INFRASTRUCTURE, METHODS AND TEST RESULTS FOR THE TESTING OF 800 SERIES CAVITIES FOR THE EUROPEAN XFEL*

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for all colleagues working on European XFEL series cavities

Abstract

The main linac of the European XFEL will consist of 100 accelerator modules, i.e. 800 superconducting accelerator cavities operated at a design gradient of 23.6MV/m. The fabrication and surface preparation of the cavities in industry is in full swing. This talk describes the infrastructure and procedures of the vertical acceptance test in the "Accelerator Module Test Facility AMTF" at DESY. The present status of the test results is given.

INTRODUCTION

The 800 pre-series and series cavities for the European XFEL [1] as well as 24 so-called "HiGrade" cavities [2] get their vertical acceptance test at the AMTF [3] located at DESY. The production and the surface treatment take place in industry and their status is reported in [4]. As the completion of one module housing eight TESLA type cavities each per week is targeted, the vertical test rate has to be at least eight cavities per week in average.

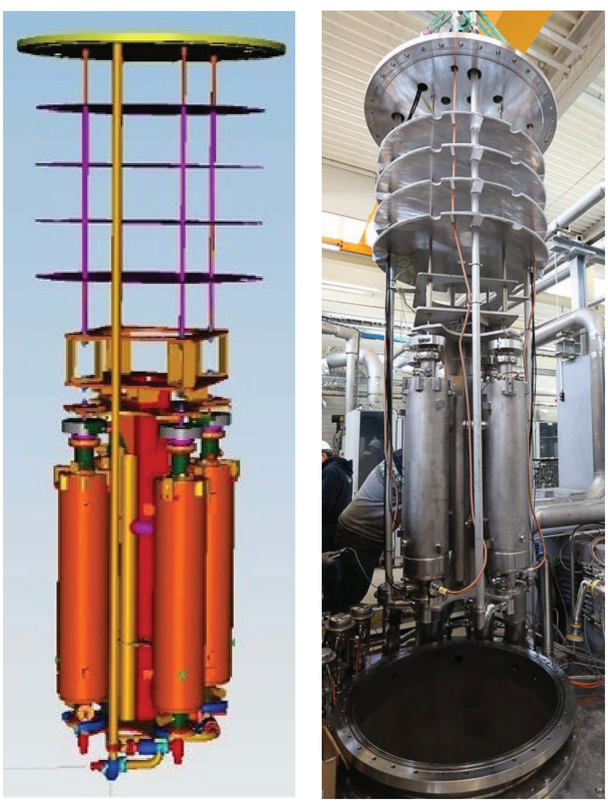

Figure 1: Insert for vertical acceptance tests in AMTF.

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VERTICAL TEST INFRASTRUCTURE

In the AMTF the vertical acceptance tests of individual cavities [5] as well as the module tests [6] take place. For the vertical tests two independent bath cryostats are available. For each cryostat an independent RF test stand is available allowing parallel measurements in both cryostats. In order to assure an efficient and fast testing of at least 8 cavities per week, each of the 6 inserts houses 4 cavities (Figure 1 + 2).

The vertical tests in AMTF started in February 2013 in a collaborative effort of IJF-PAN Krakow and DESY with the cryogenic, vacuum and RF commissioning of one insert and one cryostat. In the last months five inserts and both cryostats have been successfully commissioned. The last insert will be in operation end of September 2013.

Figure 2: Vertical test stand and cryo installations.

EUROPEAN XFEL CAVITIES

Both vendors prepare the cavities ready for testing. All cavities are fully equipped with their HOM antennas, Pick-up probe and a High Q input coupler antenna with fix coupling. The cavities arrive under UHV conditions. The transportation is done horizontally in a dedicated transport box (Figure 3).

There are 800 pre-series and series equipped with a helium tank for the assembly to the modules. In addition each vendor produces 12 HiGrade cavities without helium tank. These cavities are used as a quality control tool as they allow the application of diagnostics like Second Sound Technique or Temperature Mapping for quench location. Subsequently these cavities will be used for high gradient ILC research [2].

