INVESTIGATIONS TO UNDERSTAND THE ORIGIN OF DEGRADATION OF SUPER CONDUCTING CAVITIES FOUND IN ACCELERATION MODULES AT DESY

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Abstract

In the last decade the degradation of cavity acceleration gradients is observed frequently in module RF tests, after the assembly and installation of complete accelerator modules. In some cases no explanation for these degradations could be found from quality control records, assembly procedure protocols or notes from observers. On the PXFEL 3 module quench limitations without indication of field emission loading is observed at two cavities. Boundary conditions like storage of resonators, cleaning process for ISO 4 clean room as well as the assembly processes and handling of the resonators are under investigation. The two degraded cavities of module PXFEL 3 are removed from the cavity string and studied intensively. The actual status of our research is presented.

MOTIVATION

During the last decade several accelerator modules were assembled at DESY for prototype development and FLASH linac operation. Cavity strings are assembled in the DESY ISO 4 cleanroom. Even if the procedures for string assembly are well established, some of the module cavities show degradation of acceleration gradient (Eacc) cavities installed into module strings do not undergo a further high pressure rinse (HPR). Limitation by field emission may be explained by statistical errors origin from infrastructure problems or nonconformities during the assembly, which might be removable by HPR. Some cavities show low gradients limited by quenches without detectable X- rays. The origin of degradation without electron loading is under investigation. Two cavities, Z88 and AC127 in module PXFEL 3 show this effect and were removed from the string for studies.

ANALYSIS OF DATA

In eight out of ten cavity strings assembled, a degradation of resonators was observed. In some cases degradation is combined with increased emission of X-rays. At seven resonators gradient reduction without field emission is observed at DESY (Table 1). Minor non conformities are recorded for these cavities during string assembly. The applied preparation sequences (BCP flash; EP) do not seem to be correlated to the degradations (Table 1), even though more cavities treated by EP are affected. No strong correlation on position and degradation of cavities inside modules is found, even though positions 3 and 6 show an increased number of degraded resonators (Table 2).

Cavity AC113

Cavity AC113 installed to module PXFEL 1 showed degradation of Eacc. when the cavity was tested horizontally in CHECHIA (Fig. 1). No further reduction was found after installation to module PXFEL 1. One non conformity before CHECIA test is reported.

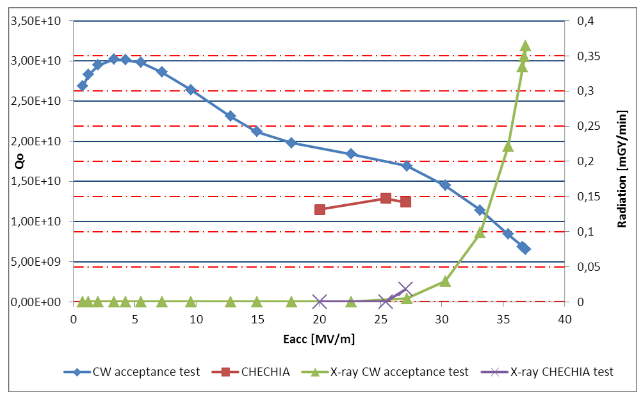

Figure 1: RF Test results of cavity AC 113.

During tank welding procedure the field measurement system had to be exchanged due to a vacuum leak.

Z88, Z108 and AC127

Cavity Z88 and AC108 have been used in module 8 before. Reduced gradients with field emission loading were observed.

Table 1: Summary of resonators showing reduced performance without field emission in DESY modules. The last column shows the gradient before module assembly.

Module	Cavity	Pos.	Final treatment	Drop (MV/m)	Start Gradient (MV/m)
6	Z85	5	EP	12	35
	Z92	6	EP	12	35
8	Z109	2	BCP +EP	8	30
PXFEL1	Z100	7	EP	11	39
PXFEL2	Z133	3	BCP flash	11	27
PXFEL3	Z88	3	EP	11	31
	AC127	6	EP	8	28
S1 global	Z108	3	EP	12	32

After retreatment the gradients recovered to 30,4 and 31,3 MV/m respectively without field emission in the vertical test. AC127 showed a gradient of 27,3 MV/m without field emission loading during vertical test.

