IMPROVEMENTS OF THE RF TEST PROCEDURES FOR EUROPEAN XFEL CRYOMODULE TESTING

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Abstract

The testing of the 100 SRF cryomodules for E-XFEL is currently ongoing at the AMTF Hall, located at DESY, Hamburg. Cold tests for the cryomodules have been developed based on TTF (Tesla Test Facility) experience. However, to be able to test the cryomodules with required test rate of one a week, some improvements to the measurements had to be made. The goal of these improvements was to reduce the time needed for testing without losing any of the important data for the cryomodule. Currently, after testing more than 30 % of the cryomodules, gathered experience is now allowing us to skip or combine some of the measurements. This paper describes changes in the cold test procedures which have been made since the testing of the first serial cryomodules delivered by IRFU.

INTRODUCTION

Before installation in the linac part of the European XFEL (X-ray Free Electron Laser), all of the superconducting cryomodules have to be tested to find optimal position in the accelerating string and to exclude failures, which prevents to install them into the accelerator. The measurement in superconducting state (2K) is the crucial parts of those tests. To be able to test all modules according to the schedule improvements were necessary at many stages of module life cycle. Test procedure was also required to be improved in order to meet deadlines and measure the most important module parameters. Time when the module is cold is a critical period during the module test. Cryogenic slots that enables us to cool down or warm up the module are limited and there is a number of measurements that cannot be done in parallel that limits our options.

In this paper we describe most important improvements done up to now. Improvements done at the cold test of the cryomodule can be split into two main parts. First part describes changes in the order of the measurements, skip or combine some of them. Second part describes the improvements in the measurements itself.

TEST PROCEDURE BEFORE IMPROVEMENTS

Test procedure for the XFEL Module includes several low and high power measurements important for determining module parameters and performance before qualifying it to be used in the accelerator. This is an important task, because a module performance can change significantly after subjecting it to high power due to a processing. Detailed information makes it possible to sequence modules in the tunnel in the optimal way, prepare correct waveguide power distributions and set LLRF parameters.

Low Power Measurements

Module test starts with low power measurements. During this step fundamental mode spectra were measured for all cavities (See Fig. 1) using dedicated software developed by IFJ PAN group [1]. This gives an information about pi mode frequencies and deviation from the reference spectra.

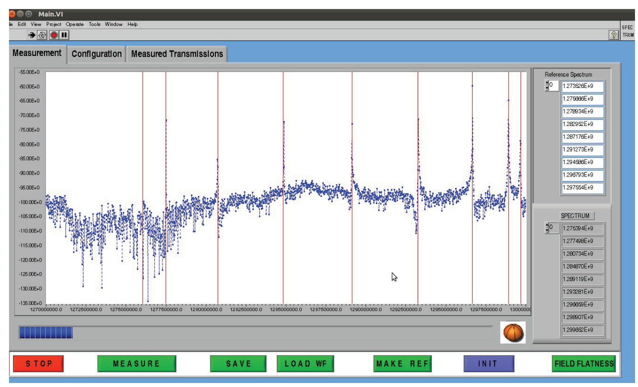

Figure 1: Fundamental mode spectra measurement application.

In addition TM011, TE111, TM110 modes through Higher Order Mode couplers are measured (See Fig. 2) [2]. After those measurements tuner test was performed. Cavities pi-mode frequency was measured after moving the step motor by a fixed number of steps. This gave us information about the relation of frequency change and tuner steps and let us estimate number of steps to tune the cavity to the operating frequency.

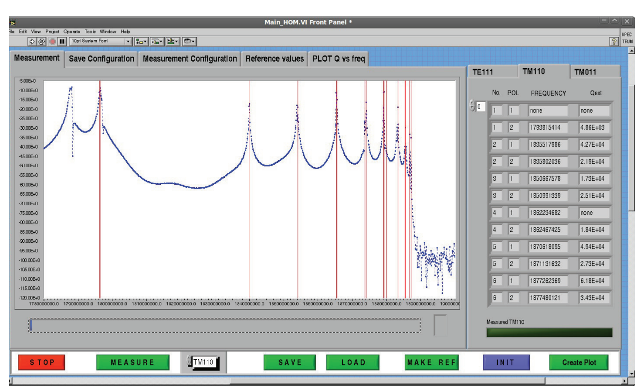

Figure 2: HOM spectra measurement application.

