UPDATE ON MODULE MEASUREMENTS FOR THE XFEL PROTOTYPE MODULES

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Abstract

The Cryo Module Test Bench (CMTB) at DESY is used since several years for the SRF module tests [1], [2]. Three XFEL [3] prototypes modules, PXFEL1,2,3, were tested on this facility. An update on the SRF modules testing activities since PXFEL1 test [2] is presented (see Table 1).

XFEL PROTOTYPE MODULES AND TESTS

Table 1: Module Tests on CMTB at DESY

Date	Module	Comment
Jun.2009	**PXFEL1**	first test
Oct.2009	**PXFEL2**	first test
Aug.2010	**PXFEL3**	first test
Feb.2011		after disassembly at DESY: single cavities tests
Mar.2011	**PXFEL2_1**	after reassembly at CEA Saclay

Table 1 summarizes the XFEL prototypes test sequence so far, next test (PXFEL3_1) is planned for the end of 2011.

MODULE TEST STAND

CMTB layout and infrastructure was already described in [1], [2].

General Description

CMTB features the following:

- Single SRF accelerating 8 cavities cryo-module test stand in a radiation shielded area.
- Cryogenic system to cool down the cavities to 2K.
- Multibeam 8 MW klystron with tunable waveguide RF distribution.
- Advanced LLRF subsystem (see Fig. 1) featuring SimCon FPGA based DAC, 3x8 channels 1 MHz ADCs for the RF signals, cavity frequency tuner and fast piezo tuner controllers.
- 5x8 channels calibrated RF power measurement (see Fig. 1) for all module RF signals.
- Vacuum subsystem (TSP / IGP / TMP pumps).
- Gamma radiation measurement (both module ends).
- Personal interlock subsystem.
- Input RF power coupler diagnostics and technical interlock subsystem.
- Computer (LabVIEW, DOOCS) control system.

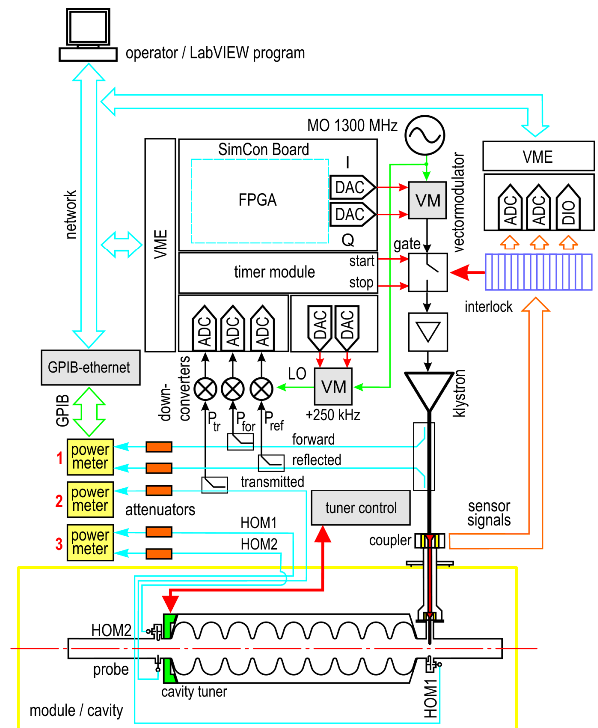

Figure 1: CMTB LLRF and RF system.

Test Procedure

Following test sequence is used to test the module:

1. RF cables (re)calibration.
2. Warm input RF couplers conditioning.
   - Up to 800kW at 20..400μs, 600kW at 1.3ms
3. Cool down to 2K.
4. Cavities Spectra measurements.
   - Fundamental / HOM spectra.
   - Cold RF cables calibration.
5. Cavities Tuners Test.
   - Tune the cavities to the 1.3GHz ± 5kHz using the Network Analyzer.
6. Couplers Q_{load} measurement.
   - Set $Q_{load} = 3\times10^6$ for each coupler.
7. Cavities on-resonance fine tuning.
   - Cavities fine-tuning to the 1.3 GHz ± 50 Hz using LLRF system (phase-tuning).
   - Q_{load}, k_t calibration ($E_{acc}=k_t\times(P_{trans})^{1/2}$).
8. Cold input RF couplers and cavities on-resonance conditioning.
   - Short RF pulse test at 2K on resonance: 100..500 μs pulse lengths up to 700kW, input coupler and cavity conditioning.

