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STATUS OF THE VERTICAL TESTING OF THE XFEL THIRD HARMONIC CAVITY SERIES

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Abstract

The prototype cavities of the XFEL 3rd harmonic system at the XFEL injector have been tested vertically before their final integration into the He tank. The Vertical Test facility has been upgraded in preparation of the series and the results so far obtained are presented.

INTRODUCTION

The 3rd harmonic 3.9 GHz section at the European XFEL (E-XFEL) injector provides linearization of the RF acceleration field seen by the beam bunch. This field linearization preserves the beam characteristics needed after the bunch compressors stages [1]. The 8-cavity 3rd harmonic module will provide a maximum voltage of 40 MV, namely about 15 MV/m. The vertical test at 2K in is the acceptance test for each cavity. The goal is to reach E_{acc} > 15 MV/m with a Q_0 better than 10^9.

All 3.9 GHz E-XFEL cavities currently in production will be vertically tested at LASA. Until now, three prototype cavities have been produced and vertically tested several times to check the production procedures, the Niobium surface treatments and the RF test facility.

In this paper, we report the Vertical Test (VT) results and the history of the three prototype cavities, as well as the upgrades done at the VT facility.

RESULTS AND HISTORY OF VERTICAL TESTS

Before starting the XFEL 3rd harmonic cavity production, three prototype cavities (3HZ01-03) have been tendered and realized at Ettore Zanon SpA, one of the two companies fabricating cavities for the XFEL main linac section since 2009. After the fabrication and primary processing such as BCP and 800℃ baking, several vertical tests have been performed at LASA. After the upgrades performed on the vertical test insert one and half years ago, the VT facility at INFN-LASA has the possibility to test at cold two cavities together, halving the number of required cooldown cycles. A set of Oscillating Superleak Transducers (OSTs) developed at Cornell [2], have also been installed since November 2012 around the cavity to assist in the identification of eventual quench locations, and working in conjunction with a fast-readout thermometry system.

Before every test, all the cavities were tuned to the goal frequency (at room temperature and atmospheric pressure) of 3892.5 MHz with field flatness better than 95%. To improve the performance of the cavity, additional surface treatments have also been performed before some tests.

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3HZ01

The first VT attempt failed due to a fault in the variable coupler design. After that, all the VTs were performed with fixed coupling. In this configuration, already during the 2nd test in September 2012 we reached a maximum accelerating gradient of 11.7 MV/m with a Q_0 of 1.6×10^9 up to the quench limit. Table 1 reports the VT history and mainly processing operations on the 3HZ01. In November 2012, 3HZ01 was sent to FNAL to crosscheck and validate the LASA RF results. The two measured data shows agreement within 25% in Q_0 and 5% in E_{acc} for the fundamental accelerating mode at 1.8 K [3]. After the crosschecking, no more VT has been done on this cavity.

Table 1: History of Vertical Test and Surface Treatments on 3HZ01

3HZ01	Max gradient (MV/m)	Q_0 (10^8) @ low field	Comment	Date
Optical inspection, Field flatness (FF) tuning, BCP (138.6 um), 800 ℃ baking				2009.10
Optical inspection, FF tuning BCP (42.3 um)				2011.05
1st test @ 2K	8.0	0.9	Limited by defective variable coupler	2011.06
800 ℃ baking, Optical inspection FF tuning, BCP (30 um)				
2nd test @ 2K	11.7	>10	Fixed coupling	2012.09
3rd test @ 1.8K	13.0	>20	@LASA	2012.11
4th test @ 1.8K	13.7	>30	@FNAL	2012.11

3HZ02

This cavity has consistently shown in several tests the lowest Q_0 at low fields among all prototypes. It is also the one that was tested several times and undergone chemical reprocessing to pursue higher performances which, however, were not reached. Table 2 gives a history of cavity 3HZ02. Among the 10 tests, the 5th to 9th VTs of 3HZ02 were done together with the cavity 3HZ03 (the 2nd – 6th, respectively). The latest 7 VT results of 3HZ02 are reported in Figure 1.

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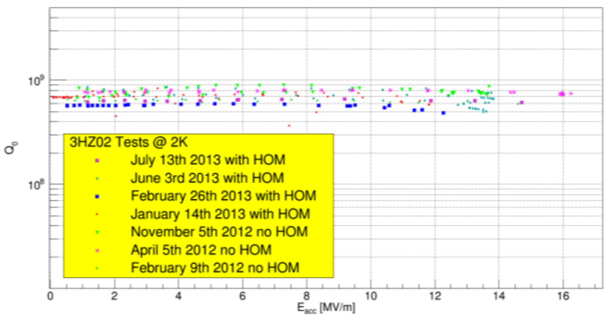

Figure 1: Q_0 versus Eacc at 2.0 K for cavity 3HZ02.

