

EUROPEAN XFEL CAVITIES PIEZOELECTRIC TUNERS CONTROL RANGE OPTIMIZATION

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Abstract

The piezo based control of the superconducting cavity tuning has been under the development over last years. Automated compensation of Lorentz force detuning of FLASH [1] and European XFEL [2] resonators allowed to maintain cavities in resonance operation even for high acceleration gradients (in range of 30 MV/m). It should be emphasized that cavity resonance control consists of two independent subsystems. First of all the slow motor tuner based system can be used for slow, wide range mechanical tuning (range of hundreds of kHz). Additionally the piezo tuning system allows for fine, dynamic compensation in a range of 1 kHz. In mentioned pulse mode experiments (like FLASH), the piezo regulation budget should be preserved for in-pulse detuning control. In order to maintain optimal cavity frequency adjustment capabilities slow motor tuners should automatically act on the static detuning component at the same time. This paper presents work concerning development, implementation and evaluation of automatic superconducting cavity frequency control towards piezo range optimization. FLASH and XFEL dedicated cavities tuning control experiences are also summarized.

INTRODUCTION

Both FLASH and European XFEL are free electron lasers facilities that build up accelerated beam energy using superconducting linacs. Superconducting cavities are or will be operated in pulse mode with 10 Hz repetition range and field gradients up to 30 MV/m. This work conditions causes extensive Lorentz force based reaction on the structure walls [3]. This cause mechanical deformation in range of few micrometers. For around 1 meter long, 1,3GHz resonant frequency, niobium resonator such a length change induces dynamic detuning modification in the range of couple hundreds of hertz. As cavities loaded quality factor is high (range from $3e6$ for FLASH to $4.6e6$ for XFEL) such misalignment results in significant accelerating field gradient drop. This have to be compensated by increase of supplying RF power - in order to maintain constant beam energy level. The other possibility to minimize this effect is external mechanical excitation provided by slow (step motors) and fast (piezo elements) cavity tuners.

MOTIVATION

Since fast tuners are foreseen for precise, in-pulse reaction to cavity dimension deviation their parameters have to be well recognized and adequately used.

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Cavity Tuning Components Characterization

The European XFEL linac installation preparation includes also cryo-module testing phase [4]. Among the others also piezoelectric components are being characterized. One of test goal is to determine coefficient that describes relationship between piezo supply voltage and superconducting resonator frequency shift. The same study allows to verify both piezo elements (actuator and sensor) tuning range and voltage polarity (see Figure 1). Other (LLRF related) test

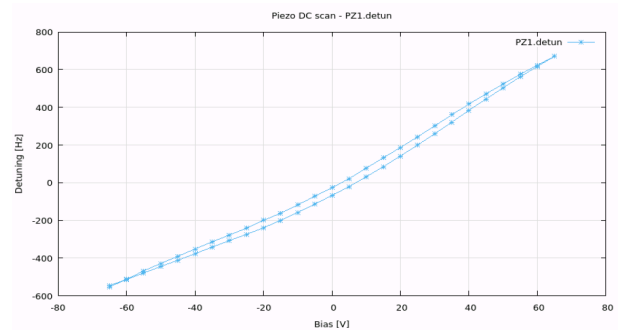


Figure 1: Piezo element tuning range characterization example (XFEL module XM51, cavity 3).

is dedicated to cavity slow motor tuners examination. This devices tuning range is not being verified (about hundreds of kHz). The cavity detuning in function of the motor position change is determined in order to evaluate transfer coefficient (like in previous test). Moreover motor backlash and movement hysteresis is determined. Exemplary measurement results can be found in Figure 2. All measurements results

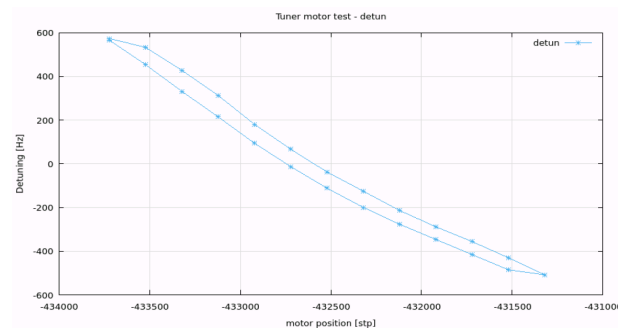


Figure 2: Slow tuner motor behavior characterization (XFEL module XM51, cavity 3).

are stored in dedicated (PostgreSQL [5] based) database. This data will be used during the XFEL linac commissioning for optimal LLRF system configuration. Additionally this information is also vital for described piezo relaxation algorithm configuration.

