ISBN: 978-3-95450-234-9 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2023-MOPMB082

SRF ACCELERATING MODULES UPGRADE FOR FLASH LINAC AT DESY

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Abstract

SRF accelerating modules with 8 TESLA-type 1.3 GHz SRF cavities are the main part of the linear accelerators currently in user operation at DESY, FLASH and the European XFEL. For the FLASH upgrade in 2022 two accelerating modules have been exchanged in order to enhance the beam energy to 1.3 GeV. The two modules have been prototype modules for the European XFEL. After reassembly both modules were successfully tested and installed in the FLASH linac. Data taken during the commissioning at the end of 2022 did confirm the test results. This paper presents described efforts and their conclusions since last two years and continues the presentation given at SRF 2021.

INTRODUCTION

The FLASH [1, 2], as well as European XFEL [3, 4] linacs are based on the TESLA SRF technology and are built with accelerating Cryo-Modules (CM) with 8 SRF cavities each. Currently 97 CMs are installed in the European XFEL linac and 7 CMs in FLASH. Before the CM assembly all SRF cavities were tested in the Vertical Cryostat Test (VT) in the Accelerating Module Test Facility (AMTF) at DESY [5]. After the assembly each CM was also tested in AMTF [6, 7]. During the FLASH upgrade in 2022 [8] two old CMs were replaced by new ones – PXM2.1 and PXM3.1.

CM RF TEST RESULTS

The CMs under discussion started as the European XFEL CM prototypes, called PXFEL2 and PXFEL3, went through re-assembly and test sequence as PXM2 and PXM3, with rather disappointing results and were re-assembled again as PXM2.1 (Fig. 1) and PXM3.1 [9]. The CMs SRF cavities are listed in Table 1. The cavities of PXM2.1 belong to an earlier production of FLASH-type cavities, while the PXM3.1 cavities are a part of the European XFEL production.

Table 1: CMs PXM2.1 and PXM3.1 SRF Cavities

Position	PXM2.1 cavity	PXM3.1 cavity
1	AC115	CAV00277
2	AC128	CAV00351
3	AC122	CAV00761
4	Z139	CAV00177
5	Z108	CAV00071
6	AC150	CAV00791
7	Z134	CAV00247
8	AC124	CAV00208

Unexpectedly, both CMs required additional repair after their test at the AMTF: PXM2.1 – cavity 7 probe cable short, fixed with further re-assembly; PXM3.1 – cavity 6 Fundamental Power Coupler (FPC) cold part issue [9], cold part was exchanged in a local clean room in AMTF in June 2021, see Fig. 2, showing the procedure.

Figure 1: Module PXM2.1 in AMTF (March 2022).

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Figure 2: Module PXM3.1 C6 FPC cold part exchange in a local clean room (center left) in AMTF (June 2022).

The CM tests are performed in pulsed operation and the maximum and operational gradient limit as well as the limitation mechanism of individual cavities are determined. Three cases can be distinguished: Thermal or magnetic breakdown (quench, BD) with $E_{acc.oper} = (E_{max}-0.5$ MV/m), field emission (FE) (with measured x-rays above the threshold of 10^{-2} mGy/min measured at one of the CM ends), achieving the limit of RF power (PWR) [6, 7].

Table 2: PXM2.1 Final CM Test Data

#	$E_{acc.max}$ [MV/m]	limit	$E_{acc.oper}$ [MV/m]	limit	X_{gun} [mGy/min]	X_{dmp}
1	33.7	BD	29.3	FE	0.07	0.01
2	29.6	BD	29.1	BD	none	none
3	34.0	PWR	34.0	PWR	6E-4	none
4	34.0	PWR	34.0	PWR	1E-3	none
5	31.4	BD	30.9	BD	none	none
6	32.0	BD	31.5	BD	none	none
7	32.4	BD	31.9	BD	2E-4	none
8	29.4	BD	28.9	BD	2E-4	2E-4

