

TESTS OF THE ACCELERATING CRYOMODULES 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 2.1 km long superconducting linear accelerator, part of the XFEL, consists of 101 accelerating cryomodules. The XFEL cryomodule is assembled with eight superconducting RF cavities, one cold magnet and Beam Position Monitor (BPM). The cryomodules are tested in dedicated test facility before installation in the XFEL tunnel. The testing procedures for the cryomodules were prepared with use of DESY expertise from TTF (Tesla Test Facility) Collaboration and FLASH (Freie-Elektronen-Laser in Hamburg). This paper describes the full set of testing procedure and incoming and outgoing inspections as well.

INTRODUCTION

The cryomodules for accelerating part of the XFEL are assembled in CEA Saclay (France) and delivered to DESY (Hamburg). After delivery the cryomodules are being checked during so called incoming inspection and followed by their preparation for the tests. Next step is cooling down of the cryomodule to the temperature of 2K. Then, RF and cryogenics measurements are performed. The cryomodule is being warmed up while the measurements are finished. The final step is performance of the outgoing inspection. According to the current estimation 14 working days organized in two shifts are needed to complete the test of one cryomodule. All of the steps mentioned above are done by The H. Niewodniczanski Institute of Nuclear Physics Polish Academy of Sciences (IFJ PAN) team [1]. Currently over 30 enginners and technicians from IFJ PAN are involved in testing the cryomodules and RF cavities in new AMTF (Accelerator Modules Test Facility) Hall at DESY in Hamburg. Performance of all cryomodules tests is a part of Polish in-kind contribution for European XFEL.

INCOMING INSPECTION

During transportation the cryomodules are equipped with vacuum monitoring system and shock loggers. Data from these devices are read as the first step of the incoming inspection. If results of the read are acceptable the restoration of high vacuum in the coupler line is performed. Next, mechanical and electrical checks are performed. The mechanical inspection consists of removal of transport caps

and visual checks of all flanges and process pipes. The electrical inspection consists of checks of all connector and feedthroughs and functionality test of cavities and couplers tuners. The measurements of the fundamental mode spectra of each cavity follow the mechanical and electrical checks. Finally, resistance test of the magnet coils is performed.

PREPARATION FOR TESTS

After the incoming inspection the cryomodule is installed on the test stand. At the beginning the cryomodule is mounted on a special trolley, transported to test stand and aligned. Next step is to connect the beam line to the vacuum system in a clean room conditions. The mass spectrometry is performed to ensure that there is no contamination in the beam line. Example of the mass spectrometry results are shown in Figure 1.

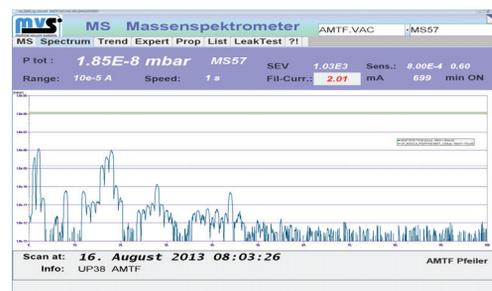


Figure 1: Mass spectrum of the beam line.

Then the following mechanical operations are performed:

- connection of process pipes,
- closing sliding muffs,
- leak check of the process pipes and the cryomodule,
- wrapping the process pipes with MLI (Multi Layer Isolation),
- installation of the thermal shields,
- wrapping the thermal shields with MLI,
- pump down of the isolation vacuum

When the preparation is done the electrical and waveguides connections are made. Finally, a warm coupler conditioning is performed to clean impurities from couplers.

09 Cavity preparation and production

K. Technical R&D - Large scale fabrication

COOL DOWN

Test of the XFEL module is performed at 2K, thus all components of the cryomodule are step by step cooled down to operation temperature. One can highlight few phases in the cool down process. During the first phase the temperature of the module is lowered to 80K with many temperature and pressure constraints. This prevents the module from thermal stresses caused by large temperature gradients. Around 80K most of dislocations in the material are blocked, thus, the cool down process of the module is proceed to 4.5K. When all vessels are filled up by liquid helium the last phase of the cool down can be performed. The pressure above liquid helium bath is lowered to 31 mbar. This provides temperature of 2K and the cool down process is considered as finished. The cool down process is shown in Figure 2. Conditioning of the couplers is also performed during the cooling down.

