## 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.

## 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 wide range tuning regime under high accelerating 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 cavity detuning by piezo automation feedback, cavity detuning by motor position change (static detuning of 300-400 Hz), cavity in resonance (operating gradient of 22 MV/m, in resonance thanks to piezo compensation for in-pulse detuning).

## 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.

## Cavity tuning components characterization

![Figure 1: Piezo tuning range characterization](image1)

![Figure 2: Slow tuner motor behavior characterization](image2)

![Figure 3: Static detuning change vs. cavity gradient](image3)

## Piezo range optimization algorithm

### 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 last tuners dynamic range by means of slow motor system readjustment. Cavity 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.