These cavities are equipped with clamped Niobium HOM antenna tips for the module application. This design of HOM antenna is successfully in use since several years

The history of Z88, AC127 and AC108 differ from the other cavities installed to PXFEL 3 and S1-global respectively. After installation of HOM couplers and the standard final six HPR treatments they had to be stored outside the cleanroom for about three months during clean room renewing. The power coupler cold parts were installed after that shut down period and no additional HPR was done. On the other six cavities installed in PXFEL3, the standard installation procedures of HOM antennas and pick-ups, six times HPR and storage inside the clean room for string assembly were applied after the cleanroom shut down period. The power coupler of these resonators was installed just before string assembly started.

Table 2: Correlation of degradation to position inside modules

Position	1	2	3	4	5	6	7	8
No of cavities	0	0	2 (3)	0	1	2	1	0

The assembly sequences and quality control for power coupler and beam pipe to bellows installation are well defined and tested [1, 2]. These procedures were identically applied for all cavities and only minor nonconformities for the cavities Z88, AC127 and AC108 were observed.

WORK HYPOTHESIS FOR INVESTIGATIONS

From the data analysis it can be assumed that the degradations seem to be more of statistical nature than correlated to specific conditions like position in module or surface preparation.

Because of the nonconformity of storage of cavities Z88, AC127 and AC108 it can be presumed that contaminations on the flange region correlated with in-proper cleaning of that region may be the origin for the degradation. After ultrasonic cleaning, theses cavities were positioned horizontally for coupler and string assembly and no additional HPR was applied for these cavities after return to cleanroom.

In addition it can be assumed that the accessories installed (power coupler cold part; HOM antennas) may be also origin of the degradations. Both assumptions are under investigation.

INVESTITAGTIONS ON CLEANING PROCESSES

Ultrasonic Cleaning

Except of the narrow slots of the sealing flanges (Fig. 3), ultrasound cleaning affects the complete resonator surface. The circulation of cleaning detergent and rinsing water is limited in the narrow slots as well. To cross check the ultrasonic bath (US) efficiency, a set of aluminium foil is exposed to the ultrasonic waves for 2.5 minutes. The impact of wave patterns of US bath is visualized on the foil. An inhomogeneity of the US bath is found between bottom and top as well as perpendicular or parallel to the basin back side wall (Fig. 2). At the position where the power coupler and beam tube flanges are located during US cleaning the highest impact of US waves is observed.

Figure 2: left side: US pattern on Al foil @ level 600 mm from bottom/ right side US pattern on Al foil @ level 1900 mm from bottom.

After 10 minutes of US impact clear resonance patterns are seen at all levels, even if there are still differences between top and bottom of the basin.

Rinsing Efficiency of Flange Area

Additional manual rinsing of the flanges by spraying UPW (ultra-pure-water) into the narrow slits of the flanges and blowing of slits and bore holes before opening flanges is part of the standard process at DESY. For test of cleaning efficiency a test resonator was exposed to normal air. One of the flanges was sealed by tape during the cleaning process while the other flanges were exposed to the cleaning procedure.

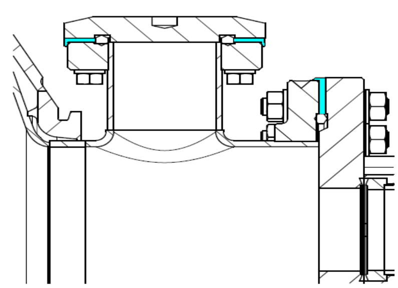

Figure 3: Cross section seals (beam tube long side).

The area of the flange slits are analysed by air particle counters and whipping with lint free tissues. The surface of the tissues is analysed with a light microscope [1].A reduction of more than 60 % of the particles after US cleaning and rinsing is found. The area of the gasket and bore hole was not completely dry and water droplets are analysed as particulates, which may have influence on the absolute numbers. Whipping test also showed that large size metal parts were not removed from the bore holes area by the US cleaning treatment. A procedure for opening flanges on resonators is defined at DESY and has to be followed strictly to avoid contaminations origin from residues inside bore holes.

For intensive cleaning and sampling of the material removed from the slits, a rinsing set up (Fig. 5) was developed. It allows analysis of procedures and optimization of cleaning procedures. A first test sequence with the new set-up is made by rinsing of the flange according to Table 3.

Table 3: Sequence of preparation steps investigations of cleaning efficiency.