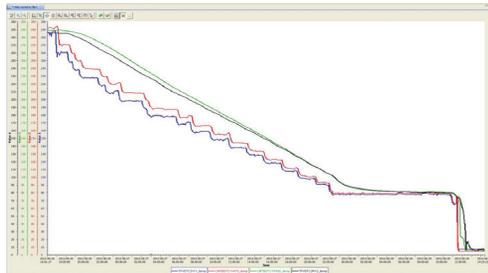


Figure 2: Automatic cool down procedure plot.

RF MEASUREMENTS AT 2K

The RF measurements in cryogenic conditions are divided in two phases. The first phase is measurements at low RF power while the second one is - at high RF power. The former measurements are performed by means of Vector Network Analyser (VNA) an RF amplifiers if needed. The latter measurements are performed with klystron.

Measurements at Low RF Power

There is a necessity to measure attenuation of the cables inside the module at 2K. This measurement is performed as a S11 measurement and has to be done inside the test stand. All the other mentioned measurements can be done outside of the test stand using cables for high RF power measurements. After that a fundamental mode spectra of each cavity is measured. Then the cavities are roughly tuned to the design resonance frequency (1.3 GHz). In parallel, an external quality factor of the couplers is set by coupler motors. Finally, the High Order Mode (HOM) Spectra measurement is performed. The results panel is shown in Figure 3.

After these operations test stand is closed and secured by the Personal Interlock.

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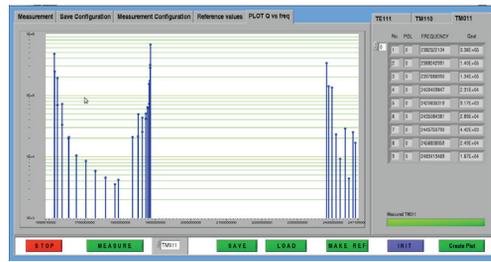


Figure 3: HOM Spectra measurements application.

Measurements with High RF Power

There is no possibility to tune the cavities to the exact resonance frequency with the VNA. Therefore the fine tuning with use of the Low Level RF (LLRF) system is needed. This is the first operation performed with the klystron. After fine tuning, the cavities are calibrated at low gradient (5 MV/m) to determine the following parameters:

- K_t - calibration coefficient used to calculate the gradient,
- Q_{ext} - External quality factor adjusted during tuning with VNA; measurement of Q_{ext} is much more accurate at high RF power
- Q_{probe} - Quality factor of the Probe antenna
- Q_{HOM1} and Q_{HOM2} - Quality factor of the HOMs antennas

A new software for cavities calibration has been written by IFJ PAN Team (Figure 4)

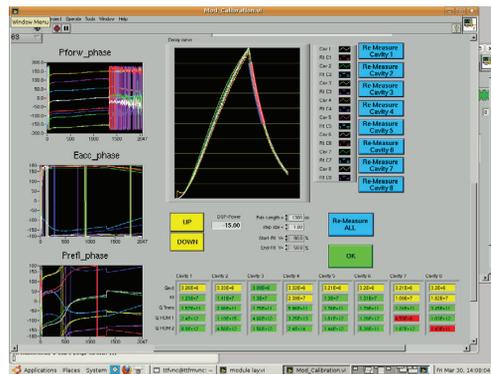


Figure 4: Calibration application.

