Narrow bandwidth Active Noise Control for microphonics rejection in superconducting cavities at LCLS-II*

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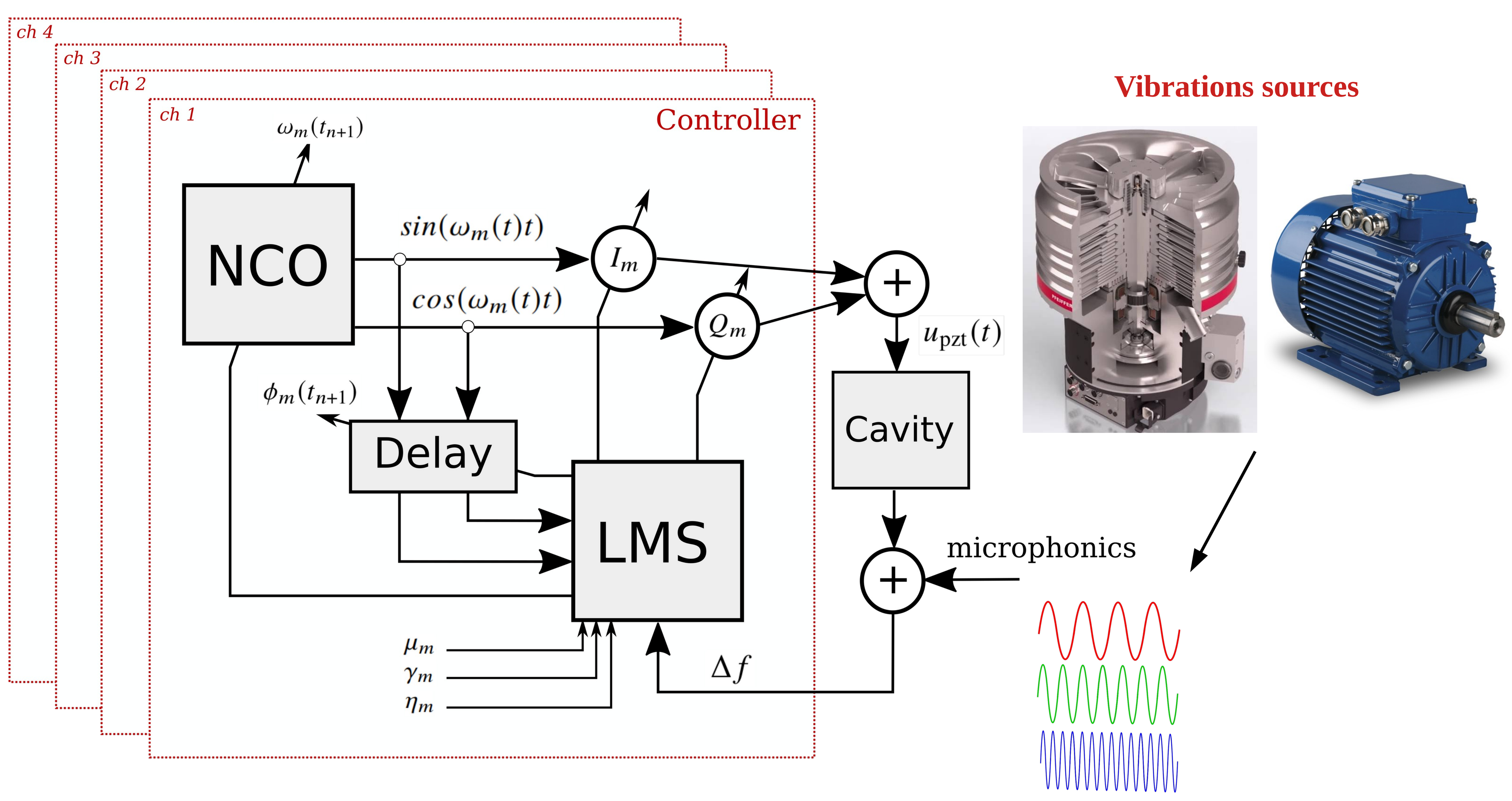
ABSTRACT

