ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPMN031

AUTOMATED QUENCH LIMIT TEST PROCEDURE FOR SERIAL PRODUCTION OF XFEL RF CAVITIES

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Abstract

In the Accelerator Module Test Facility (AMTF) at DESY in Hamburg RF cavities and accelerating cryomodules are tested for the European X-ray Free Electron Laser (XFEL). Measurements are done by team of physicists, engineers and technicians from The Henryk Niewodniczanski Institute of Nuclear Physics Polish Academy of Sciences in Krakow, Poland, as a part of Polish in-kind contribution to XFEL. The testing procedures providing information about maximum available gradient and heat loads measurement are performed for the high gradients (up to 31MV/m). During these tests the cavity deformation caused by the Lorentz force is compensated by piezo (fast) tuners. For this purpose automated high level software was developed. This paper describes a method used to tune automatically the cavities during the RF tests. It was validated with the XFEL cryomodules. This improvement was implemented into the testing software and it is successfully used for testing of serial production cavities.

INTRODUCTION

In the Accelerator Module Test Facility (AMTF) at DESY in Hamburg serial-production accelerating cryomodules for the European X-ray Free Electron Laser (XFEL) are tested. Currently (status 28 April 2015) 28 out of 101 modules have been tested. The two vital acceptance measurements for them are called: flat top and heat loads [1, 2].

From RF point of view, during these measurements, it is critical to automatically regulate RF fields inside the cavities. It is essential for the time schedule as well as for the precision of the measurement. This is done by the high level feedback controller that regulates step (slow) motor and piezo actuators. The software is written in LabVIEW (see Fig. 1) . It was validated and successfully used for cryomodules testing.

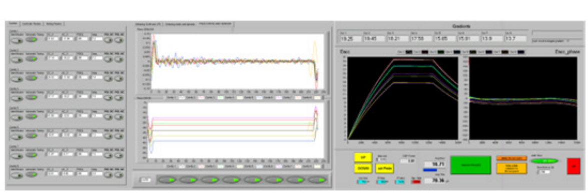

Figure 1: The controller software (left) and test software (right) during the heat loads measurement of the cryomodule XM33.

TESTING PROCEDURE

Flat Top Measurement

The aim of the flat top measurement is to obtain the following cavity parameters:

a) gradient when field emission is started – is visible on the X-ray detectors
b) (if possible) gradient when radiation starts exceeding 10^{-2} mGy/min
c) the maximum gradient (0.5 MV/m less than the quench, measured up to 31 MV/m)
d) power measured for the maximum gradient

31 MV/m is the gradient equivalent to maximum power for the single cavity, which will be available in the XFEL tunnel with respect to the planned klystron power (10 MW), losses in the waveguide system and power distribution. Single klystron will supply 4 cryomodules (in sum 32 cavities).

Also during this measurement the operating gradient is obtained as the minimum value from:

a) gradient when radiation starts exceeding 10^{-2} mGy/min
b) the maximum gradient
c) gradient when temperature measured on the input power coupler rises rapidly
d) gradient when input power coupler vacuum rises rapidly

Heat Loads Measurement

The aim of the heat loads measurement is to evaluate thermal loads during normal XFEL cryomodule operation. From the RF point of view, this procedure is done by changing power distribution in the waveguides. Values saved during flat top measurement are used as reference. As a result the cavities gradients used during heat loads measurement are limited by:

- operating gradient taken from the flat top measurement or
- 23.6 MV/m (XFEL goal gradient)

Furthermore, the waveguide power distribution during the AMTF measurements is paired, which means that the same power is set to the neighboring cavities. This determines the chosen gradient as the weakest from the cavity pair (1-2, 3-4, 5-6, 7-8).

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AUTOMATED PROCEDURE

Procedure of testing XFEL cavities is automated as follows:

- RF is switched on
- RF Feedforward is switched on
- Cavities are tuned using step motors by operator
- Piezo Enables are switched on
- Feedback in the software is switched on and cavity detuning is decreased during the measurement by automated controller for piezos and the step motor
- Then standard measurement procedure is done as described above, without controlling piezos and step motor parameters by the operator.

CONTROLLER

As noticed, the compensation of the Lorentz force is done by piezo deformation. Previously during the AMTF measurements this was done manually, by changing its parameters: AC voltage, DC voltage, frequency, and delay. When cavity was tuned by the user its static detuning was usually decreased by the step motor, which cause time extension or tuner overheating error by many executed steps. Moreover the piezo parameters were changed roughly without any algorithm. To avoid these issues the novel software was implemented based on well known tuning algorithm used also in FLASH at DESY [3]. Firstly the cavity Lorentz force detuning (LFD) is calculated form the electrical-mechanical model of the cavity and compensation is done by the Proportional-Integral controller. Cavity detuning (1), which is used as the input for the controller, is written in Cartesian coordinates as follows:

$$\Delta\omega = \frac{-\left(\frac{dI_{probe}}{dt} - coeff \cdot I_{for}\right)\cdot Q_{probe} + \left(\frac{dQ_{probe}}{dt} - coeff \cdot Q_{for}\right)\cdot I_{probe}}{I_{probe}\cdot I_{probe} + Q_{probe}\cdot Q_{probe}} \quad (1)$$

Where following parameters are defined as:

- I_{probe}- In-phase component of the Probe signal
- Q_{probe}- Quadrature component of the Probe signal
- I_{for}- In-phase component of the Input (Power forwarded) signal
- Q_{for}- Quadrature component of the input (Power forwarded) signal
- coeff – cavity half bandwidth component

The errors for controllers are divided into two parts: static and dynamic. Both are received from the plot of the LFD calculated during the RF pulse duration. The static detuning is calculated in the middle of the flat-top and the dynamic is calculated as the difference from LFD at the beginning and at the end of the flat-top. The static detuning is compensated mostly by DC voltage. It can also be compensated by the step motor. The dynamic is compensated mostly by AC part.