9. Module Performance Measurement.
   - Module $E_{acc.MAX}$ test with 500 + 100 µs short flat-top pulse.
   - Module accelerating gradient measurement at 10 Hz rep.rate with cryo losses (Q_0) and gamma radiation measurements (500 + 800 µs full flat-top pulse).
10. Single Cavities Measurements.
    - Detune all cavities except the one under test.
    - Flat-top pulse measurements at 10 Hz rep.rate with cryo losses (Q_0) and radiation measurements, cavities limits test.

MODULES TESTS DATA

Next diagrams summarize the module test results of PXFEL2_1 (also PXFEL2) and PXFEL3 modules. Single cavities performance, accelerating gradients limits and field emission onsets and scales, are shown in Fig. 2 – 4 (PXFEL2_1) and in Fig. 6 – 8 (PXFEL3). Integral module data, dynamic cryogenic losses, Q_0 and gamma radiation, with all 8 cavities tuned on resonance or some cavities, limiting the performance, detuned are presented in Fig.5 (PXFEL2_1) and in Fig.9 (PXFEL3).

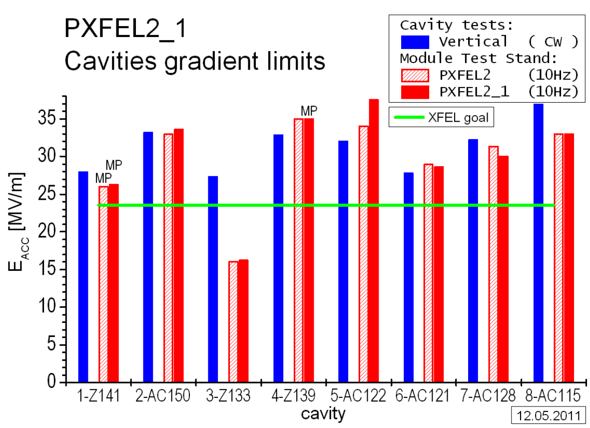

Figure 2: Module PXFEL2_1 cavities gradient limits.

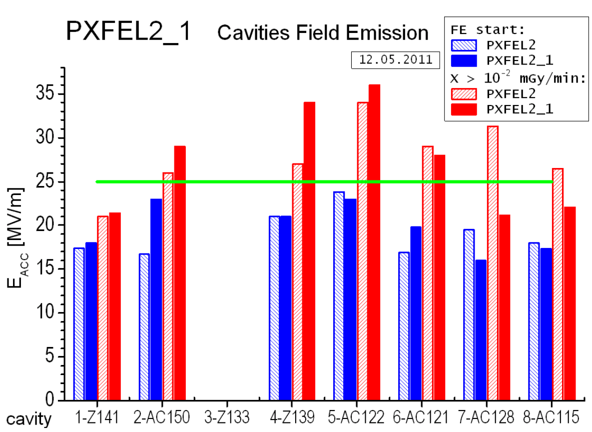

Figure 3: Module PXFEL2_1 cavities Field Emission onsets compared to maximum gradient.

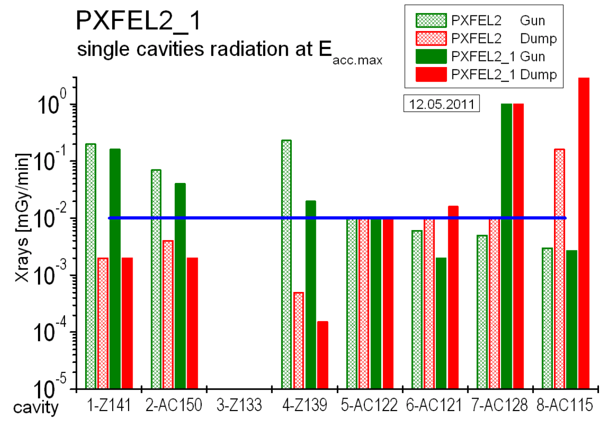

Figure 4: Module PXFEL2_1 gamma radiation.