LCLS-II is an X-Ray Free Electron Laser (XFEL) commissioned in 2022, being the first Continuous Wave (CW) hard XFEL in the world to come into operation. To accelerate the electron beam to an energy of 4 GeV, 280 TESLA type superconducting RF (SRF) cavities are used. A loaded quality factor (QL) of 4×10^7 is used to drive the cavities at a power level of a few kilowatts. For this, the RF cavity bandwidth is 32 Hz. Therefore, keeping the cavity resonance frequency within such bandwidth is imperative to avoid a significant increase in the required drive power. In superconducting accelerators, resonance frequency variations are produced by mechanical microphonic vibrations of the cavities. One source of microphonic noise is rotary machinery such as vacuum pumps or HVAC equipment. A possible method to reject these disturbances is to use **Narrowband Active Noise Control (NANC)**[1] techniques. These techniques were already tested at **DESY/CMTB** and **Cornell/CBETA** [2]. This proceeding presents the implementation of a NANC controller adapted to the **LCLS-II Low Level RF (LLRF)** control system. Tests showing the rejection of microphonics disturbances are also presented.

INTRODUCTION

- Superconducting RF (SRF) cavities can withstand acceleration voltages in the order of tens of MV with duty factors between 1-100%. Consequently, the efficiency in accelerating the beam is essential to lower the RF costs of an SRF LINAC.
- To operate LCLS-II efficiently, the RF cavity detuning should not be greater than +/- 10 Hz with respect to the nominal resonant frequency.
- Since external microphonic disturbances can drive the detuning outside the specifications, Active Noise Control (ANC) techniques using piezoelectric cavity tuners are required.

NANC WORKING PRINCIPLE



- Most of the external microphonic **disturbances are generated by rotary machinery.** Therefore they can be described by a superposition of sinusoidal signals of unknown phase and amplitude.
- The **NANC** uses a **Numerically Controlled Oscillator (NCO)** to generate a sinusoidal signal. This signal is then modulated by an I&Q vector. The resulting value drives the piezoelectric actuator.
- To match the detuning disturbance, a **Least Mean Square (LMS)** algorithm using **Stochastic Gradient Descent (SGD)** adapts the I&Q. To estimate the I&Q correctly, the actuator delay has to be calculated as well.
- In this work, we improved the NANC algorithm by adding a ***frequency adaptation of the NCO***. This feature is beneficial to accurately track frequency shifts of the detuning disturbance in time and **maintain the maximum rejection of the microphonic noise**.

I&Q ADAPTATION

$$I_m(t_{n+1}) = I_m(t_n) - \mu_m \Delta f(t_n) \times cos(\omega_m(t)t_n - \phi_m(t_n))$$

$$Q_m(t_{n+1}) = Q_m(t_n) - \mu_m \Delta f(t_n) \times sin(\omega_m(t)t_n - \phi_m(t_n))$$

μ_m : I&Q adaptation rate

η_m : delay adaptation rate

γ_m : frequency adaptation rate

CHAIN DELAY ADAPTATION

$$\phi_m(t_{n+1}) = \phi_m(t_n) - \eta_m \Delta f(t_n) \times \{I_m(t_n)\sin(\omega_m(t)t_n - \phi_m(t_n)) - Q_m(t_n)\cos(\omega_m(t)t_n - \phi_m(t_n))\}$$