Table 3: PXM3.1 Final CM Test Data

#	$E_{acc.max}$ [MV/m]	limit	$E_{acc.oper}$ [MV/m]	limit	X_{gun} [mGy/min]	X_{dmp}
1	24.8	BD	24.3	BD	1E-3	7E-5
2	26.3	BD	25.8	BD	none	none
3	31.5	BD	31.0	BD	none	none
4	34.0	PWR	34.0	PWR	6E-4	3E-5
5	34.0	PWR	34.0	PWR	3E-4	none
6	32.4	BD	31.9	BD	4E-4	none
7	31.5	BD	31.0	BD	5E-4	none
8	34.0	PWR	34.0	PWR	8E-4	5E-4

Tables 2 and 3 and Figs. 3 and 4 are summarizing the PXM2.1 and PXM3.1 final CM test results – accelerating gradients and gamma radiation data together with single cavities limits.

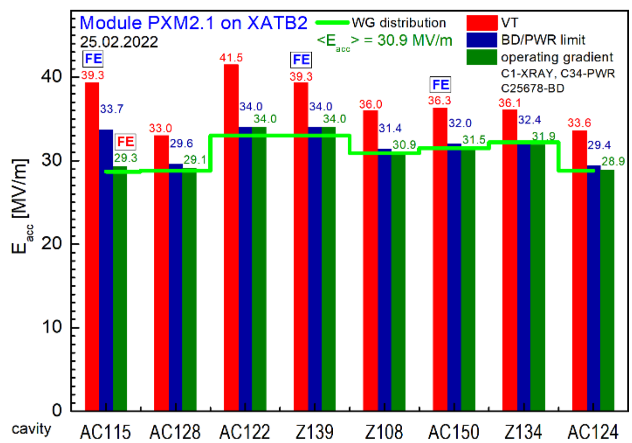

Figure 3: PXM2.1 cavities: comparison of max. gradients of VT (red) and CM tests (blue), the operating gradient is indicated in green, the green line gives the gradients with an adapted RF power waveguide distribution.

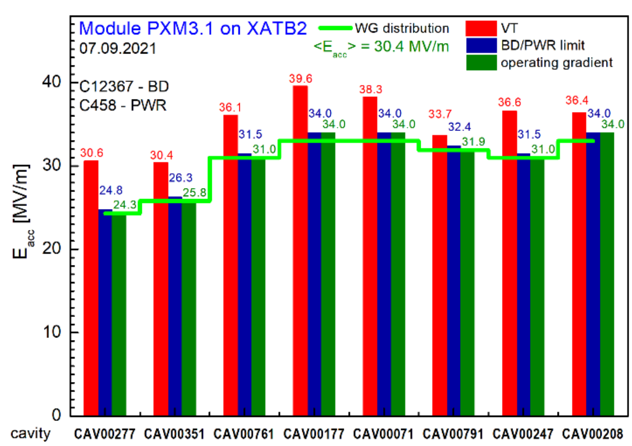

Figure 4: PXM3.1 cavities: comparison of max. gradients of VT (red) and CM tests (blue), the operating gradient is indicated in green, the green line gives the gradients with an adapted RF power waveguide distribution.

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Figure 5: Module PXM3.1 installed in FLASH.

