INVESTIGATION ON MODULE ASSEMBLY AND REPAIRS

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Abstract

At DESY several cavity strings for modules of the FLASH accelerator and studies on XFEL prototypes are completed. In some modules cavities have been exchanged for upgrade of applicable module gradients or exchange of resonators showing performance degradation in the module test. Assembly and repair sequences and quality control plans for cavity string are developed and applied. From module string PXFEL3 six out of eight cavities are removed and handed over to CEA Saclay for training of string and module assembly. On two of these cavities the procedures for assembly and exchange of cavities in cavity strings are crosschecked. These cavities are tested at 2 K as removed from string without additional treatments to cross check assembly and repair sequences.

INTRODUCTION

Several cavity strings for modules are set up at DESY. In the modules No 1 to 3 cavities equipped with niobium lips on the sealing area are exchanged to cavities with the actual Niobium- Titanium flange design. On the modules 3**, 6, 8 and PXFEL3 cavities showed gradient degradation between vertical test and RF test on the module test bench (CMTB) [1], [2]. For repair or upgrade of these modules several cavities needed to be exchanged without re-processing of all cavities. Investigations are made to find procedures allowing exchanging individual cavities or cavity sub-units in a module string without re-treatment and a new vertical test of all resonators.

ASSEMBLY SEQUENCES FOR MODULES

All components in use for string assembly in ISO 4 are cleaned in respect to particle contamination [3]. After qualification in an RF test at 2 K in the DESY test area the cavities are cleaned for ISO 4 cleanroom application by ultrasonic cleaning, and ultra-pure water rinsing. Before installation to the cavity string an intensive quality control of cleanliness takes place [4].

After that cleaning process the RF input antennae are exchanged from high Q antenna to the power coupler cold part antenna (PCA) for string assembly. No post-assembly cleaning by high pressure rinsing (HPR) can be applied here without losing the conditioning of the power couplers.

The standardized assembly procedure for string assembly (Table 1) starts with integration of Beam Position Monitor (BPM), quadrupole and gate valve to a Beam Position Quadrupole Unit (BQU). These units are qualified by particle count control and vacuum leak check before installation. Eight resonators, one BQU and a gate valve are connected by bellows at the beam tubes inside ISO 4 cleanroom and build up the cavity string.

Table 1: Generalized assembly steps for sting assembly of DESY / XFEL Cavity strings

1	Align cavity #1 and gate valve on rail
2	Vent cavity to normal air pressure
3	Connect gate valve to cavity #1
4	Pump down and leak check unit
5	Vent cavity and gate valve to normal air pressure
6a	Align cavity #N on rail
6b	Align bellow and beam tube flange long side
6c	Clean beam pipe flange cavity long side
6d	Remove beam tube flange
6e	Connect bellow to beam tube long side
7a	Clean beam tube short side flange
7b	Align bellow and beam tube flange short side
7c	Remove beam tube short side
7d	Connect bellow to beam tube side short
8	Repeat step 6a to 7d for cavity #2 to #8 and BPM Quadrupole unit
9	Adjust coupler distance
10	Pump down string and leak check unit
11	Vent string to normal air pressure

Cavity beam position monitors were in use for the module No 1 to 8. These cavity BPMs are equipped with welded-on bellows. This design leads to limited space for assembly at the connection to cavity 8. The alignment and connection to the cavity string was done manually, without assembly tools being applicable.

The XFEL prototype BPM installed to module PXFEL1 to PXFEL3 is designed with a separated bellows unit. These bellows is of identical geometry as in use for the cavity to cavity connection. This set-up allows making use of the identical tools and handling processes as applied for the cavity to cavity connections.

The refurbished DESY cleanroom [5] allows improvements in preparation and assembly steps of the string assembly. The assembly of XFEL BQU takes place independent from the string assembly itself [5].

Before assembly to the cavity string each part is qualified by controlling particle contaminations with blowing with ionized air guns towards air particle counters [6].

