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 and European XFEL 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.

Motivation

Resonators tuning approaches

Slow motor tuner:
- provide wide range of tuning
- reaction is a time consuming
- suitable for static tuning

Piezo tuner:
- limited range (1,2 kHz)
- fast reaction
- suitable for dynamic and static tuning

Lorentz Force Detuning (LFD) increases rapidly with accelerating gradient. It is desired to compensate for in-pulse detuning.

Piezo operation:
- DC voltage - static detuning regulation,
- AC voltage - dynamic detuning regulation

Cavity tuning components characterization

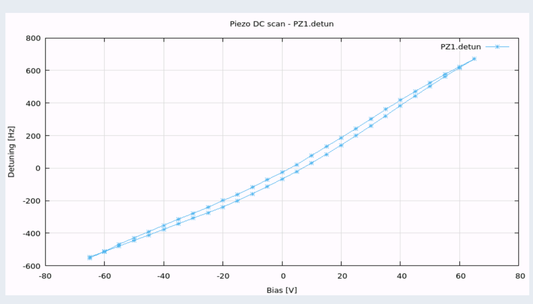

Figure 1: Piezo tuning range characterization

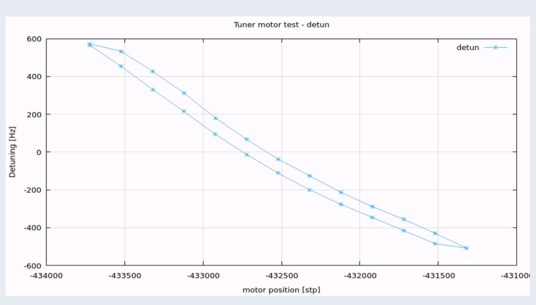