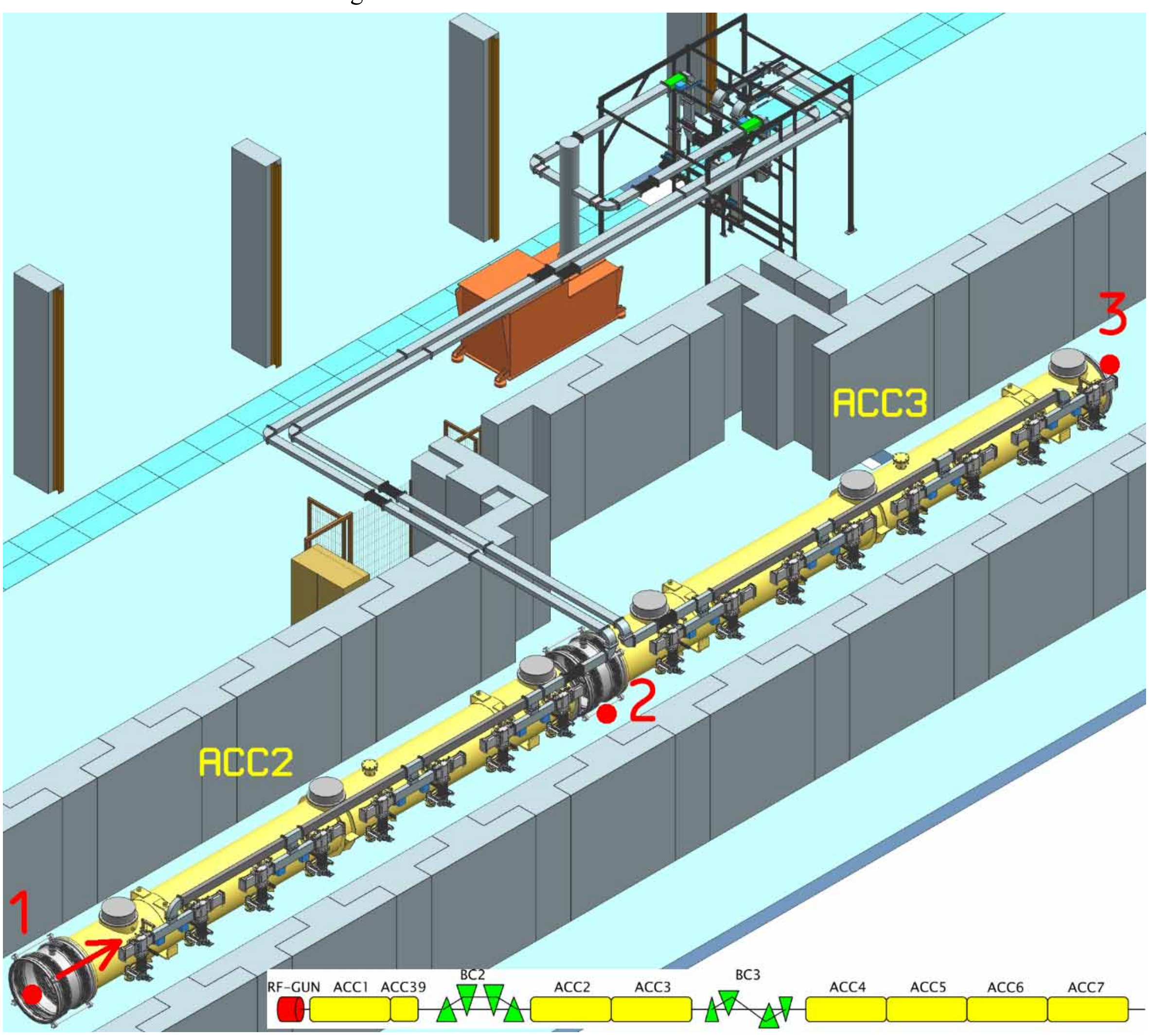

Figure 6: PXM2.1 and PXM3.1 with RF power distribution in FLASH (red dots are X-ray sensors 1,2,3).

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CM COMMISSIONING AT FLASH

The CMs PXM2.1 and PXM3.1 (Fig. 5) were installed in the FLASH linac on positions ACC2 and ACC3 with adapted wave guide RF power distribution (Fig. 6) to achieve higher total energy of 1.3 GeV. In order to monitor the gamma radiation during CM commissioning three radiation sensors type UNIDOS (1 liter / 5 kV chamber) were installed as marked with 1, 2, 3, in Fig. 6 (red dots). As an additional important activity of the FLASH 2020+ shutdown the FPC technical interlock system was completely rebuilt and upgraded with state-of-the-art components. Warm FPC conditioning was done before the cooldown without any problems.