REPAIR SEQUENCES

Preparation for Strings upgrade

During module installation and module test, the exterior of the cavities is exposed to normal air and contaminated by particulates and other residues of the assembly processes like for example tape from wrapping on the superinsulation foil

To re-enter the ISO 4 cleanroom the string cannot be cleaned by the standard ultrasonic cleaning and rinsing. A manual cleaning by well-trained cleanroom personal is required. In contradiction to the standard string assembly sequence (see Table 1), the cavities are vented to normal pressure outside of the clean room to relax forces on the power coupler bellows for module disassembly.

The cleanroom itself is exposed to normal air during the time the string is rolled back into the ISO 6 area. This time is kept at a minimum of about 3 to 5 minutes. After that entering process, the ISO 6 and ISO 4 conditions of the cleanroom air have to be reestablished again.

Cleaning Procedures

Cavities not being affected by the repair or exchange are wrapped in cleanroom foil hermetically. Only the areas where access to bellow units or to the complete cavity is needed are not wrapped in. The whole surface of the cavity string is cleaned according to Table 2 to enter the different cleanliness classes of the cleanroom.

Table 2: General sequence for cleaning of cavity strings re-entering the ISO 4 assembly area.

#	Activity	area
1	Intensive cleaning of string by ethanol and lint free tissues	hall
2	Transfer string to cleanroom	ISO 6
3	Restoring cleanroom air quality	ISO 6
4	Cleaning of string by ethanol and lint free tissues	ISO 6
5	Flushing of flanges and gasket area with ethanol	ISO 6
6	Cleaning of string by blowing with ionized air blowing	ISO 6
7	Transfer of string to ISO 4 area	ISO 4 Sluice
8	Particle control and final cleaning of string	ISO 4 Sluice
9	Final control of surfaces and flange regions before opening beam line flanges	ISO 4
10	Cleaning and quality control of flanges, gasket and bore hole area standard process from string assembly ref.3	ISO 4

At the first cleaning operation inside ISO 6 area up to 50000 particles are detected at the flange area when the exterior is blown with ionized air. The final cleaning, done in the sluice to the ISO 4 region, this cleaning operation is repeated until less than 10 particles per minute are detected with the air particle counter during blowing with ionized air.

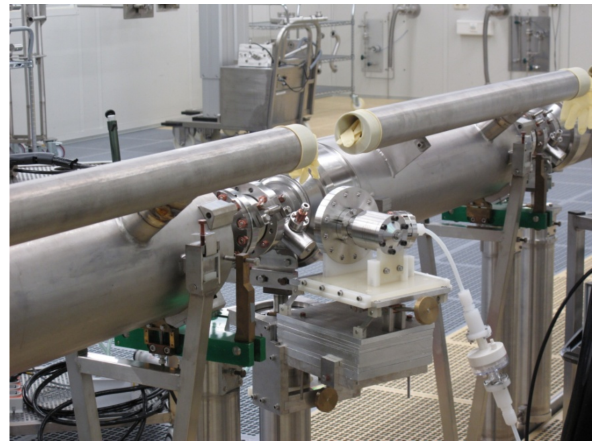

Figure 1: View on Cavity connection in preparation for disassembly.

Before open a flange connection a well-defined procedure of quality control and cleaning of flanges and bore holes is applied [6].

Upgrade and Repair Sequence

Pre-qualified flushing pipes with point of use filter units installed are connected to the string extremities, the gate valves (Fig.2). Dismounting of individual cavities (Fig.1) is done according to the sequence given in Table 3. Two teams are working in parallel to minimize the time when cavity interior is exposed to cleanroom air.

Table 3: Generalized dismounting procedure for cavity strings.

	Team 1	Team 2
1	Quality control of flushing units	Quality Control of flushing units
2	Connect flushing line 1 to gate valve one	Connect flushing line 2 to gate valve two
3	Set pressure to sting	Connect flushing line 3 to pump port flange of cavity 8
4	Disconnect BQU from sting	Close BQU bellow by blank-off flange
5	Install pump port flange to cavity 8	Dismount bellow from BQU and close unit with blank off flange
6	Leak test BQU	Shift BQU to ISO 6 area
7	Disconnect bellows between cavities 7 and 8	Dismount bellows from cavity 8 and seal cavity with blank-off flange
8	Install pump port to cavity 7	Leak test cavity 8
9	Repeat step 7 to 8 until cavity 1	Repeat step 7 to 8 until cavity 1
10	Install pump port flange to cavity 1	Remove gate valve from cavity 1
11	Leak test Cavity 1	Seal cavity 1 with blank-off flange

