XFEL 3.9 GHZ PROTOTYPE CAVITIES TESTS

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Abstract

In preparation for the XFEL components production, three prototype 3.9 GHz cavities have been manufactured and vertically tested at INFN-LASA. Several tests, with and without HOM antennas and in a double cavity test configuration, have been performed. Further tests of one of the prototypes took place at FNAL, to compare results between the test facilities. Results were consistent with those obtained at INFN.

INTRODUCTION

The European XFEL [1] needs a high brightness (high current, low emittance) beam to generate the 1 Å FEL radiation delivered to the experimental users. In order to reduce space charge effects at the low energy injection stage the beam current is kept low, and increased in several compression stages along the linac. The longitudinal phase space of the relatively long bunch in the first accelerating module is thus deformed by RF curvature effects and a 3rd harmonic 3.9 GHz section is needed for its linearization, in order to preserve the beam characteristics in the following bunch compressors stages. The 8-cavity 3.9 GHz system for the European XFEL is a joint in-kind contribution by INFN and DESY.

Three cavity prototypes have been produced and vertically tested in several configurations to validate the production and testing infrastructures. All 3.9 GHz XFEL cavities will be tested at the vertical test facility at INFN-LASA, capable of testing two cavities per cycle.

This paper summarizes the results so far achieved, the recent improvements to the experimental setup, and the status of the XFEL 3.9 GHz module components.

CAVITY PROTOTYPES

Three prototype cavities have been built and tested prior to the upcoming series production for the European XFEL. These prototypes are based on the FNAL design [2] developed for FLASH with minor modifications to make the cavities compatible with the XFEL infrastructures and standard components.

The 8-cavity 3.9 GHz system needs to provide a maximum voltage of 40 MV (i.e. ~15 MV/m) to achieve RF linearization after the first injector module, and the design gradient for the vertical test is set to 20 MV/m. Thus a standard BCP treatment is used for bulk and final chemistry. After fabrication, all prototype cavities have been vertically tested (without HOM antennas) to validate the whole production and treatment process. Two of the three cavities have been equipped with HOM antennas and retested. During all the tests, slow thermometry and Second Sound detectors (SSD) were installed to diagnose quenches and thermal drifts.

Test without HOM antennas

Figures 1, 2 and 3 report the experience of all vertical tests performed on the three prototypes.

Cavity 3HZ01 failed to qualify in a first attempt in 2011 (red dots in Fig. 1) [3], was completed retreated and retuned. During its second test, the cavity quenched at the moderate field of 12 MV/m, without any X-ray emission and a flat Q_0 above 1 10^9 up to the quench limit. This cavity was sent to FNAL for comparative measurements.

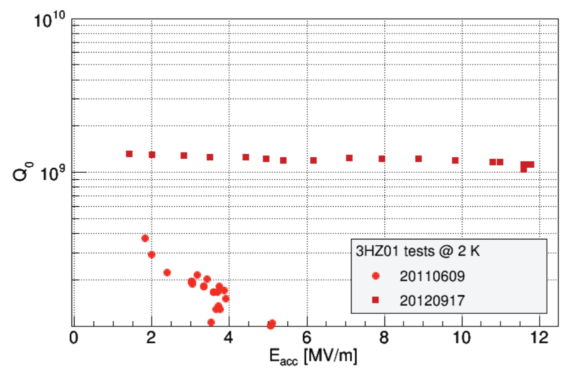

Figure 1: Cavity 3HZ01 test at LASA Q_0 vs. E_{acc} in first test (red dots) and after retreatment (red squares).

3HZ02, whose test results are shown in Fig. 2, showed the lowest Q_0 of the three cavities. This cavity was treated two times with light BCP (tens of µm) trying to increase

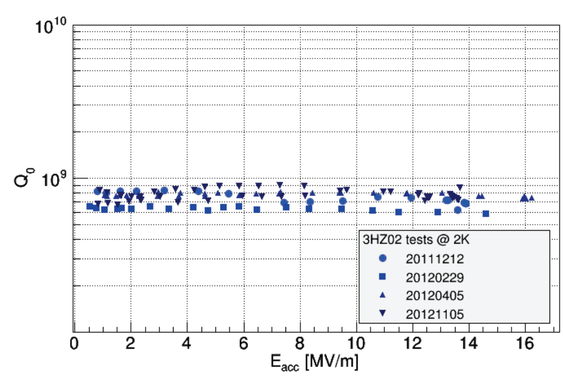

Figure 2: Cavity 3HZ02 Q_0 vs. E_{acc} for tests performed after different treatments. In all the cases, we observed a sharp quench without substantial Q degradation.

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its performance. The maximum accelerating field was about 16 MV/m with a flat Q_0 of 8 10^8 up to a sharp quench but, without X-ray emission.

Fig. 3 shows the results for 3HZ03, the best performing cavity. In the first test, we reached a maximum accelerating field of 20 MV/m with a low field Q0 of 2 10^9 with quench and negligible field emission levels.