Figure 2: Slow tuner motor behavior characterization

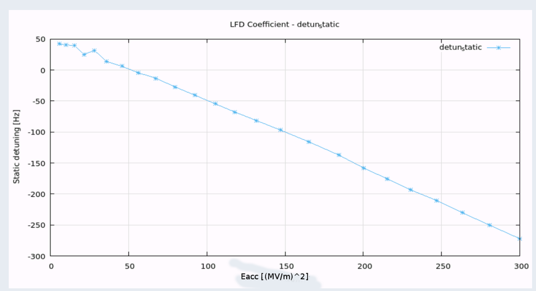

Figure 3: Static detuning change vs. cavity gradient

Piezo range optimization algorithm

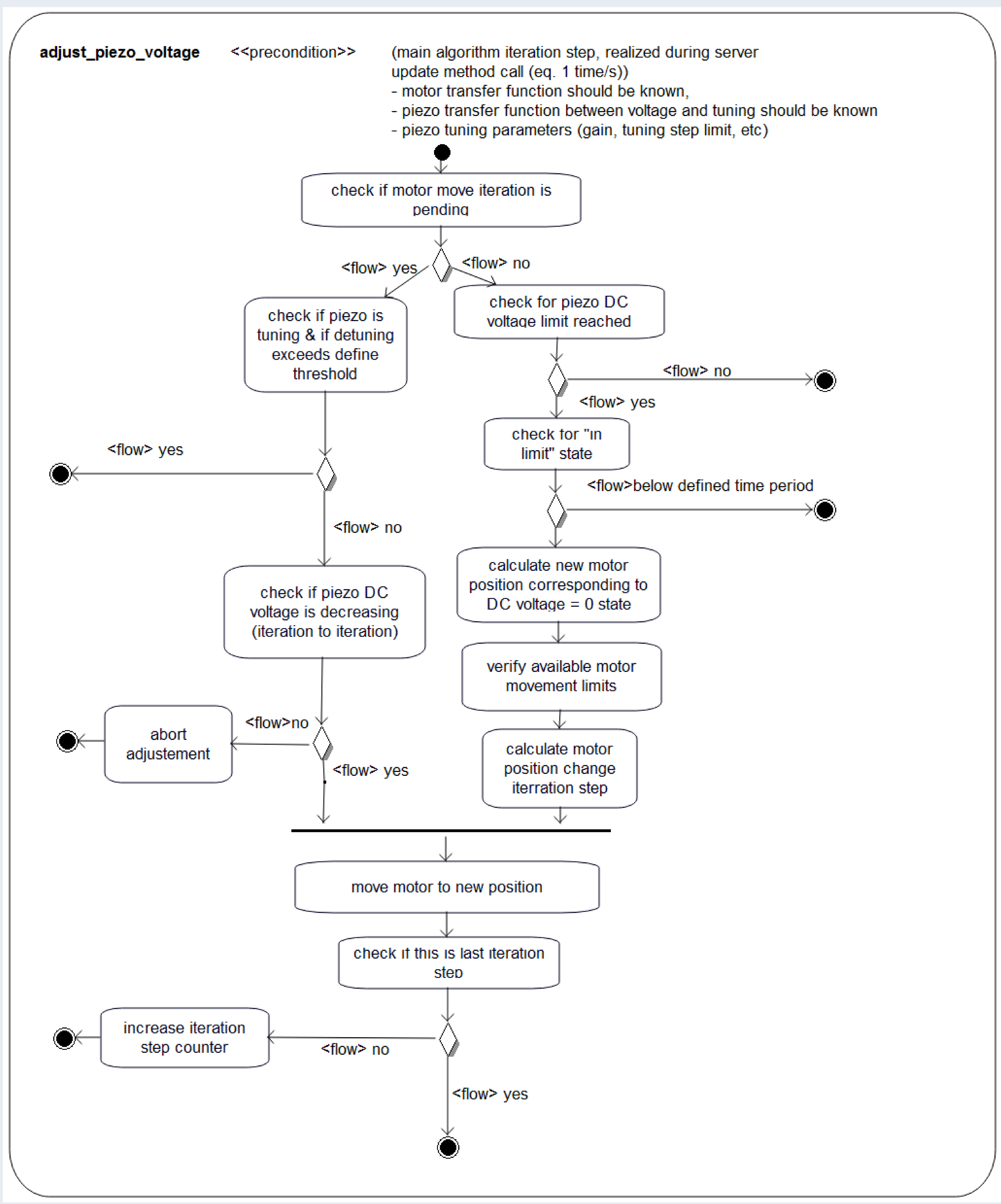

Figure 4: Piezo dynamical range optimization algorihtm overview

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. 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.

Algorithm implementation

The piezo range optimization algorithm has been developed and implemented as DOOCS server. 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. Additionally it connects to the LLRF controller server that provides information about current piezo components drive settings. Since slow motor tuner acts as a actuator in this slow feedback loop also communication with motor management server is provided.