Cryomodule Calibration

To be able to take calibration point for each of the cavities in the cryomodule a few power measurements are required. Data from power meters are taken to calculate accelerating field in the cavities. To measure RF power as accurate as possible measurement of the RF cables attenuation is needed. Two groups of RF cables need to be measured: “warm cables” are cables between patch panels and so-called A flanges of the module, “cold cables” are located inside of the module in the insulating vacuum and are going through thermal shields. Those cables are cooled down very slowly and their attenuation changes with temperature. Therefore it is necessary to wait several hours to reach thermal equilibrium of the “cold cables”. Measured attenuation values are used to calibrate the cryomodule.

After setting interlock and turning on the klystron cavities are fine-tuned to the resonant frequency. Step motor values are saved as a reference for future accelerator operation. The electric field in the cavities is raised to roughly 5 MV/m to proceed with the calibration. During this step we measure a number of parameters: $Q_{external}$, K_t, Q_{trans}, Q_{HOM1}, Q_{HOM2}. Results of the calibration are shown on Fig. 3.

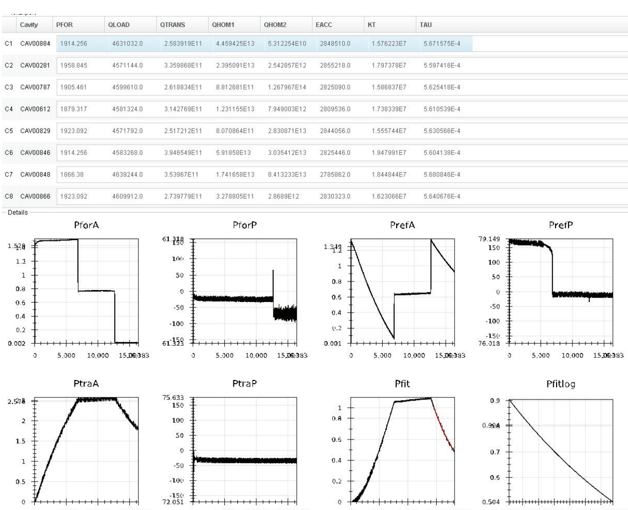

Figure 3: Cryomodule calibration results.

Single Cavity Measurement

During so-called "Flat - top" measurement an estimation of the maximum electric field in a certain cavity is done. In addition information about X-ray and input power is gathered. This is the critical information to effectively plan and assemble the accelerator. The amount of time needed for this measurement is heavily dependent on the cavity performance: better performance means less time is needed for processing and testing. For each of the cavities in the cryomodule this measurement is done individually. This means that only one cavity is on resonance at the same time. To cross check the results at least two measurements are done for each cavity. If it is required first measurement is done with processing. Application used to perform this measurement (See Fig. 4) collects all important parameters such as: accelerating field, input power, power measured on all antennas, radiation, cryogenic and vacuum parameters.

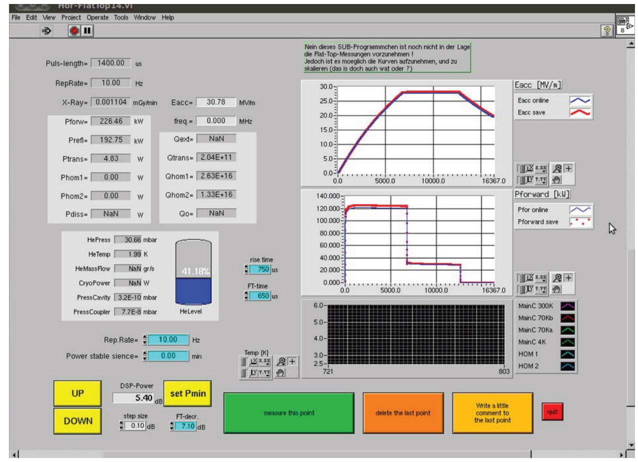

Figure 4: Flat - top application.

LLRF Test

Those tests are measuring the cavity response in relation to input signal, piezo and tuner parameters. More about this test can be found in [3].

