TESTS OF THE 1.3 GHz SUPERCONDUCTING CAVITIES FOR THE EUROPEAN X-RAY FREE ELECTRON LASER

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Abstract

The European X-ray Free Electron Laser (XFEL) is currently under construction in Germany in Hamburg area. A linear accelerating part of the XFEL is going to consist of 808 superconducting 9-cell Niobium cavities installed in 101 accelerating modules. Before assembly into modules the cavities are tested in a dedicated test facilities.

The testing procedures are prepared based on DESY expertise and available software from Tesla Test Facility (TTF) Collaboration and Free electron LASer for Hamburg (FLASH). RF test provides the most important information about cavity performance: maximum available gradient and dependence of quality factor and radiation on the gradient. Results of the RF test determine, whether a cavity is shipped to CEA Saclay (France) to be assembled into a module or send for retreatment to improve its performance. In this paper we present the most important aspects of the cavity RF test procedure.

INTRODUCTION

The XFEL cavity consist of 9 cells, acting as RF resonator with the nominal resonant frequency of 1.3 GHz at the temperature of 2 K. Figure 1 shows the XFEL cavity in the transport frame (without tank). The material used for manufacturing of XFEL cavities is Niobium – superconductor of II type (critical temperature of 9.2 K). Electrons passing through the cavity along its vertical axis of symmetry will be accelerated by gradient of about 23.6 MV/m. In order to drive RF powering of the cavity, it is equipped with 4 antennas: input coupler, pickup probe and two higher order modes (HOM) couplers.

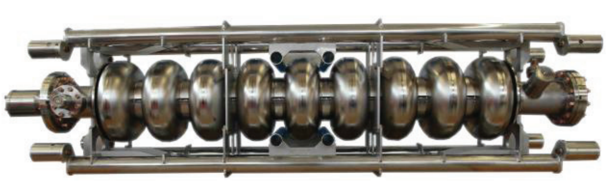

Figure 1: XFEL cavity in the transport frame (without tank).

The RF cavity tests are prepared and performed by The Henryk Niewodniczanski Institute of Nuclear Physics Polish Academy of Sciences (IFJ PAN) team [1]. According to the current estimation 7 working days organized in two shifts are needed to complete the test of eight cavities using two vertical test stands. The tests are performed in AMTF (Accelerator Modules Test Facility) at DESY in Hamburg. Performing of cavities tests is a part of Polish in-kind contribution for the European XFEL.

CAVITY TEST

Incoming Inspection

The XFEL cavities are manufactured in two external companies: Research Instruments (RI) and E. Zanon. After delivery to DESY, cavity must pass the incoming inspection – mechanical, vacuum and RF check. It is necessary to check, whether all cavity components are installed properly and none of the antennas is short-circuited. Then the cavity frequency spectrum (Figure 2) is measured and compared with the reference tuning data. The dedicated software used for the measurement speeds it up. The result of comparison, so called mean spectrum frequency deviation (MSFD), indicates even slight mechanical deformation of the cavity.

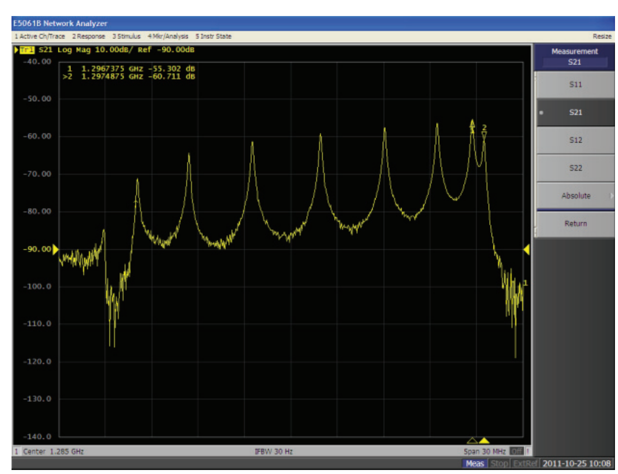

Figure 2: RF spectrum of an XFEL cavity (VNA display).

Preparation for the Test

Before RF measurements the cavity is prepared for the test. The cavity is installed in the insert and connected to

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the vacuum line. Every insert used in AMTF can contain up to 4 cavities (Figure **3**). Due to following operations it is required to reach the vacuum level of 10^{-7} mbar. At the end of preparation the mass spectrum is measured and the leak check is performed.

Figure 3: Inserts with cavities in the preparation area.

RF Measurement (Room Temperature)

RF measurement at room temperature (Figure 4) comprises frequency spectrum measurement (input-pickup) and tuning of higher order modes couplers (input-HOM2, pickup-HOM1). The main purpose of the tuning is to setup properly the minimum of fundamental mode rejection filter in order to minimize transmission through the HOM couplers and to dump effectively other modes. After tuning RF cables are connected to the cavity and the insert is transported to the cryostat.

Figure 4: An XFEL cavity in the insert – RF measurement (room temperature).

Cool Down to 2 K

XFEL cavities gains their superconducting properties and high quality factor (> 10^{10}) in temperature of 2 K. To measure cavity performance it is necessary to cool it down and to maintain stable cryogenic conditions during the test (Figure 5).