The June 2013 test shows that the maximum accelerating field is 13.7 MV/m with a Q_0 of 6×10^8 up to a sharp quench, with no X-ray emission. OSTs and temperature sensors indicate consistently that the quench position is located at the 2nd cell on 3HZ02 (close the side of main coupler, see Figure 2) [4].

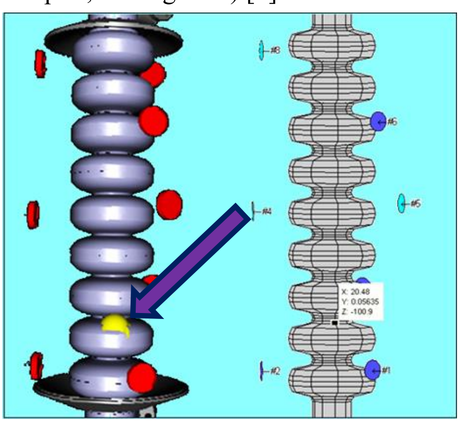

Figure 2: The quench position on 3HZ02 as reconstructed by OSTs two different reconstruction models [2,4].

Although additional BCP treatments have been done on cavity 3HZ02, it consistently showed low Q_0 values at small fields. The measurements of the surface resistance during the subcooling show an unexpectedly high surface resistance in all range, reaching about 300 nΩ at 2 K (see Figure 3).

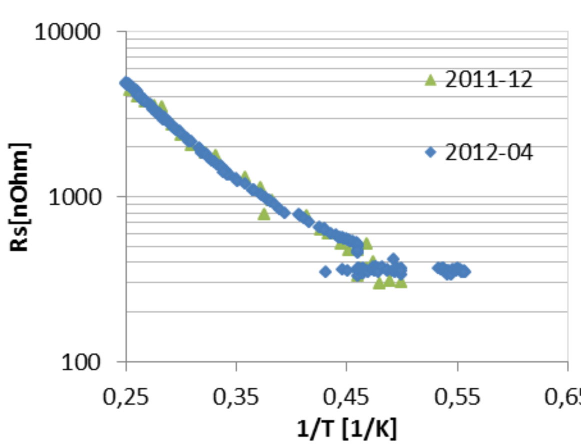

Figure 3: Residual resistance R_s vs 1/T for 3HZ02.

Because of these results, after the last test of 2013 the cavity undergone a standard surface treatment including further BCPs (115.7 um + 38.6 um) in the 1.3 GHz XFEL chemistry facility at Zanon, 800 ℃ baking and optical inspection. The further processing was performed in order to recover nominal performances and to achieve lower surface resistances. However, performances observed in the 10th tests in 2014 were even lower than those of previous tests, the cavity showed an extremely poor low-field Q_0 of 10^8, and the test was limited to 6.9 MV/m by the available RF power transmitted under these non-ideal coupling conditions.

Excitation of the fundamental modes of the passband gives indication that single cells of the cavity reach substantially higher fields.

Table 2: History of Vertical Test at 2K and Surface Treatments on 3HZ02

3HZ02	Max gradient (MV/m)	Q_0 (10^8) @ low field	Comment	Date
Optical inspection, FF tuning BCP (136.9 um), 800 ℃ baking				2009.09
Optical inspection, FF tuning BCP (7.5 um)				2011.09
1st test @ 2.08K	2.6	0.1	Vacuum leak	2011.10
2nd test	14.2	7.8	Fixed coupling	2011.12
BCP (26 um)				2012.02
3rd test	14.6	6.0	No HOM	2012.02
4th test	16.0	8.0	No HOM	2012.04
5th test	13.7	8.0	No HOM	2012.11
6th test	11.8	6.0	HOM	2013.01
7th test	12.2	5.0	HOM	2013.02
8th test	13.7	6.0	HOM	2013.06
9th test	14.7	6.0	New variable coupling	2013.07
Optical inspection, FF tuning, BCP bulk (115.7 um), 800 ℃ baking, Optical inspection, FF tuning, BCP flash (38.6 um)			To possibly improve the surface condition and to check the new chemistry instrument	2014.04 2014.05
10th test	6.9	1.0	To be understood	2014.06

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3HZ03

This cavity has been the most performance of the three prototypes, and now has been integrated in the helium tank for horizontal test at AMTF in DESY. The goal performance of 15 MV/m has always been reached in all the tests, with values of Q_0 above 10^9 at this field. Furthermore, the maximum gradient achieved at 2.0 K is 19 MV/m with a Q_0 of 8.9×10^8 up to a quench and a low-field Q_0 well in excess of 2×10^9. The surface resistance at 2K reached a value of 90 nΩ.