Heat Loads at 2K Circuit

To estimate required cryogenic supply thermal load measurement is done. To measure loads on 2K circuit the supply of liquid helium is closed and the module is working at the operating electric field. Evaporation rate of helium is used to estimate future cryogenic supply required in the accelerator. In addition the cryogenic losses at 2K circuit are used to calculate the cryomodule quality factor. In this measurements all cavities are on resonance at the same time.

Heat Loads on the Shields

Cryogenic losses on 2K circuit is not the only factor that contributes to cryogenic requirements. The other are losses on 4/8K and 40/80K circuits. To measure those losses module was working at the operating gradient for 12 hours to reach thermal equilibrium state at the thermal shields.

Old Procedure Measurement Duration

To perform all of the measurement mentioned around 5 working days were needed. Moreover, to be able to limit testing time the cool down to 2K and the warm up to room temperature were usually done over the weekends. Cold measurements of one cryomodule, used to take one week. Detailed plan of those measurements is shown on Fig. 5.

NEW TEST PROCEDURE

Low Power Measurements

In the new test procedure we are still measuring fundamental mode spectra. However, HOM spectra are now measured

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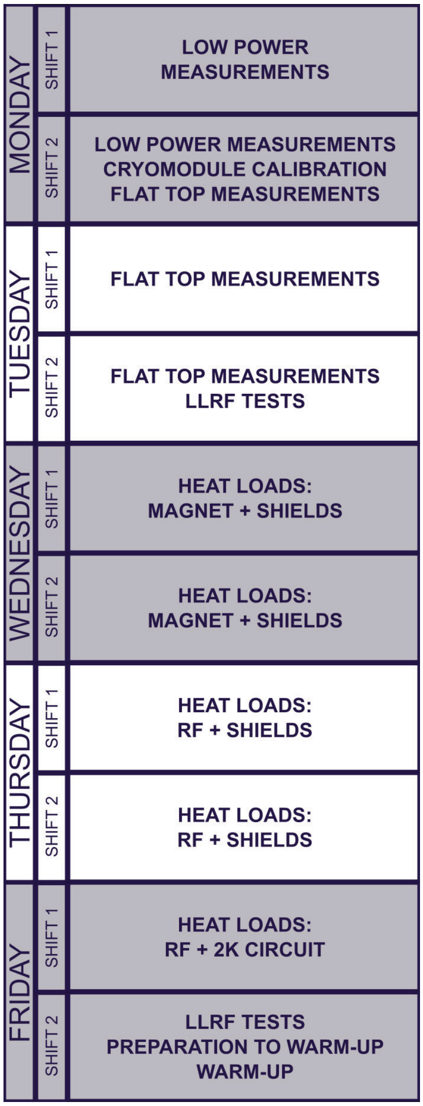

Figure 5: Overview of old test.

in the vertical cryostat, before installation in the module. Moving this measurement to vertical cryostat, which have higher throughput than module test stands, helps us achieve overall improvement in terms of testing time. The results from HOM spectra measurements do not change between vertical test of single cavity and measurement inside the cryomodule. After measuring fundamental mode spectra cavities are tuned to the resonant frequency. The test of the tuner motors have been skipped at cryogenic conditions. The ability to tune the cavity to the resonant frequency proves correct tuner operation.

First Flat - Top Run

The factor that significantly slowed us during module test was waiting period to let the "cold cables" reach thermal equilibrium. Due to the fact that lengths of the cables in all XFEL modules are the same we prepared an averaged cable attenuation values for cavities at each position. It's distribution is gaussian and the deviation contributes to just 0.3 % of total teststand attenuation. Therefore the first flat top run is done with averaged cable attenuation calculated from previous measurements.

Cold Cable Calibration and Cryomodule Calibration

After around 8 hours cold cables are reaching thermal equilibrium. Teststand is opened and "cold cable" attenuation is measured for 8 probe cables (instead of 24 cables in the old procedure). Cold cables attenuation for HOM antennas are needed only to calculate quality factor of the HOM rejection filter at 1.3 GHz. The order of magnitude is a sufficient information for this measurement. Therefore small differences of the attenuation of those cables are irrelevant. For the cryomodule calibration in the new testing procedure averaged attenuation values of HOM cables and measured probes attenuation values are used.