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Acceptance Criteria and Usable Gradient

The acceptance criteria are defined such that a cavity with a maximum gradient > 26 MV/m with an unloaded $Q_0 \geq 10^{10}$ and a radiation (X-ray) level < 10^{-2} mGy/min is accepted. The gradient of 26 MV/m gives a margin of 10% compared to the required design operation gradient (23.6 MV/m at $Q_0 \geq 10^{10}$) of the European XFEL. Of higher importance for the accelerator operation than the maximum gradient is the "Usable Gradient". It is defined as the lowest value of:

- Quench gradient
- $E_{acc}(Q_0 \leq 10^{10})$
- E_{acc} for radiation > 10^{-2} mGy/min.

Obviously within the typical measurement errors there are cavities, which are with respect to one or more of the above listed criteria close to the acceptance criteria. In such a case the DESY / IFJ-PAN experts have to come to an agreement, if the cavity is accepted or not.

If a cavity is accepted, it is prepared for string assembly (see below). If a cavity is not accepted with respect to its acceptance test performance, a re-treatment in the responsibility of DESY has to be decided. As there is no performance guarantee by the vendors, such cases are in the responsibility of DESY.

VERTICAL TEST PROCEDURES

Incoming Inspection

After the arrival at DESY the cavities are visually checked for damages during transportation and obvious assembly errors. The pi-mode frequency and the fundamental mode spectrum [7] are measured and compared with the data sent by the respective vendor [8]. All antennas are checked for mechanical damages and shorts. If there is any distinctive feature, it is reported to the vendor for clarification. If the cavity does not fulfil its specification, it is not accepted and sent back.

Preparation for Vertical Test

If the incoming inspection is passed the cavities are assembled to the insert. In preparation of the RF test the fundamental mode rejection filters of the HOM couplers are tuned. All RF cables are connected and checked by a Time-Domain Reflectometer measurement. The vacuum system of the cavity is leak checked for < $1 \cdot 10^{-10}$ mbarl/s and a residual gas analysis is done in order to rule out any hydro carbon contamination.

Vertical Acceptance Test

Cooling down to 2K is done by filling up the cryostat with the individual helium tank of each cavity open to the bath. The vertical acceptance tests follow a standardized procedure, which includes the measurement of $Q_0(E_{acc})$ at 2K and the frequencies of the fundamental modes. For each point of the $Q_0(E_{acc})$-curve the x-rays are measured on top and below of the cryostat (inside the concrete shielding). Though in one insert four cavities are cooled down at a time the RF measurement is done one by one cavity. The vertical test stand as well as the software with automated phase adjustment have been newly developed in-house and tested using the existing vertical test facilities at DESY. The data of the vertical test are stored as raw data and a selection is transferred to the XFEL Cavity Data Base [9].

Outgoing Inspection

The outgoing inspection follows more or less the incoming inspection in a backward direction. If the cavity is accepted, it is sent in a transport box to CEA Saclay for string assembly.

Figure 3: Series cavity in its transport box.

VERTICAL TEST RESULTS

For the presentation of the results no selection of cavities or any "cut" has been applied.

As Received (1. Pass of Treatment)

Here the results of 79 cavities tested "as received" (1. pass of treatment) are reported. The 79 cavities are distributed in 23 cavities produced by Research Instruments GmbH (RI) and 56 cavities produced by Ettore Zanon Spa. (EZ) 50 cavities passed (15 cavities from RI; 35 cavities from EZ). With very few exceptions the acceptance criteria have been applied very strictly and some cavities have been decided to be re-treated though the acceptance criteria have been met formally. In total 29 cavities have been decided to require a re-treatment (see below) followed by an additional vertical test.

The yield and the number of cavities for the usable and maximum gradients as received are shown in Figure 4a + 4b, respectively. Applying the standard deviation error the average gradients are shown in Table 1.

It is remarkable that both the average gradients as well as their standard deviation are nearly identical for both vendors. Though the average gradients are above the required operational gradient a significant number of cavities are even well below 22 MV/m. For each cavity the cavity performance including the limitation and

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important test information are immediately reported to the respective vendor as a feedback and for further improvement of the production and surface treatment procedures.