1	Ultrasonic cleaning and rinsing		
2	Pollution of sealing area with 2ccm fine dust particles (1-80 µm size) solution		
3	Ultra sonic cleaning and rinsing		
4	Cover flange by tape	Install split flange and rinse with 2 liters of pure ethanol	Install split flange and rinse with 2 liters of ultra-pure water
5	Remove tape resp. split flange, dry in ISO 4 area		
6	Analyze residual contamination		

To calibrate the test, a volume of about 2 ccm of a solution of fine dust particles (1-80 µm) and Ultra- Pure Water (UPW) is injected into the slits. After a second standard ultrasonic cleaning the flanges are rinsed with 2 litre of UPW or pure ethanol via the split ring. The cavity flanges are positioned in vertical orientation for 12 hours during drying in ISO 4.

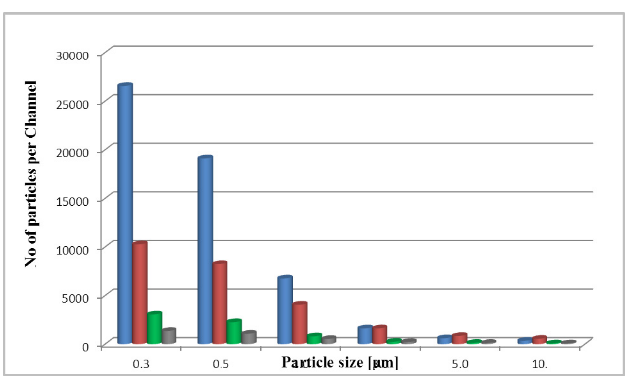

Figure 4: Test results of rinsing of beam pipe slit [Blue- Reference data of polluted slit; Red- Standard ultrasonic rinse; Green- Rinsed via split ring with ethanol; Grey- rinsed via split ring with ultra-pure water.

The efficiency of rinsing is checked by an air particle counter (®Met one) and by blowing ionized filtered air for 3 minutes into the slit. The enforced flow of rinse by ethanol or UPW showed significant reduction of particulates in respect to the standard US rinsing procedure (Fig. 4).

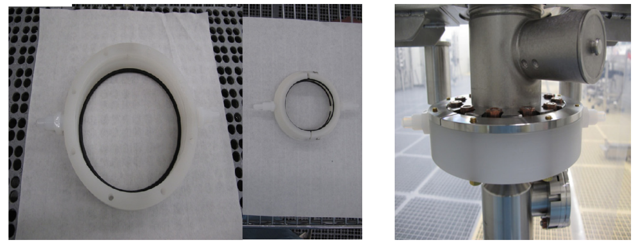

Figure 5: View on the rinsing set up/
left side: split rings for power- and beam pipe flanges / right side: rinsing set up installed to beam tube cavity long side.

RF MEASUREMENTS

Cavity AC127 and Z88 were disassembled from module PXEFL3 and retested individually in the horizontal cryostat (CHECHIA). The CHECHIA tests corresponded to the results of the module tests. The test results are unchanged in respect to module test (Table 4.) The disassembly did not affect the cavity performance in addition, if defined procedures for the removal of cavities from module string are followed [3].

Table 4: Test results of the resonators AC127 and Z88 [Maximum gradient and field emission onset gradient (data in brackets) shown in MV/m]

#	Test mode	Antenna type	HOM installed	AC127 gradient	Z88 gradient
1	Vertical	HQ	No	27,6 (27)	30,4 (30)
2	Module	PC	Yes	19,2 (19)	18,5 (18)
3	CHE CHIA	PC	Yes	20,4 (19)	19,9 (18)
4	CHE CHIA	HQ	Yes	-----	12,8 (11,3)
5	Vertical	HQ	Yes	19,7 (14)	
6	Vertical	HQ	No	(17,7) 12,7	
HQ = high Q antenna long pulse mode RF test PC = power coupler operated with klystron in pulse mode					

To study the influence of power coupler, HOM couplers or orientation of the resonators a test sequence presented in Table 4 was started. The residual gas analysis (RGA) measurements of resonators with power coupler installed show no irregularity [4]. During horizontal test (CHECHIA) the gradient measured in the module test are reproduced (Table 4.)