Figure 2: View on the BQU during preparation for disassembly (left side flushing unit installed to gate valve)

*Conversion Module 3** to 3****

For this upgrade the position of three cavities needed to be shifted, while the cavity in position 8 remained in its position (Table 4). The three cavities remained connected to each other as a subunit. A special fixture was developed that allows lifting up this subunit and shifting it to the new, optimized position. With exception of AC58 and AC117 the resonators kept their RF performance within the measurement tolerances. Cavity AC58, not exposed to manipulations, degraded by 4 MV/m. Cavity AC117 showed a 3 MV/m higher maximum acceleration gradient in module 3***.

Table 4: Exchange of resonator position during upgrade of module 3 ** to 3*** and module 8 to PXFEL1 with correlated RF test results in module.

	Module 3**				
Cavity	**AC119**	**Z94**	**AC58**	**AC118**	**AC117**
Position	**1**	**2**	**3**	**4**	**8**
E_{acc}(max) [MV/m]	**25**	**28**	**32**	**32**	**34**
	Module 3***				
Position	**2**	**3**	**4**	**5**	**8**
E_{acc}(max) [MV/m]	**24**	**25**	**29**	**31**	**37**

	Module 8		
Cavity	**Z103**	**Z93**	**Z100**
Position	**5**	**6**	**7**
E_{acc}(max) [MV/m]	**36**	**39**	**29**
	PXFEL 1		
Position	**5**	**6**	**7**
E_{acc}(max) [MV/m]	**36**	**39**	**28**

Conversion Module 8 to PXFEL1

For the upgrade of module 8 to PXFEL1 the resonators located in positions 5 to 7 kept their position (Table 4). In addition to the exchange of five cavities an extension beam tube, located between BPM and Quadruple had to be removed to adapt the length of the cavity string of module 8 to the once needed for prototype of the XFEL modules. For the three cavities transferred to module PXFEL1 no change in RF performance within the measurement tolerances was found in module test of PXFEL1 [1,2], Table 4.

Conversion Module PXFEL3 to PXFEL3_1

For training of personal and commissioning of infrastructure at the designated place of XFEL string and module assembly at CEA Saclay in France, the cavities of module PXEFL3 had to be removed from string and qualified again before sending them to CEA.

Two cavities, Z88 and Z127, of module PXFEL3 showed gradient degradation from 31 MV/m down to 18 MV/m (Z88) and from 28 MV/m down to 20 MV/m (AC127). These cavities are limited by a quench without indication of field emission during test at the CMTB [1]. These resonators are not transferred to CEA Saclay for string assembly. They undergo a special test sequence to study the degradations observed [7].

TEST OF ASSEMBLY AND DISASSEMBLY PROCEDURES

Test Procedure

Within the time frame for the transfer of cavities to CEA Saclay, not all six cavities removed from string PXFEL3 could be used to cross check the procedures of assembly and disassembly of cavity strings. A general decision was taken that these six resonators had to be high pressure rinsed (HPR) before the requalification by a vertical test and hand over to CEA Saclay.

Table 5: Preparation steps for vertical test of cavities in "as removed from string" condition

1	Dismount cavity from string according Table 3
2	Cavity is connected with flushing line
3	Install assembly tool to remove power coupler
4	Remove power coupler cold part
5	Install high-Q antenna
6	Turn cavity to vertical position
7	Pump down and leak check cavity
8	Vent cavity
9	Perform six times HPR and dry in ISO 4 area
10	Install vacuum pumping port and leak check unit
11	Hand over for RF test

To verify the procedures applied on cavity strings as well as to ensure that the test results of investigations of Z88 and Z127 are not influenced by these assemblies, two out of the six cavities were tested without additional HPR, just as removed from the string.