The conditioning of the SRF cavities took about a week with a snapshot of the performance achieved shown in Fig. 7. Most of the time was dedicated to dark current and gamma radiation conditioning. Gamma radiation decrease was observed with ACC2/3 center sensor (Fig. 8) and ~ 10^{-2} mGy/min level was measured at the end. This shows a clear improvement of 10^2 less radiation compared to the values from the CM removed from position ACC3 (Module 7 with ~1 mGy/min at 25 MV/m measured [10]).

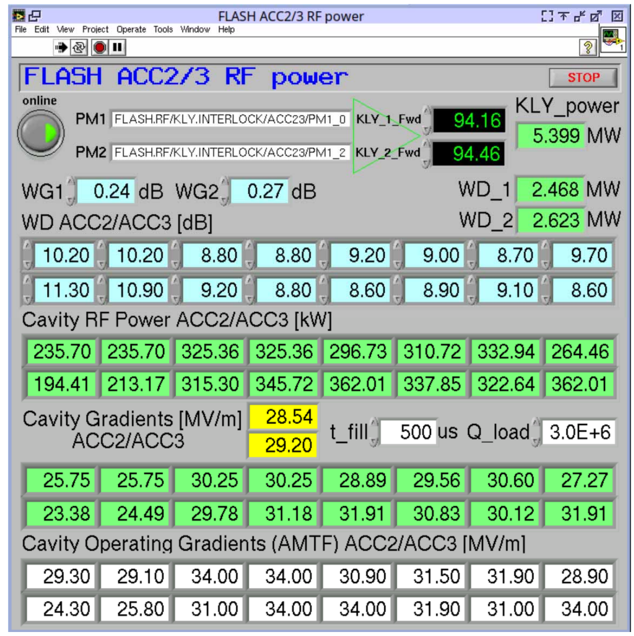

Figure 7: FLASH ACC2/3 RF power and gradients in the test interface snapshot (actual data in green fields).