Only some increase of field emission on cavity Z88 was observed. After exchange of the power couplers to high Q antennas (HQ) the maximum gradient of Z88 reduced to 13MV/m in the CHECHIA test with long pulses [5]. Strong heating of the cavity and the HOM coupler antennas is observed here and limited the resonator (Fig. 6).

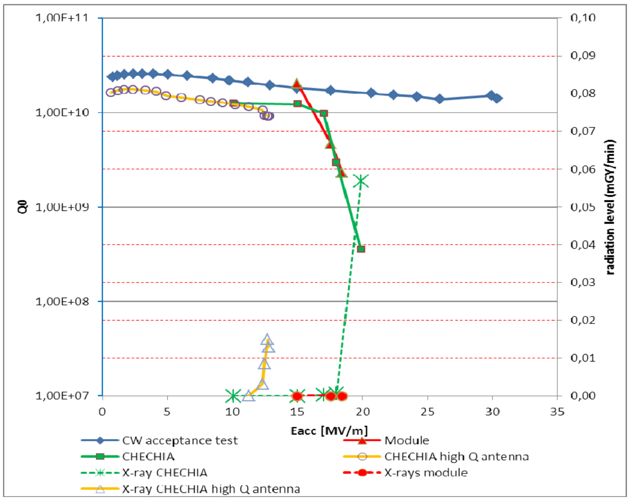

Figure 6: RF test results of Resonator Z88 analysis

On the tests of cavity AC127 no change of performance was seen between the module and CHECHIA results (see Fig. 7). After exchange of the power coupler to the HQ antenna no test in CHECHIA could be performed. The knife etch of the Helium tanks filling line Conflat flange (CF®) was deformed and did not allow to cool down the cavity.

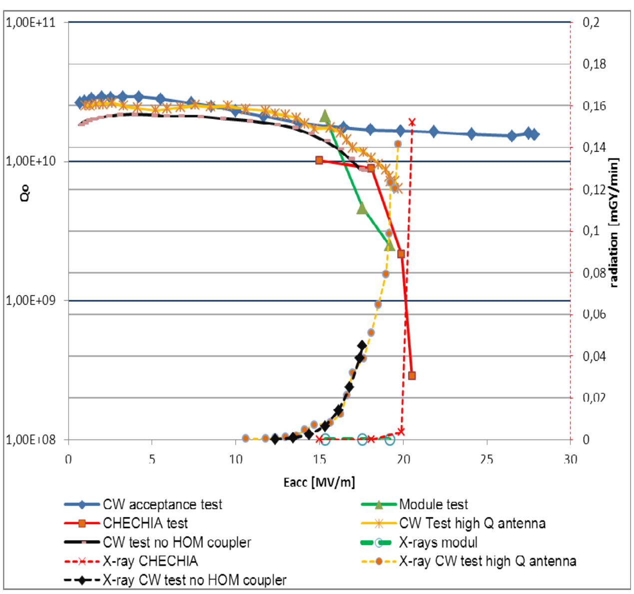

Figure 7: RF Test results of Cavity AC127.

In the following vertical test of AC 127 in long pulse mode [5] with HOM Antennas installed, a slightly reduced maximum gradient and increased field emission levels were observed (Fig. 7). After removal of the HOM coupler antennas no improvement in gradient was seen in the vertical measurement. The analysis of the maximum gradients of the different resonator modes showed, that the origin of gradient limitation is located in cell number 2 or 8 of this cavity [6]. For AC127 where no additional cleaning by HPR after each assembly step was applied it can be excluded, that power coupler or the HOM antennas limited the cavity. The maximum acceleration gradients and X-ray loading of AC127 did not change significantly between the test in CHECHIA and in vertical test operation.

CONCLUSION

Several cavities installed to modules and a cavity tested in CHECHIA showed significant acceleration gradient drops without indication of field emission. This effect seems to be of statistical nature and mostly independent on the position of the resonators in the modules. The cleaning of the sealing areas is not perfect and seems to be one of possible source of degradation. In addition, the cleaning of flange areas with the present methods applied is improved to reduce risk of contaminations of the resonators. Improved control and cleaning methods are under investigation. Two cavities (Z88 and Ac127) are removed from module PXEFL 3 and analysed in detail. The studies to understand the origin of degradation of these cavities is started and will be continued. For the resonator AC127 it could be excluded that the power coupler cold part or the HOM antennas in use were limiting the gradient (Fig. 7).

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