Two independent and well educated teams dismounted the resonators from the string PXFEL3 according to Table 5. Each team exchanged the power coupler cold part to a high-Q antenna, installed on the power coupler port and prepared the cavities for HPR. In addition no information on an RF quality control measurement without HPR of the resonators was given to the teams. Randomly, just right before the cavities were vented for HPR (step 8 of Table 5), the information was handed out that the dedicated cavity had to be handed over for vertical test without additional HPR.

Test Results

The two cavities, Z101 and Z140, neighboring the cavity AC 127 (Fig.3) are selected and tested vertically at 2 K without additional HPR.

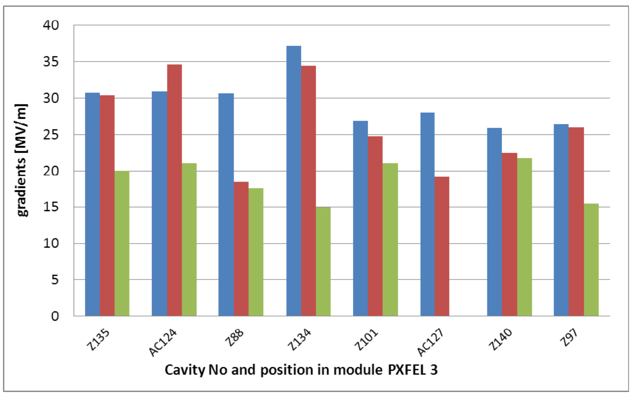

Figure 3: Test results of PXFEL3 module on CMTB. (Blue bars - maximal gradient in vertical test; Red bars - maximum gradient in module test; Green bars - X-ray onset gradient in module test).

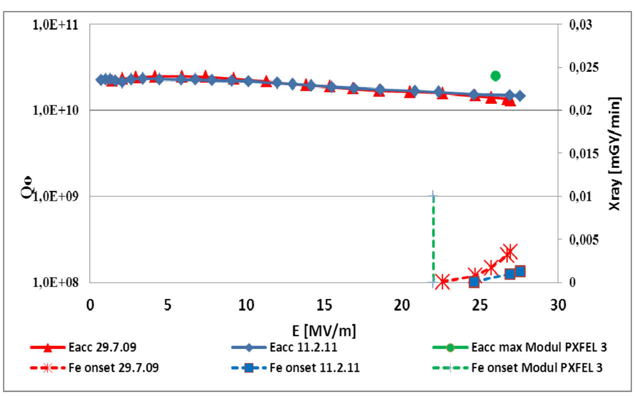

Figure 4: Test results of cavity Z101 before (blue lines), during (green lines) and after (red lines) application in module.

Within the tolerances of RF measurements the RF test results of Cavity Z101 (Fig.4) and Z140 (Fig.5) did not show changes between vertical test before and vertical test with long pulses [8] after use in module PXFEL3.

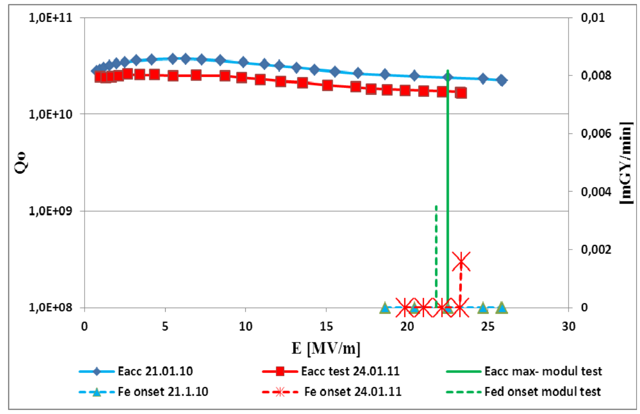

Figure 5: Test results of cavity Z140 before (blue lines), during (green lines) and after (red lines) application in module.

CONCLUSION

At DESY several cavities in module string have been exchanged to upgrade the module performance.

Assembly and repair sequences for cavity strings are developed. For module upgrade cavities were successfully exchanged or shifted to optimized position successfully. A crosscheck of the procedures by removing two cavities from string PXFEL3 was done. These cavities have undergone all assembly, module test and disassembly procedures. They are tested in the vertical test stand as removed from the sting without additional surface cleaning by high pressure rinsing. No change of gradient or significant increased electron loading is observed in respect to the vertical test before string assembly.

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