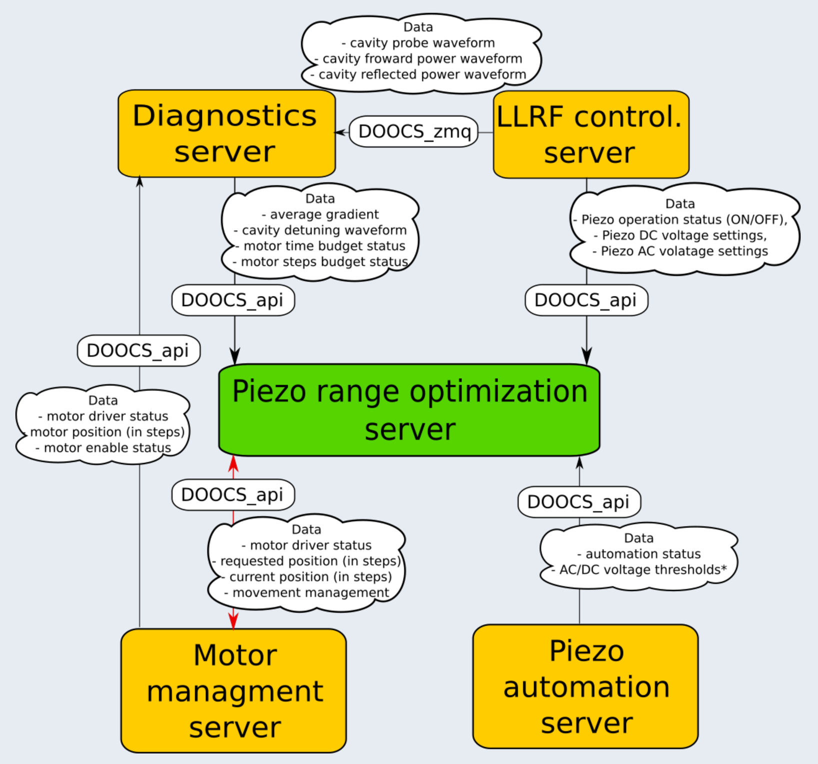

Figure 5: Piezo tuning range characterization

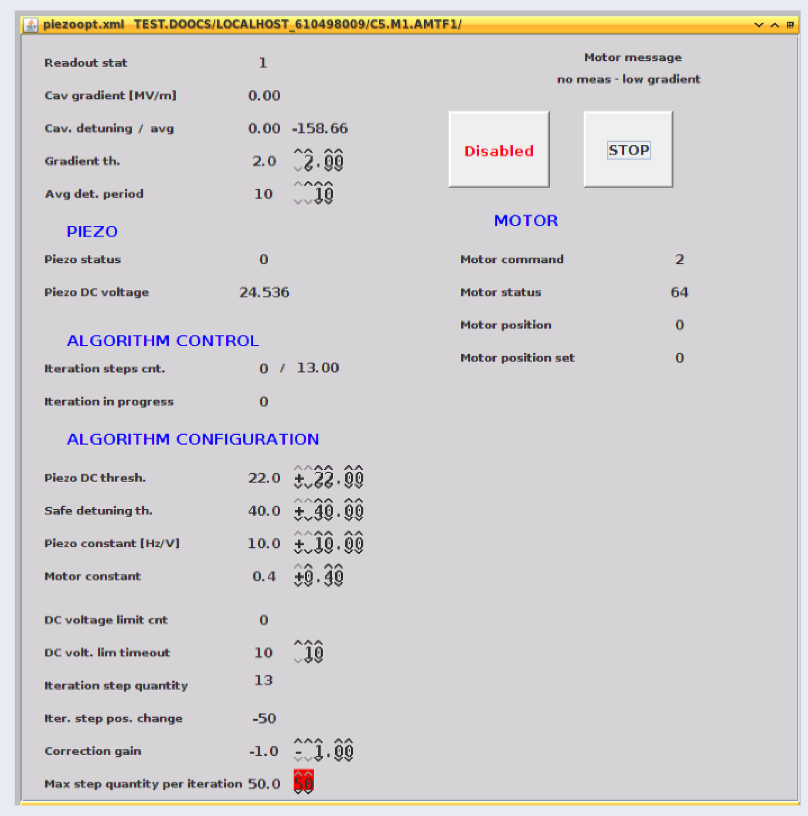

Figure 6: Expert GUI example

Initial algorithm evaluation

Algorithm tests environment:
- FLASH facility (ACC3)
- AMTF (XFEL Accelerator Module Test Facility)

Test conditions
- single cavity piezo range optimization,
- cavity in resonance (operating gradient of 22 MV/m, in resonance thanks to piezo automation process),

Test scenario
- cavity detuning by motor position change (static detuning of 300-400 Hz),
- cavity frequency regulation by piezo automation feedback,
- optimization algorithm start-up,
- evaluation of algorithm performance

Outcome
- application moved step motor to the position corresponding to minimal DC voltage settings,
- acceptable detuning deviation (configured by user) - not violated.

The algorithm has been extended by exception handling mechanisms:
- 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,

Conclusions

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.