The relevant steps of the history of cavity 3HZ03 are given in Table 3. Figure 4 shows the performances reached by 3HZ03 in all VTs.

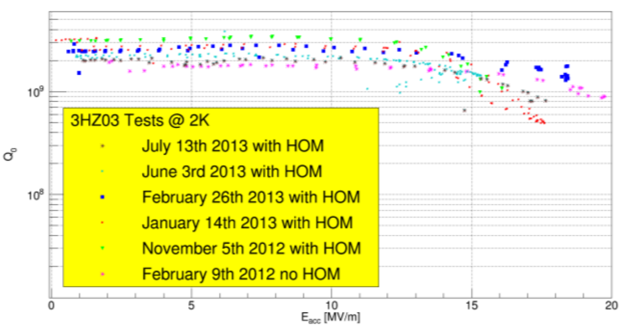

Figure 4: Q_0 versus E_{acc} at 2.0 K for 3HZ03. The first two tests with the cavities equipped with the HOM pickups showed a strong field emission starting from approximately 13 MV/m.

Table 3: History of Vertical Test and Surface Treatments on 3HZ03

3HZ03	Max gradient (MV/m)	Q0 (10^8) @ low field	Comment	Date
Optical inspection, FF tuning, BCP (131.1 um), 800℃ baking				2009.10
Optical inspection, FF tuning BCP (29.3 um)				2012.01
1st test	19.7	>10	Fixed coupler	2012.02
2nd test	16.0	>20	Field emission, HOM	2012.11
3rd test	17.6	>20	HOM	2013.01
4th test	18.0	>20	HOM	2013.02
5th test	15.0	>20	Field emission, with HOM	2013.06
6th test	17.6	>20	No FE, HOM	2013.07
Integration of helium tank				2013.11

After the integration of the helium tank the cavity has been prepared for the horizontal testing in the AMTF at DESY for final validation of the complete cavity package in operating conditions.

VT FACILITY UPGRADE

With the aim of maximizing the test throughput of the upcoming XFEL 3rd harmonic cavities production, several upgrades have been performed on the vertical facility. The vertical insert has been upgraded so that now it is possible to test two cavities during a single cool down. In addition to the OSTs, recently the existing thermometry system has been equipped with a fast readout, which was used during the last test (10th on 3HZ02) to assist in detecting the quench position (see Fig.5).

A 2500 m^3/h pump (Roots-type) has also been installed to increase the cryogenic capacity during the subatmospheric pumping, thus reducing the subcooling time to reach 2 K operation.

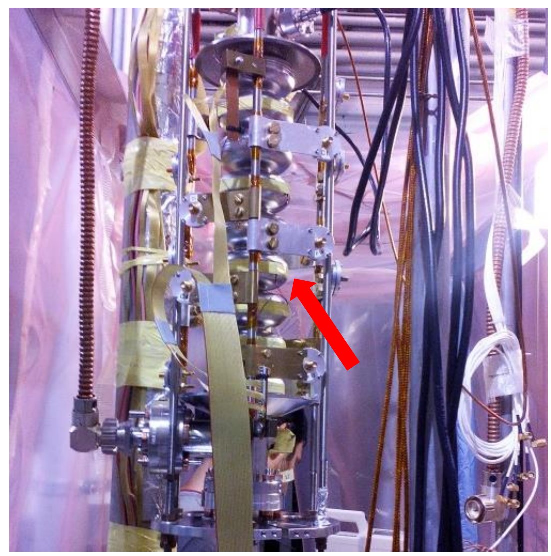

Figure 5: Fast thermometry sensors installed on the cavity together with OSTs.

CONCLUSION

The three XFEL 3rd harmonic prototype cavities have been tested through a long time period, with scattered but consistent in time, results. Experience has been gained with the construction, preparations and testing of these devices and the many tests performed, the good performance of the 3HZ03 cavity and the deployment of different diagnostics prepared our laboratory for the oncoming testing of the series cavities. The fabrication of the series cavities will benefit from the increased cleanliness and quality control procedures available at the vendor with the deployment of the XFEL main linac cavities production line, which was not available at the time of the prototypes fabrication. The upgrades on the VT facility have improved our test throughput and decreased their duration.

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