Second - Flat - Top Run

During first run cavities are especially prone to change of behavior due to radiation, processing etc. Second confirmation curve is done after the probe calibration. It is used as the confirmation of the measurement validity.

LLRF Tests

Most of the LLRF tests remains unchanged. There are two notable improvements. One is a change in Tuner Motor Scan measurement. It required particularly long time due to a number of measurement points. Tuner motors are in the insulation vacuum and are prone to overheating. Reducing the number of points helps to avoid this problem and the measurement is done now two times faster. The second improvement is combining closed loop test with heat loads measurement.

Heat Loads at 2K Circuit and Close Loop Operation

The important factor contributing to the precision of this measurement is the stability of RF power fed into the cavity. Therefore in the improved procedure we moved the closed loop test to be done during heat loads at 2K circuit. Such change makes the RF power level more stable and as a result the evaporation rate of helium in also more stable. The measurement is done as long as the helium level inside of the cryomodule is above required level. This let us roughly estimate thermal loads on the inner (4/8K) thermal shield as well.

New Test Procedure Duration

As mentioned above Flat - top duration depends on the individual cavities performance, especially on the processing. In the new testing procedure single cavities measurement takes around 50% of the test time. There are two main plans of the new test. When cavities do not require prolonged conditioning it is possible to perform whole 2K measurements of the cryomodule in 2.5 working days (See Fig. 6).

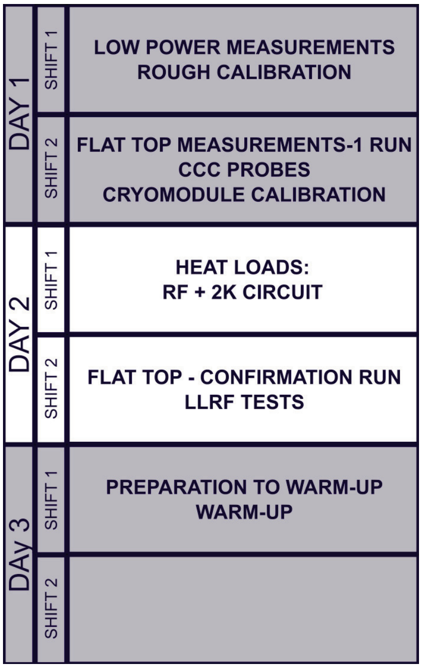

Figure 6: Overview of new test (no conditioning required).

If cavities need more time for conditioning full cryomodule test at 2K takes around 3 days. This scenario is shown on Fig. 7.

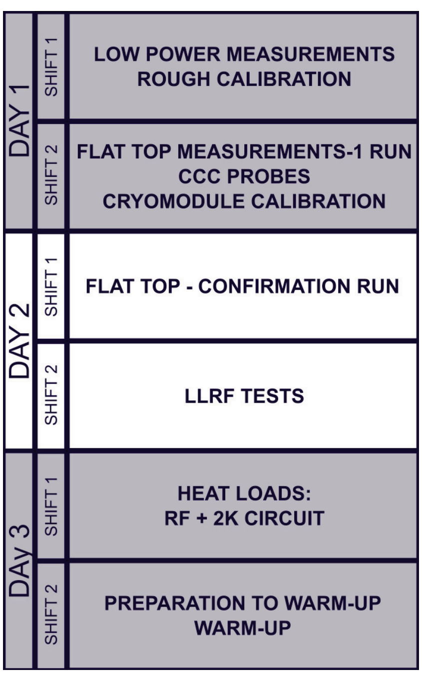

Figure 7: Overview of new test (conditioning required).

OTHER IMPORTANT IMPROVEMENTS

Cavity Tuner Application

To be able to perform Flat - top measurement cavity have to be in resonance. Dedicated application was developed for this purpose (See Fig. 8). This application allows to drive any of 8 cavities tuners at once and observe the response from the cavities. In addition there is an option of automatic tuning based on the calculated static cavity detuning. Application is very useful at lower gradient (below 17 MV/m).