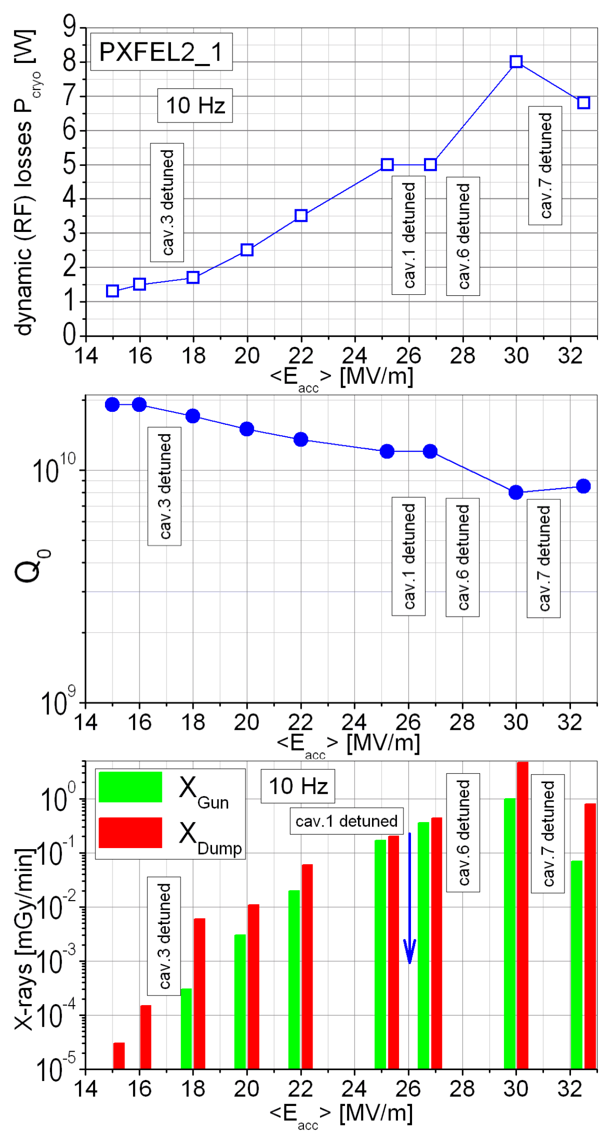

Figure 5: Module PXFEL2_1dynamic cryogenic losses, module Q_0 and gamma radiation.

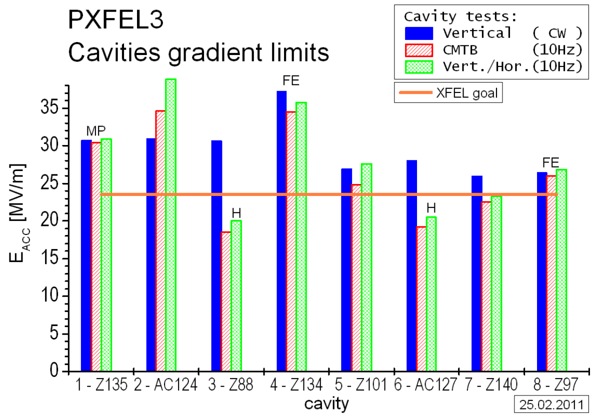

Figure 6: Module PXFEL3 cavities gradients limits (green – single cavities retested after disassembly: H – horizontal cryostat pulsed test, others – vertical cryostat CW test).