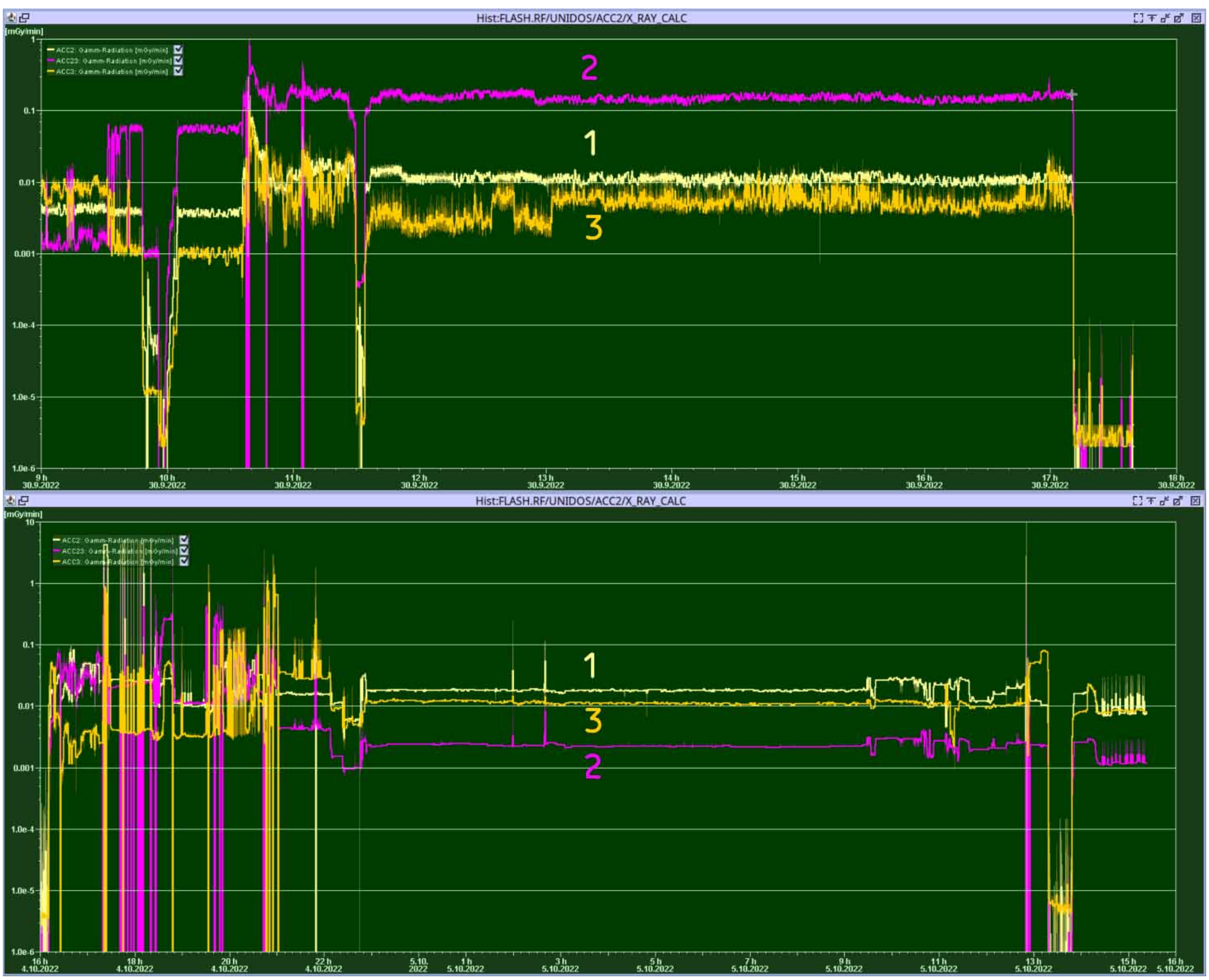

Figure 8: FLASH ACC2/3 Gamma Radiation measured during commissioning (1st day + last 2 days).

SUMMARY

- Two European XFEL prototype SRF accelerating modules, PXFEL2&3, reassembled at DESY as PXM2&3, underwent additional reassembly and additional repairs. Finally they were installed as PXM2.1 and PXM3.1 in the FLASH linac at positions ACC2 and ACC3 during the upgrade in 2022 [8].
- Additional repairs were required to fix the PXM2.1 cavity 7 probe cable and PXM3.1 cavity 6 cold FPC part [7].
- RF test results at AMTF confirmed the expected performance after the respective VT. Low/no radiation was observed in almost all cavities confirming the high quality of string and module assembly at DESY.
- CMs installation in FLASH went well. FPC technical interlock system was upgraded as well in 2022.
- Commissioning at FLASH showed smooth FPC warm conditioning and SRF cavities cold test. Last took about a week with successful gamma radiation conditioning.
- Both tested modules, PXM2.1 and PXM3.1, met the FLASH linac energy upgrade goal of 200+200 MeV for the ACC2&3 RF station and were already successfully tested with beam operation. ACC2&3 RF station could be operated up to a Set Point (SP) of 450 MeV during the commissioning. Previously ACC2&3 was operated at ~300 MeV and after shutdown and upgrade in 2022 ACC2&3 SP was increased to ≥400 MeV, hence new ACC2&3 modules gave FLASH linac the energy gain of +100 MeV and FLASH linac reached 1.3 GeV in May 2023 (limited by ACC4&5 gamma radiation).

ACKNOWLEDGEMENTS

We want to express our gratitude to all colleagues from DESY contributing to and supporting the cryo module assembly, testing and commissioning in FLASH.

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