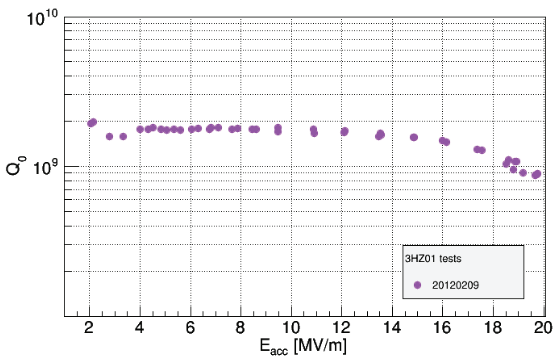

Figure 3: Cavity 3HZ03 Q0 vs. E_{acc} qualification.

Test with HOM antennas

Cavity 3HZ02 and 3HZ03, after the vertical tests described earlier, were equipped with High Order Mode antennas. In these first tests, we used removable HOM antennas, mounted on old TTF-style feedthroughs. The HOM notch filters were tuned for fundamental mode rejection at room temperature with the cavity filled with N_2 to compensate for the atmospheric pressure. The notch filters were adjusted to minimize the π mode transmission, achieving at least 20 dB attenuation. Afterwards, the cavity was prepared for the vertical test.

After HOM antennas installation 3HZ03 achieved a low field, Q_0 of 3 10^9. During the test, strong X-ray emission started at 13 MV/m and the final accelerating gradient was limited to 16 MV/m by available RF power. In a further test, after some RF processing the cavity reached 17.5 MV/m with X-ray emission starting from 13 MV/m. After this second test, the cavity went through further HPRs cycle in order to cure field emission to the levels obtained prior to the HOM installation.

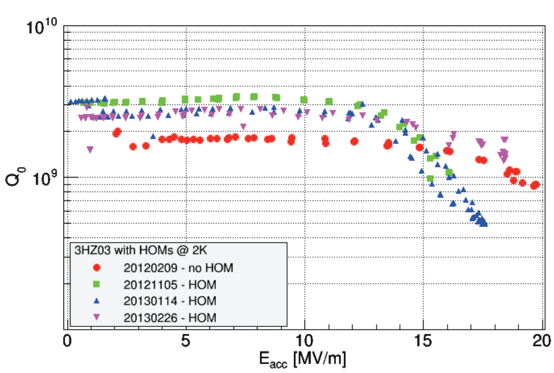

Figure 4: 3HZ03 Q_0 vs. E_{acc} with HOM pickups installed. For comparison, we have included the measurement without HOM of figure 3. The first two tests with HOM showed a strong field emission starting from 13 MV/m.

In this last test, we achieved Q_0 = 2.5 10^9 and E_{acc}= 18.6 MV/m at 2 K, recovering the performance shown during the tests in which the HOM flanges were blanked. Fig. 4 shows all 2 K tests of 3HZ03.

The notch filter of both HOM antennas and the HOM lines transmission were measured at 2 K. Fig. 5 shows the fundamental band transmissions from the HOM1 (Main Coupler side) to the field Pick Up (PU) and from the HOM2 to the Main Coupler (MC). The MC to PU transmission is reported for a comparison.

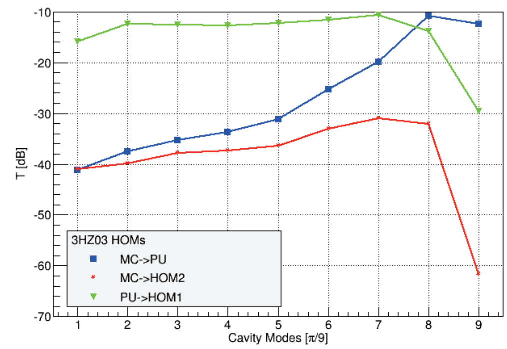

Figure 5: HOMs transmission for cavity 3HZ03. The damping on π mode is nearly 20 dB for the HOM1 and nearly 50 dB for HOM2.

3HZ02 was then equipped with HOM antennas and vertically tested. The cavity performance did not substantially degrade in term of quality factor and of maximum accelerating field, as shown in Fig. 6. Nonetheless, 3HZ02 consistently shows a modest Q_0 at low-field, indicating a poor surface condition, in spite of several BCP treatments.

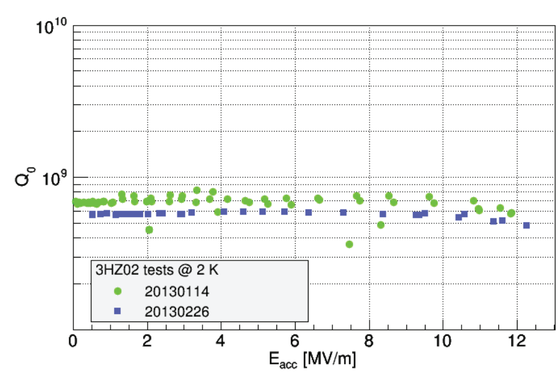

Figure 6: 3HZ02 test with HOM antennas.