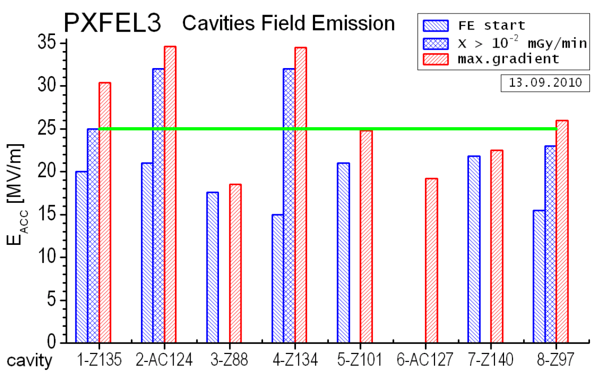

Figure 7: Module PXFEL3 cavities Field Emission onsets compared to maximum gradient.

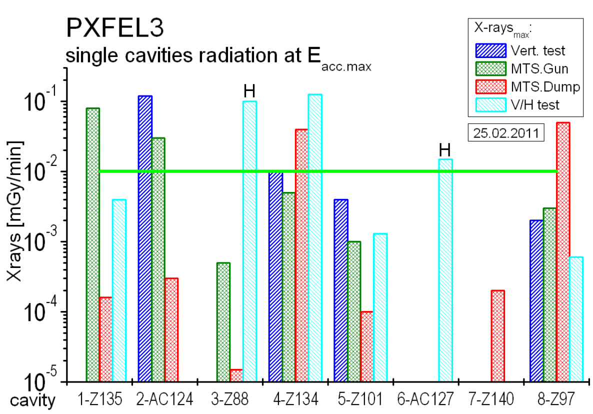

Figure 8: Module PXFEL3 cavities gamma radiation (cyan – single cavities retested after disassembly: H – horizontal cryostat pulsed test, others – vertical cryostat CW test).

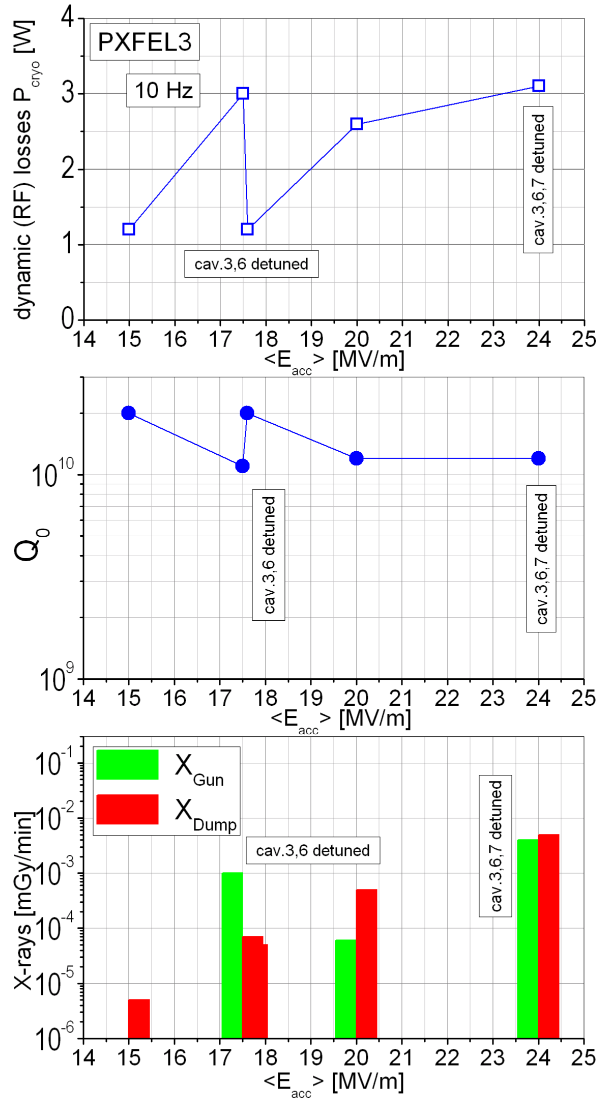

Figure 9: Module PXFEL3 dynamic cryogenic losses, module Q_0 and gamma radiation.

PXFEL2 cavities string was not reassembled for PXFEL2_1 module, but vented from cavity 8 and quadrupole assembly (dump) side.