Table 1: Maximum and Usable Gradient "As received"

	Maximum E_{acc} [MV/m]	Usable E_{acc} [MV/m]
Total	28.1 ± 7.8	25.0 ± 7.7
EZ	27.6 ± 7.7	24.5 ± 7.6
RI	29.2 ± 8.2	26.1 ± 7.8

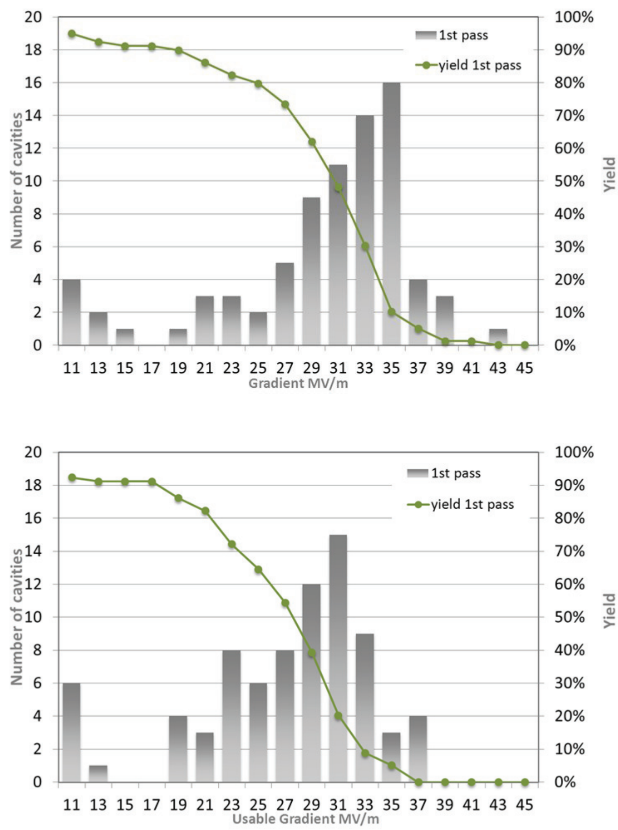

Figure 4a + b: Yield and number of cavities for maximum gradient (top) and usable gradient (bottom) as received (1.pass of treatment).

After Re-treatment (2. Pass of Treatment)

A re-treatment after the first vertical test is decided mainly because of field emission - indicated by radiation - and/or a low Q-value. For such cavities two options of re-treatment are available at DESY:

- High Pressure Ultrapure Water Rinsing (HPR)
- A short (typically 10µm) BCP + HPR + 120°C bake

As the series cavities are already assembled to their helium tank and no re-tuning is possible, more removal would shift the π-mode frequency out of the tolerable range.

Up to now 13 cavities have been re-treated by HPR and re-tested with 11 cavities passed. A BCP treatment was applied to only one cavity limited by quench, which could not be improved. The remaining 15 of 29 cavities are still in the procedure of re-treatment and re-testing.

It is important to note that the yield after re-treatment (2.pass of treatment) is calculated based on the 50 cavities passed as received plus the 14 cavities after re-treatment. Therefore the total number of cavities tested after 2.pass is 64 compared to 79 cavities tested as received.

Table 2: Maximum and Usable Gradient after Re-treatment

	Maximum E_{acc} [MV/m]	Usable E_{acc} [MV/m]
Total	30.9 ± 4.4	29.0 ± 3.9
EZ	30.4 ± 4.5	28.4 ± 4.0
RI	32.3 ± 4.1	30.6 ± 3.1

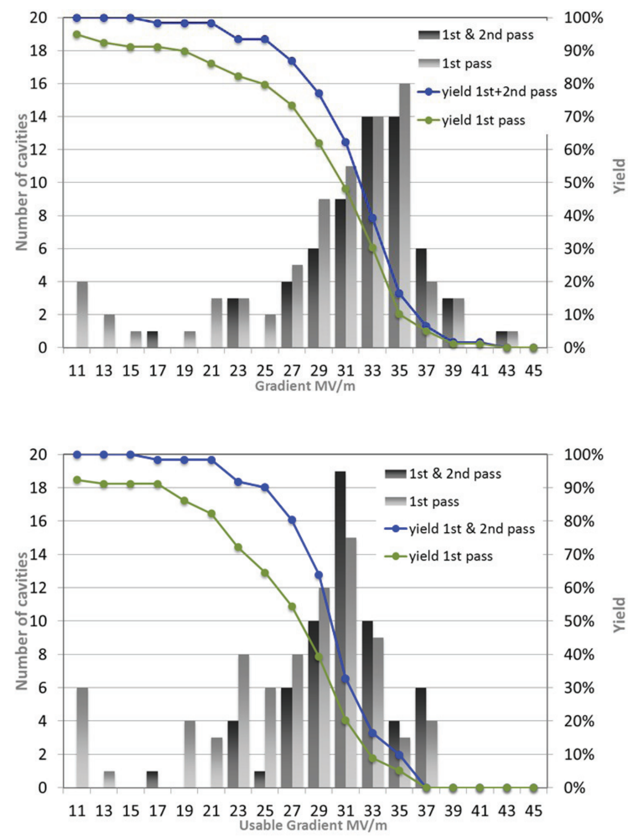

Figure 5a + b: Comparison of yield and number of cavities for maximum gradient (top) and usable gradient (bottom) as received and after re-treatment (2.pass of treatment).