After calibration the cavities are tested one by one. Because of the power distribution system there is a necessity to detune all cavities except one. Most important results of this measurement are listed below:

- Quench limit [MV/m],
- Operating gradient - Value of Gradient when radiation do not exceed 10^{-2} mGy/min [MV/m],
- X_{rays} start - Value of Gradient when radiation starts [MV/m],
- X_{rays} quench - Value of radiation just before cavity quench [mGy/min],

- P_{for} - power used to drive a cavity to the quench limit

The measurements results of a pre-series XFEL cryomodules (XM-3) are shown in Figure 5. After completing the performance test, all cavities are again tuned to the resonance frequency in order to perform the cryogenic measurements.

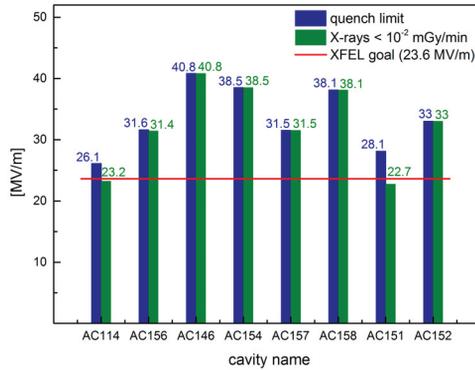


Figure 5: Results of the performance test.

CRYOGENIC MEASUREMENTS

The cryogenic measurements are divided into two phases. The first phase is a static measurements, when there is no powering inside either cavities or the magnet. The second one, so called Heat Loads Measurements is performed with the powered cavities.

Static Measurements

The thermal performances of the accelerator modules is a vital issue to estimate the load budget of the refrigerator system. Variety of measurement considers the losses on cryogenic lines such as 2K, 4.K and 40/80K are performed.

Heat Loads Measurements

This measurements are performed by two operators: one from cryogenic site and another from RF site (RF operator application is shown in Figure 6). First, the zero measurement is performed in order to obtain the cryogenic load without power. Then all cavities in cryomodule are powered to certain level of the gradient. Next the series of measurements at different gradients are proceeded. During those measurements a few points are obtained: at gradient just below the X_{rays} start, when radiation exceeds 10^{-2} mGy/min (if available). Next at 23.6 MV/m (XFEL goal gradient) and just below the lowest cavity quench limit. If there is only one cavity with low limit in cryomodule the cavity is detuned. The cryomodule is operated without the weakest. The cryogenic calculation of heat loads are shown on Figure 7. From cryogenic load total Quality factor of all cavities inside the cryomodule is calculated. Thus, Quality factor from this measurements is averaged for each cavity. Software for this measurements has been written by IFJ PAN Team.

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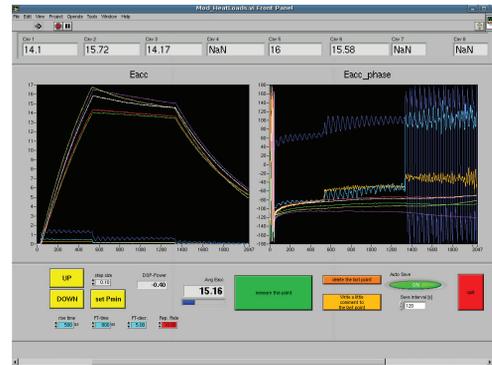


Figure 6: Heat Loads measurement - RF operator application.

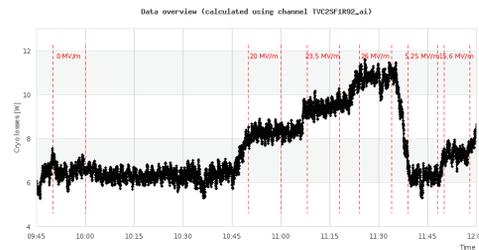


Figure 7: Heat Loads measurement - Cryogenic calculations.

WARM UP, DISASSEMBLY, OUTGOING INSPECTION

After measurements at 2K the cryomodule is warmed up and disassembled from the test stand. Next, the outgoing inspection is performed in order to confirm that there was no damages during the tests procedure. Results of outgoing inspection is put into Outgoing Inspection Report. Finally, the cryomodule is handed over to the next work packages for further installation.

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