and also partially exchanged against spare ones. Then re-assembly followed with mixed results and need of re-iteration in some cases. Some degradations might be explained.
- Module XM46.1 showed good performance: the repair was immediately successful. Also transport from AMTF and installation on CMTB did not change this. Module was stored and transported with cavities string under vacuum.
- Module XM50.1 successful repair was reported at SRF2019 [9]. After transport and installation on CMTB for CW test first two cavities did suffer from some degradation. The cause is not exactly defined. But the module performance is still in specs.
- Modules PXM2 and PXM3 planned for FLASH linac upgrade in 2022 both got degraded cavities after assembly. Modules storage and transport under dry N_2 pressure, compared to that under vacuum conditions, might explain problems faced later, as contaminating particles may move in gas from string ends. For the first two cavities of PXM3 the fundamental power coupler antennae did touch the cavity surface through the accident during coupler cold parts bellows adjustment, also coupler 6 cold part was exchanged in the clean room. Module PXM2.1 is being currently assembled.
- Module PXM3.1 cavities re-treatment and re-assembly was successful: cavities did not degrade anymore. But the new cold part of FPC, cavity 6, showed a degraded performance in the module test in AMTF with strong RF discharge. Faulty FPC cold part must be exchanged, new module test will follow.

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