Detuning Caused by LFD

Superconducting niobium cavity mechanical deformation can be caused (among the others) by high Lorentz force (LFD) acting on the resonator walls in presence of high accelerating field. In case of short pulse operation of TESLA based structures detuning caused by this phenomenon is often described by linear detuning change during RF pulse flat-top phase. Dependency between cavity field gradient and linear detuning is determined also in the scope of modules characterization (see Figure 3). As it is known the LFD

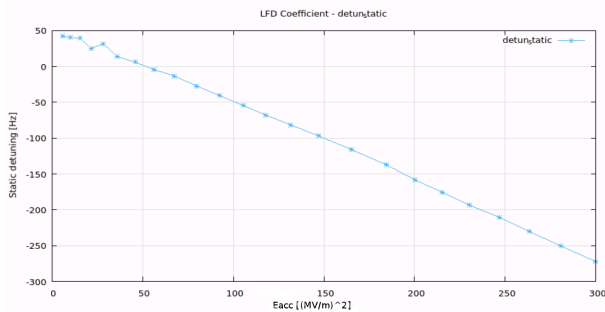


Figure 3: Static detuning change measured in function of cavity gradient.

is proportional to square of cavity gradient. The proportionality coefficient is determined during this tests. Typically this parameter has value in the range of $-(0.8-0.9)$.

Resonators Tuning Approaches

The cavity detuning is being controlled during RF pulse operation in order to minimize system power consumption. In case of resonator misalignment the accelerating field gradient loss is compensated by the RF power increase. The motor tuner can provide wide range of tuning while its reaction is a time consuming. That is why it can be used for static superconducting structure tuning. The piezo elements provide fast mechanical response (reaction time within RF pulse duration). On the other hand its range is often limited (typically around 1,2kHz). This system can be used both for static and dynamic tuning. Since LFD increases rapidly with accelerating gradient it is highly desired to preserve piezo system frequency shift capabilities to compensate for in-pulse detuning. LFD influence on the cavity operation is minimized by means of piezo components excitation that counteracts resonator dimension change in presence of high accelerating field. In this compensation approach the DC component of piezo voltage excitation is being used for static tuning while AC excitation (sin waveform shape) is used for dynamic misalignment handling. Piezo operation has been automated (for FLASH and AMTF facilities). The algorithm provides both static and dynamic frequency shift reduction

PIEZO RANGE OPTIMIZATION ALGORITHM

The piezo relaxation algorithm main goal is to minimize tuner driver DC stimulus to provide full voltage range for

AC signals (to maximize linear tuning boundaries). This requirement can be fulfilled by combined piezo and motor actions. Main idea of this application has been presented in Figure 4.

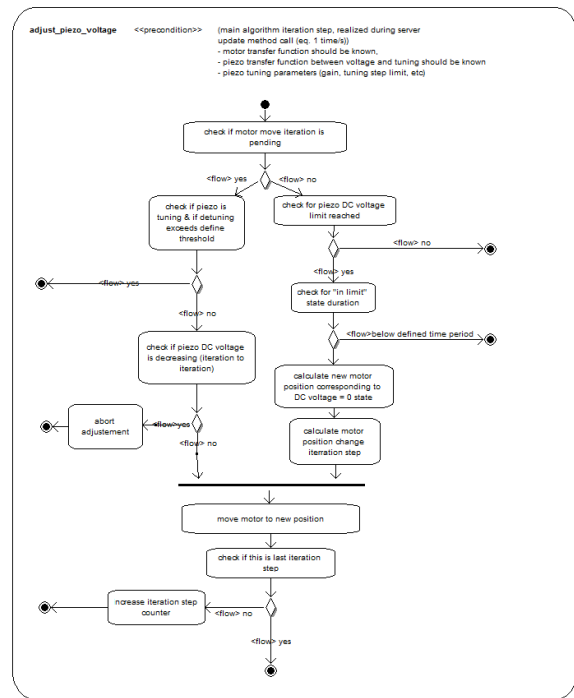


Figure 4: Piezo dynamical range optimization algorithm overview.

In the scope of this application DC voltage level is monitored. In case its value exceeds predefined threshold (near to the driver saturation) required cavity frequency correction is evaluated. Then the motor adequate position change is determined. New slow tuner settings are calculated according to the piezo tuning resolution and motor steps to cavity frequency modification factor (evaluated during module examination). Overall position change is then divided to several steps iterations. Individual iteration size is determined taking into account piezo automation algorithm ability of resonator tuning. One of the application requirement defines maximal deviation from resonance which is acceptable during relaxation actions. Constant monitoring of cavity behaviour allows for algorithm adjustment or termination in case of operation conditions change or exception occurrence. Application concludes after last iteration step execution. Afterwards system continues piezo operation status monitoring and performs range optimization as soon as DC voltage threshold is being exceeded.

ALGORITHM IMPLEMENTATION

The piezo range optimization algorithm has been developed and implemented as DOOCS server [6]. Application has been realized basing on the DOOCS framework. Piezo and motor operations are relatively slow process in comparison to fast LLRF feedback loop. That is why the server

has been prepared as a middle layer process. The server communicates with the LLRF diagnostics server in order to receive cavity detuning calculations readout (see Figure 5). Additionally it connects to the LLRF controller server that provides information about current piezo components drive settings. Since slow motor tuner acts as an actuator in this slow feedback loop also communication with motor management server is provided.