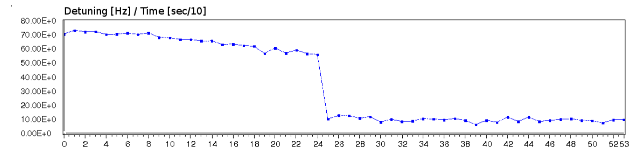

Figure 2: Compensation done by the step motor and the piezo actuator for the cavity 5 in the XM33.

LABVIEW SOFTWARE

The new software has a few improvements. Firstly DC voltage of piezo actuator and step motor tuner are combined together – they do not react at one time. The slow tuner reacts, when static detuning is higher than defined value. Fig.2 shows tuning of the cavity 5 in the XM33. Apart from 2.4 sec, when cavity is tuned by the step motor, piezo DC controls the compensation. Besides in case of any problems LLRF (ex. quench detection) the controller does not react.

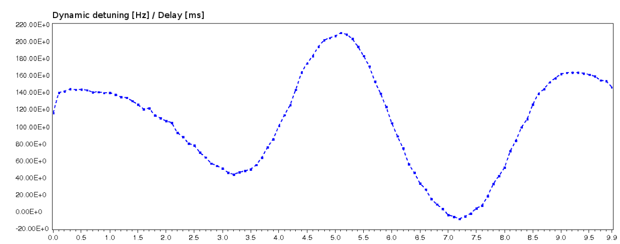

Figure 3: Optimal delay search for the cavity 1 in the XM33.

Moreover the AC and DC voltage signals are limited by the maximum piezo voltage and maximum voltage change per cycle. Furthermore the optimal delay is also determined. At the beginning of the controller operation some AC voltage is given to the actuator. The dynamic detuning scan is performed as a function of delay. The minimum value is stored. See an example (Fig.3), where cavity 1 in the cryomodule XM33 is measured. Here 7.3 ms for delay was chosen. During controller operation delay is not changed anymore.

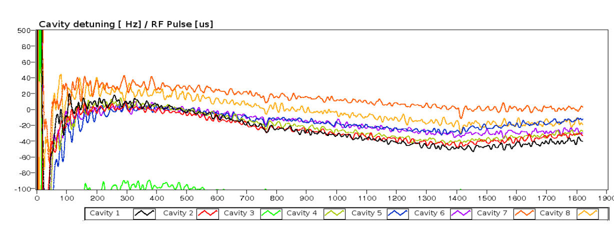

Figure 4: Detuning as a function of time in the RF pulse for all cavities before the 12h measurement of heat loads for XM33.

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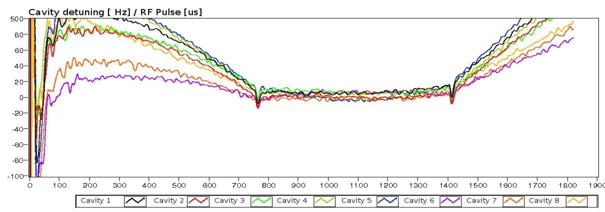

Figure 5: Detuning as a function of time in the RF pulse for all cavities during the 12h measurement of heat loads for XM33.

VALIDATION

Flat Top Measurement

The software was validated successfully for the cryomodule XM33. For the flat top measurement controller satisfactory reacted to the power change. When quench occurred the controller stopped responding to the signal. Also no slow tuner errors occurred.

Heat Loads Measurement

For the heat loads measurement operator did not have to take care about cavity detuning during the measurement. Even if the fluctuating power from the klystron changed cavity detuning, the controller immediately tuned all cavities in parallel (see Fig.4 and Fig.5). In the Fig.6 cavity detuning is shown. During 30 minutes of 2K circuit heat loads controller successfully tuned all cavities. At the first two minutes the power was raised to the desired level.

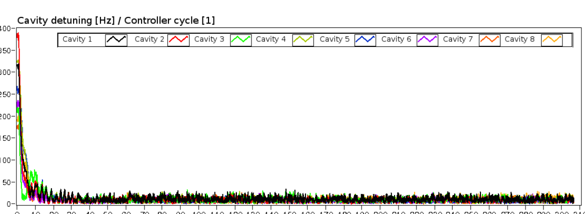

Figure 6: Cavity detuning as a function of controller cycles for all cavities in XM33.

ACNOWLEDGMENT

This work is funded by the Ministry of Science and Higher Education in Poland (MNiSzW) as a part of Polish contribution to the construction of the European XFEL

We acknowledge all the colleagues from the IFJ PAN Krakow, TUL-DMCS and DESY for supporting us at the XFEL project.

CONCLUSIONS

- The new software is a vital improvement for the time schedule as well as for the precision of the measurement
- Software was tested in the AMTF for all cavities in cryomodule XM33 separately and together.

FUTURE PLANS

- Firstly the operator should have a possibility to choose, whether automatic tuning should be done only by the slow tuner. Using piezo actuators below 19 MV/m, where Lorentz force could have been neglected, was unnecessary. Below this gradient for example, the delay scan was not always satisfactory.
- Secondly the only left parameter, which is not changed automatically, is the frequency of the piezo actuators. An algorithm of finding the optimum will be implemented. From the sensor piezo signal FFT will be calculated. The calculated frequency will be used to compensate mechanical resonance. The expected value should range from 200 to 300 Hz.
- Finally the delay scan can be performed for the two opposite values of AC (ex. 10V and -10V). And two results from scans could be averaged. Moreover, the possibility of automatic change of the delay, during controller operation, not only at the beginning, will be added. Change will be possible up to ±0.2 ms.

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