3HZ01 at FNAL

In order to crosscheck the LASA RF results, 3HZ01 was shipped to FNAL and tested at the infrastructure developed at A0 for the FLASH 3.9 GHz system. Fig. 7 shows the Q_0 vs. E_{acc} data at 1.8 K for the fundamental accelerating mode. The data taken at LASA and FNAL agree within 25% in Q_0 and 5% in E_{acc}. The cavity was equipped with SSDs and fast thermometers for quench detection. In π mode, only SSDs reacted at the quench event and the position was consistent with Second Sound measurement at LASA, suggesting a quench in Cell 7.

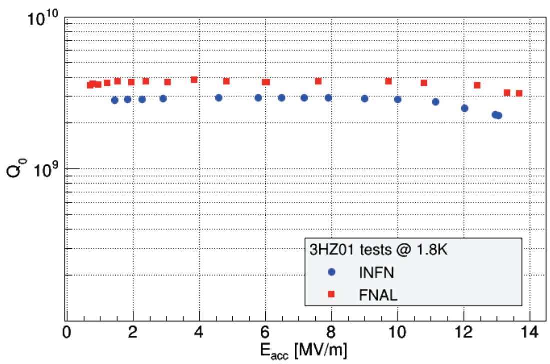

Figure 7: Comparison between 3HZ01 Q_0 vs. E_{acc} curves at INFN and FNAL (data taken at 1.8 K).

Since no HOMs antennas were installed, a few fundamental bandwidth modes (5, 6, and 7 π/9) were excited and the quench position detected by SSDs and fast thermometry as shown in Table 1. The indication from mode field pattern and diagnostics are consistent with a quench in Cell 1.

Table 1: Accelerating Field Distribution (units MV/m) in Cells for Different Modes. Maximum Field is in Bold. Quench Detected by SSDs in Orange, by Thermometry in Magenta and by Both Diagnostics in Blue.

Cell	Mode 5π/9	Mode 6π/9	Mode 7π/9	Mode π
1	10	14	13	**13.7**
2	7	0	7	**13.7**
3	13	**14**	2	**13.7**
4	2	**14**	10	**13.7**
5	**14**	0	**14**	**13.7**
6	2	**14**	10	**13.7**
7	13	**14**	2	**13.7**
8	7	0	7	**13.7**
9	10	**14**	13	**13.7**

INFRASTRUCTURE UPGRADE

The 8 cavities foreseen for the XFEL 3rd harmonic cryomodule will be vertically tested at LASA.

To increase the throughput, the vertical insert allows now the testing of two cavities in a single cooldown.

Fig. 8 shows the vertical insert with 3HZ02 and 3HZ03 assembled in their test frames. SSDs can be mounted around each of the two cavities.

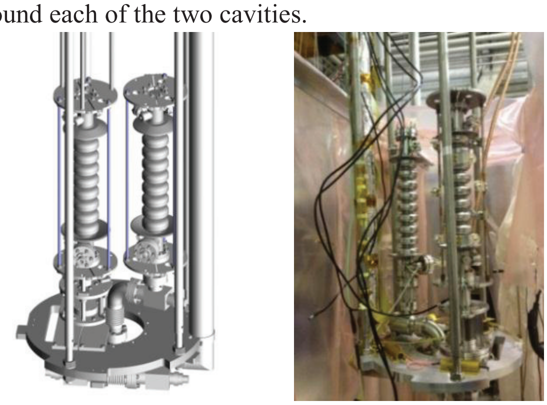

Figure 8: Sketch (right), and picture of the modified vertical insert (left) for testing two cavities.

This configuration was used to perform all tests since November 2012.

We have also recently improved the sub cooling system by installing a 2500 m^3/h roots pump, increasing the cryogenic capacity from 17 W to 50 W @ 2K and consistently reduced the subcooling time.

TUNER UNITS

As part of the preparation work for the series production, three coaxial tuners of the blade type [4] have been produced and tested at room temperature. A dedicated test set up, shown in Fig. 9, has been prepared to test mechanically each tuner in conditions simulating the action against the cavity stiffness. Elongation and applied force have been acquired simultaneously in order to verify the tuner design stiffness and tuning range.

Figure 9: Setup for testing 3.9 GHz coaxial tuner units.

The tests were performed on a cavity helium tank before its integration on the cavity. Measurements after integration of the tank with the cavity will allow a direct measurement of the actual tuning range.

CONCLUSIONS

Three cavity prototypes were fabricated and vertically tested for complete RF characterization. Two were equipped with HOM antennas, qualifying our handling and treatment procedures. Cavity 3HZ01 was used to compare at FNAL the INFN RF results. In view of the upcoming XFEL 3rd harmonic cavities production, we have upgraded the vertical station to increase the test throughput. Finally, we mechanically characterized three tuner units and we are proceeding to their integration with the cavities for horizontal testing.

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