The average gradients are shown in Table 2 (with standard deviation). The average gradients increased and the spread decreased significantly. As can be seen in Figure 5a + b the yield for both maximum and usable gradient is above 90% after re-treatment. Nearly all cavities with low gradients could be improved to gradients above the design operational design. For the few remaining “failed” cavities there are the options of a second re-treatment or a possible usage with a gradient below the design gradient.

Q-values

For the vertical acceptance tests the cavities are equipped at the vendors with an input antenna with a fix coupling. The nominal Q-value of the coupling is set to $8 \cdot 10^9$. The measured coupling Q-values vary between $5 \cdot 10^9$ and $1 \cdot 10^{10}$. This results in an overcoupled measurement situation at low and medium gradients, but allows a processing – if necessary – at high gradients. The overcoupling causes a higher measurement error for the low gradient Q_0-value than for the optimum matched coupling. A detailed analysis is in preparation.

The average unloaded Q_0-value at low gradient for the tested 79 cavities “as received” is $(2.2 \pm 0.4) \cdot 10^{10}$. After re-treatment the average unloaded Q_0-value at low gradient for the tested 64 cavities is $(2.4 \pm 0.4) \cdot 10^{10}$. The error given is the standard deviation.

Few cavities showed an extraordinary low Q_0-value “as received”. In such cases an immediate feedback to the companies is given.

SUMMARY AND OUTLOOK

In the beginning of 2013 the commissioning and operation of the vertical test stands in the AMTF facility at DESY started successfully. Dedicated handling, inspection and testing procedures for the efficient testing of the European XFEL series cavities have been developed and are in application. The vertical acceptance tests of these cavities show satisfactory results for both vendors. Re-treatment mainly by HPR at DESY was applied very successfully to cavities, which did not fulfill the acceptance criteria “as received”. 44 cavities have been shipped to CEA Saclay for string and module assembly [10].

A task for the near future is the reliable ramp-up of the weekly test rate to > 8 cavities and a short term feedback of the test results to the vendors. The results for gradient and Q_0-value will be followed up thoroughly. The obvious goal is the increase of the “as received” yield as close to 100 % as possible.

ACKNOWLEDGMENT

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REFERENCES

[1] “The European X-Ray Free-Electron Laser; Technical Design Report”, DESY 2006-097 (2007). http://xfel.eu/en/documents.

[2] A. Navitski et al., “ILC-HiGrade cavities as a Tool of Quality control for E-XFEL”, MOP043, this conference

[3] Y. Bozhko et al., Cryogenics of European XFEL Accelerator Module Facility, Proceedings of the twenty-third International Cryogenic Engineering Conference 2010 (ICEC23),ed. M.Chorowski et.al., Oficyna Wydawnicza Politechniki Wroclawsjiej, Wroclav 2011, p.911.

[4] W. Singer et al., “The Challenge and Realization of the Cavity Production and Treatment in Industry for the European XFEL”, MOIOA03, this conference.

[5] K. Krzysik et al., Test of 1.3 GHz Superconducting Cavities for the European X-ray Free Electron Laser”, MOP037, this conference.

[6] M. Wiencek et al., “Tests of the Accelerating Cryomodules for the European X-ray Free Electron Laser”, MOP054, this conference.

[7] K. Kasprzak, M. Wiencek, “Fundamental Mode Spectrum Measurement of RF Cavities with RLC Equivalent Circuit”, THP093, this conference.

[8] A. Sulimov et al., “RF Aspects of Quality control for Industrial XFEL Cavity Fabrication”, MOP052, this conference.

[9] S. Yasar et al., “A Data Base for the European XFEL”, MOP041, this conference

[10] C. Madec et al., “The Challenge to Assemble 100 Cryomodules for the European XFEL”, THIOA02, this conference.

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