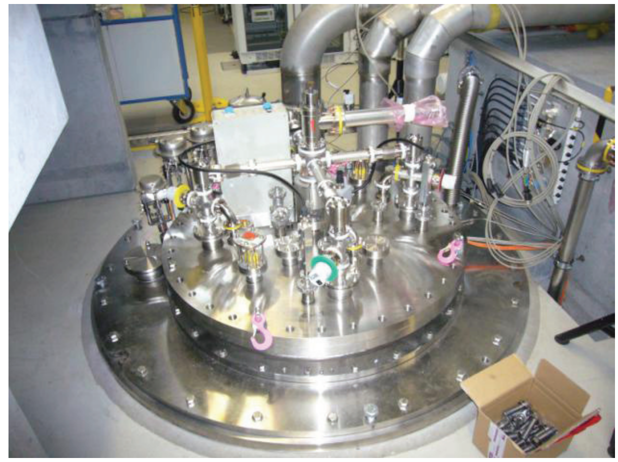

Figure 5: The insert inside the cryostat.

RF Measurement (2 K)

Main part of the cavity test is RF measurement at 2 K – so called "vertical test". It is performed in order to provide the most important cavity parameters: maximum available gradient and dependence of quality factor and radiation on the gradient. The vertical test consists of spectrum measurement (only frequencies of fundamental modes) and Q(E) curves for 9/9π mode. To shorten time needed for the serial cavities tests, measurement of the quality factor dependence on temperature Q(T) is not being done. The RF measurement takes place in a special test-stand, equipped with vacuum, cryogenic and RF systems and driven by dedicated software (Figure 6).

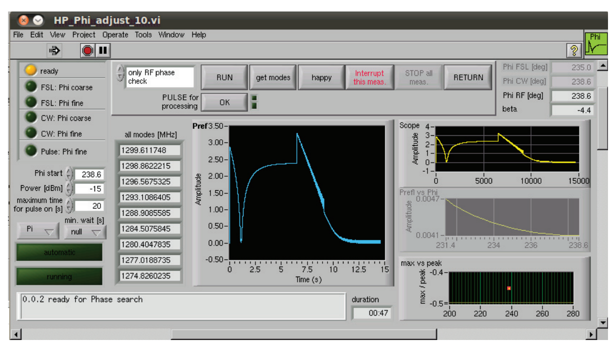

Figure 6: Software dedicated to the vertical test.

The measurement starts with cable calibration and setup of the interlock system. Due to radiation hazard, the test-stand is equipped with concrete shielding, which has to be closed before high power is turned on. Next step is spectrum measurement – it is performed to obtain fundamental modes frequencies, especially frequency of 9/9π – the operating mode for the XFEL cavities. Then Q(E) dependence measurement starts. Q(E) curve consist of set of points measured for increasing power. Each point contains information about cavity response for long pulse, like: power levels, quality factors (cavity itself, antennas), radiation, and vacuum- and cryogenic-conditions. Q(E) points are measured until limitation is met, which can be either the hard quench or the power limit (about 200 W). During this process cavity performance and the quality factor may improve (eg. due to burning out impurities) or degrade (eg. due to particle pollution), so for every cavity it is necessary to measure Q(E) curves several times until no significant changes in cavity performance are observed.

Outgoing Inspection

After the vertical test, cavity is warmed up to the room temperature and transported back to the preparation area. There, it is disconnected from the vacuum line and dismounted from the insert. Depending on the results of the vertical test the cavity is prepared for shipment to CEA to be assembled into the XFEL module or send for retreatment to improve its performance.

Outgoing inspection is the last action performed for cavity in DESY. The outgoing inspection procedure consists of the same steps as the incoming one – mechanical, vacuum and RF check. In addition spectrum measurement for input-HOM2 and pickup-HOM1 configurations is done, to determine, whether HOM couplers have been detuned during the vertical test. After passing the outgoing inspection the cavities is placed in ~~a~~ transport box and shipped to CEA.

RF Test Results

All RF measurement results obtained during the cavity test – calibration offsets, RF spectra and Q(E) curves – are uploaded to the data base. The data base is not only a container for the measurement data, but also a useful tool for comparison and statistical analysis (Figure 7). The database is connected with the tests management system that improves cooperation of various groups handling the cavity tests and preparing reports for the EDMS system.

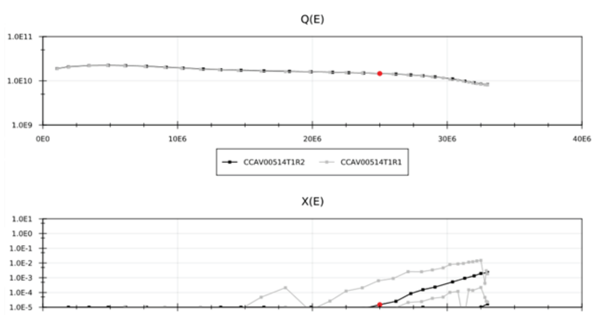

Figure 7: Results of the vertical test (IFJ PAN cavity database viewer, beta version).

SUMMARY

In period from November 2011 to September 2013 IFJ PAN team has performed about 150 tests of cavities. This number includes tests of reference cavities from RI and E. Zanon, tests done for commissioning of DESY infrastructure and serial tests of XFEL cavities. All test done so far provide not only information about cavity performance, but are also clear proof of high qualifications of members of IFJ PAN team.

In parallel IFJ PAN team developed own software for presentation of results of measurements and the test management system. Those tools turn out to be crucial in case of such complex project and allow to significantly increase efficiency of work of IFJ PAN team.

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