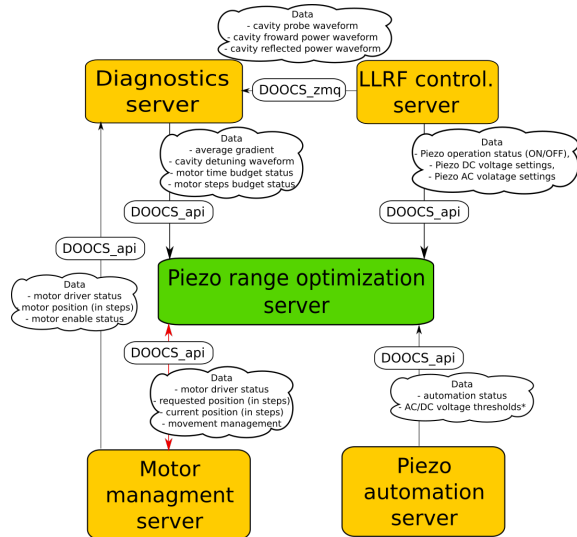


Figure 5: Server interconnections overview.

Server parameters configuration and management has to be performed by RF system users. In order to facilitate server management dedicated GUI (based on JDDD [7]) has been provided (see Figure 6).

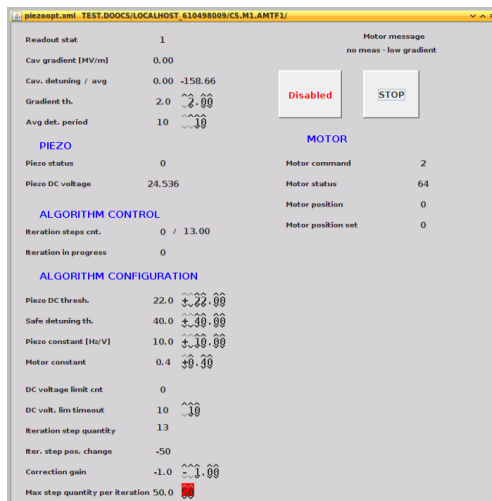


Figure 6: Example of expert GUI.

INITIAL ALGORITHM EVALUATION

Algorithm has been evaluated in the accelerator environment. The FLASH facility is not only FEL research centre but it is also commonly treated as a pilot project to XFEL.

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That is why it has been perfect place to conduct study concerning future operation automation software component. First test have been performed for single cavity in accelerating module (ACC3). Initially (before algorithm execution) this resonator has been tuned and operated with gradient of 22 MV/m. The piezo automatic tuning algorithm have had been enabled to maintain resonance conditions. Test began with motor tuner position change which corresponded to 300Hz cavity frequency shift. As automatic tuning process caused piezo driver DC voltage increase and threshold violation the algorithm started motor readjustment. In case of FLASH and AMTF study it was observed that application moved step motor to the position corresponding to minimal DC voltage settings. At the same time boundary detuning deviation (configured by user) had been not violated. At the time of tests the algorithm has been extended by some exception handling mechanisms. The most important were:

- range optimization temporary blocking due to the motor steps budget defined for specific period of time,
- range optimization temporary blocking due to the motor operation time budget defined for specific period of time,

AMTF hosts temporally all cryomodules dedicated for XFEL for components examination. That is why piezo range optimization is integrated with the LLRF systems operating in this facility. Scenario of constant cavities gradient increase (during the quench level studies) is the best candidate for piezo range optimization algorithm usage.

CONCLUSION

Piezo based cavity tuning system is widely used during operation of TESLA cavities in high gradient conditions. Tuner range optimization for Lorentz force detuning suppression is a must in case of variable energy settings for the linac. Presented algorithm optimizes fast tuners dynamic range by means of slow motor system readjustment. Cavities characterization provide necessary data for best application configuration. Initial tests performed in accelerator environment proofs algorithm usefulness. That is why the decision has been taken concerning application integration in overall software framework for automatic tuners systems operation.

REFERENCES

- [1] Official Free Electron Laser in Hamburg website: <http://flash.desy.de>
- [2] Official European X-ray Free Electron Laser website: <http://www.xfel.eu>
- [3] T. Schilcher, *Vector Sum Control of Pulsed Accelerating Fields in Lorentz Force Detuned Superconducting Cavities*, (Hamburg: Universitat Hamburg, PhD thesis, 1998).
- [4] J. Branlard, V. Ayvazyan, M. Grecki, H. Schlarb, C. Schmidt, W. Cichalewski, K. Gnizinska, A. Piotrowski, K. Przygoda, W. Jalmuzna, "LLRF tests of XFEL cryomodules at AMTF: first experimental results", THP087, SRF2013, Paris, France (2013).

- [5] PostgreSQL website: <https://www.postgresql.org/>
- [6] Distributed Object Oriented Control System (DOOCS) website: <http://doocs.desy.de/>
- [7] Java DOOCS Data Display website: <http://jddd.desy.de/>