Module PXFEL3 was disassembled after the test on CMTB. All cavities were tested separately in the vertical (CW) and/or in the horizontal (pulsed RF) cryostat with same gradients limits measured (see Fig.6). Horizontal cryostat pulsed RF test results for two deteriorated cavities (3 and 6) are presented in Fig.10, dynamic cryo-losses increase (Q_0 drop) was found compared to test before module assembly. Module PXFEL3 will be reassembled as PXFEL3_1 with cavities 3 and 6 exchanged.

For comparison of the gamma radiation data between the different cavity test stands at DESY (Fig.4,8) calibration measurements done [5].

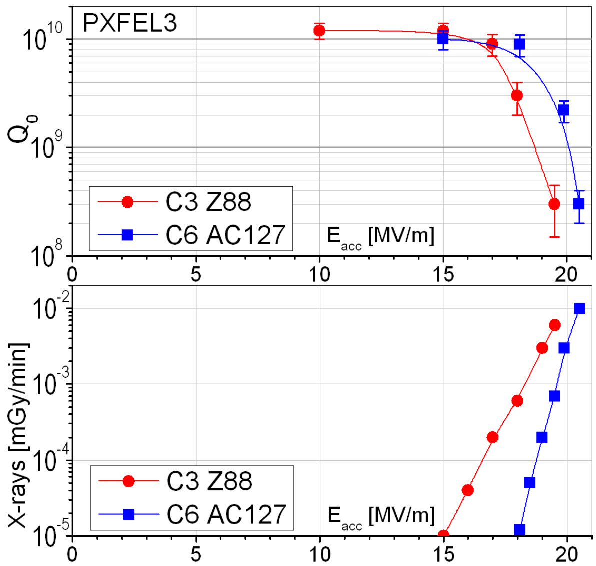

Figure 10: Module PXFEL3 cavities 3 and 6 retested in the horizontal cryostat after module disassembly.

MODULES TESTS SUMMARY

- PXFEL2_1 Cavity 1 had strong multipacting at 19..21 MV/m with high FE (up to 3 mGy/min) and BD, it was successfully conditioned. Cavity 4 had multipacting at 20..21 MV/m as well. Cavity 3 is limited at 16.2 MV/m, without field emission (FE), like in PXFEL2. Cavity 5 went to 37.5 MV/m an was RF power limited. Cavities 7 and 8 showed strong FE increase, it was partially conditioned during the test. Accelerating gradient limits of PXFEL2_1 are close to PXFEL2 ones, no degradation (see Fig.2). Cavity 3, degraded since PXFEL2, does not present any measurable dynamic cryogenic heat load or field emission, the conditioning attempts did not succeed.
- Module PXFEL3 suffered from two cavities degradation (see Fig.6): cavity 3 – 18.5 MV/m with very low FE, cavity 6 – 19.2 MV/m – no FE measured. Cavities 3 and 6 show high dynamic cryogenic losses just before the quench. Cavity 1 had multipacting at 22.5 MV/m, it was successfully conditioned. Cavities 4 and 8 have high FE, starting from 15 MV/m. Stable operation was possible with average gradient of 17.5 MV/m with low gamma radiation (10^{-3} mGy/min). Cavities retested after the module disassembly showed the same gradient limits (see Fig.6). Both cavities 3 (Z88) and 6 (AC127) showed high cryo-losses (up to 20 W) in horizontal pulsed RF test just before BD, cavity 6 showed FE (partially conditioned), see Fig.10.
- HOM coupler multipacting at 1..2 MV/m cavity gradient was detected in XFEL prototype modules cavities [4].

SUMMARY

- High and low power RF tests, as well as cryogenic tests are conducted on the accelerating SRF modules and cavities/couplers using the Cryo Module Test Bench (CMTB) at DESY. 10 SRF modules (including one 3.9 GHz module) were tested until now at CMTB. XFEL Accelerating Module Test Facility (AMTF) is under construction.
- Two next XFEL prototype accelerating modules (see Table 1) were tested on CMTB at DESY. Coupler and cavity conditioning procedure was done with PXFEL modules.
- Both tested modules suffered from some cavities degradation, but the degraded cavities behavior is different. Cavity degradation phenomena is under investigation.

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