Figure 8: Cavities tuning software for low gradients.

Cavity Fast Automatic Tuner with Piezo Support

When the accelerating field in the cavity exceeds level of 17 MV/m piezos are activated and LFDC (Lorentz Force Detuning Compensation) adjustment software is used [4]. It automatically alters the step motor tuner and four piezo parameters: frequency, delay, DC Voltage and AC Voltage, based on the cavity static and dynamic detuning. It assures that the cavity is constantly tuned as accurate as possible, even at a high level of accelerating field. (Fig. 9)

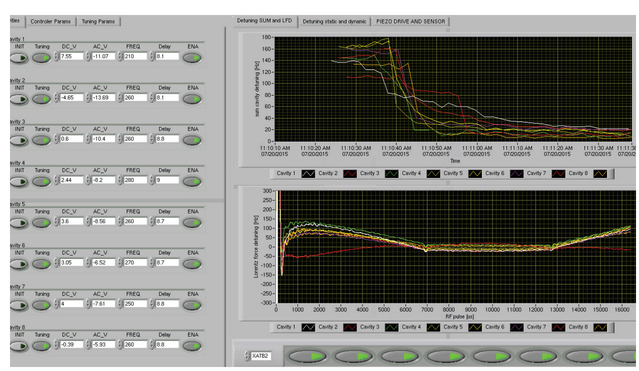

Figure 9: Cavities tuning software for high gradients.

Special Panel for Operator

During all high power measurements RF operator has to observe a lot of parameters, which influences the process of the test. The dedicated panel (See Fig. 10), which merges all important vacuum, cryogenic, temperature, interlock, power

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meters, timing and cavities behavior, has been developed. Its upper part consists of two charts with six similar tabs each. They allow the operator to choose two most important plots at any given time. Below the operator can observe probe phase and amplitude, interlock status and LLRF parameters.

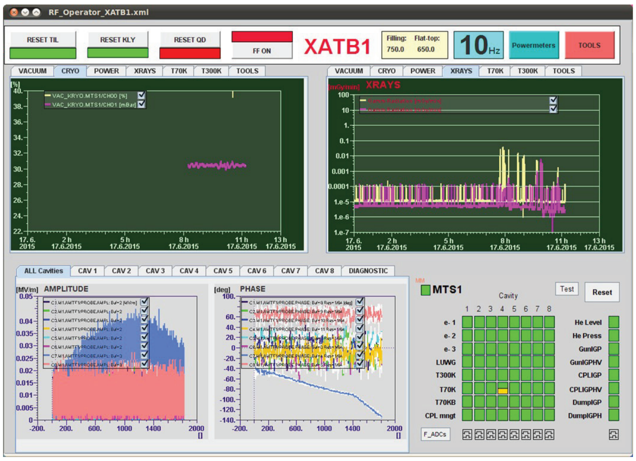

Figure 10: Dedicated operator panel with all important parameters.

CONCLUSION

The most time consuming steps during the old test procedure were: HOM spectra, reaching thermal equilibrium of "cold cables" and long heat loads on shields. New test procedure shortens time of test nearly by a factor of two. By changing the order of steps and optimizing the way measurements are done we limit the impact those activities have on the test while still measuring most important module parameters. The time needed for measurement at 2K has been gradually reduced since the beginning of the serial test at AMTF Hall (See Fig. 11) by applying some of those improvements and testing their impact on the test duration.

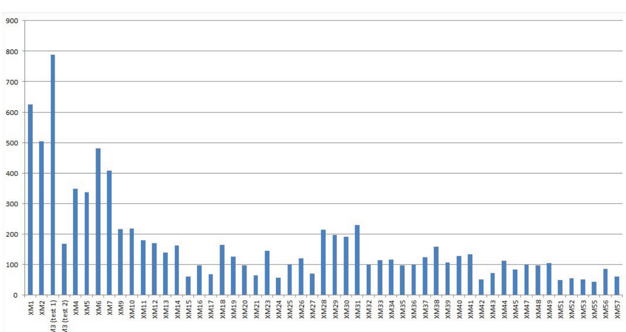

Figure 11: Time in hours at 2K (Y-axis) for each of the cryomodule already tested.

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