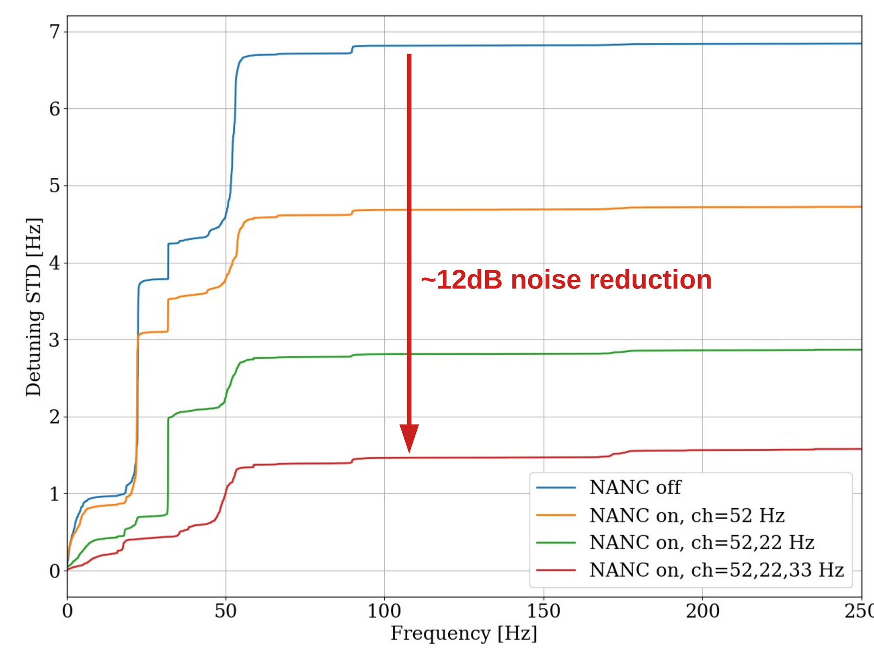
FREQUENCY ADAPTATION (NEW!)

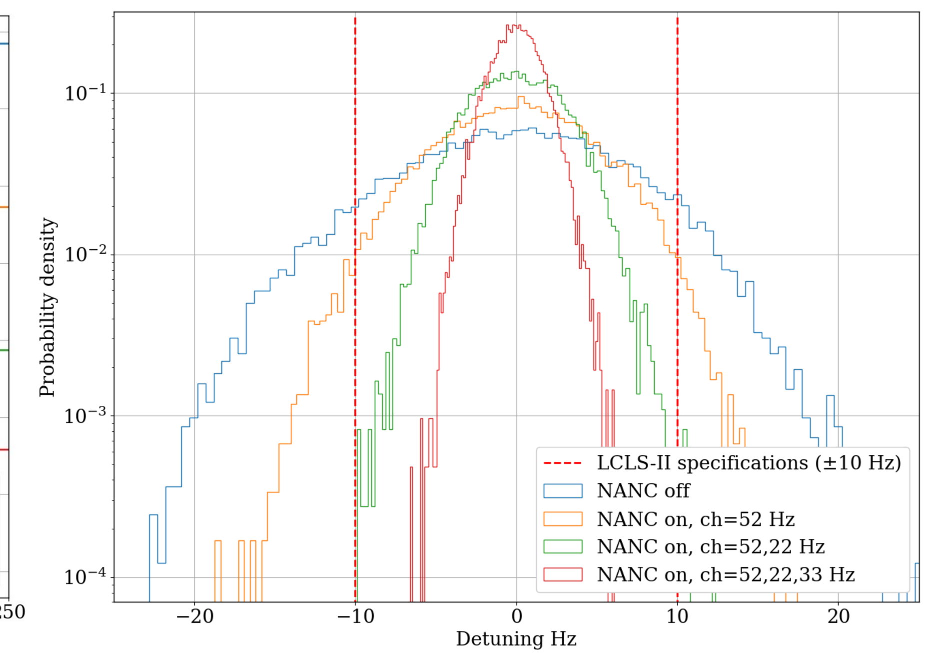
$$\omega_m(t_{n+1}) = \omega_m(t_n) + \gamma_m \frac{I_m(t_n)Q_m(t_{n+1}) - Q_m(t_n)I_m(t_{n+1})}{I_m(t_n)^2 + Q_m(t_n)^2}$$

BENEFITS OF THE PROPOSED ALGORITHM

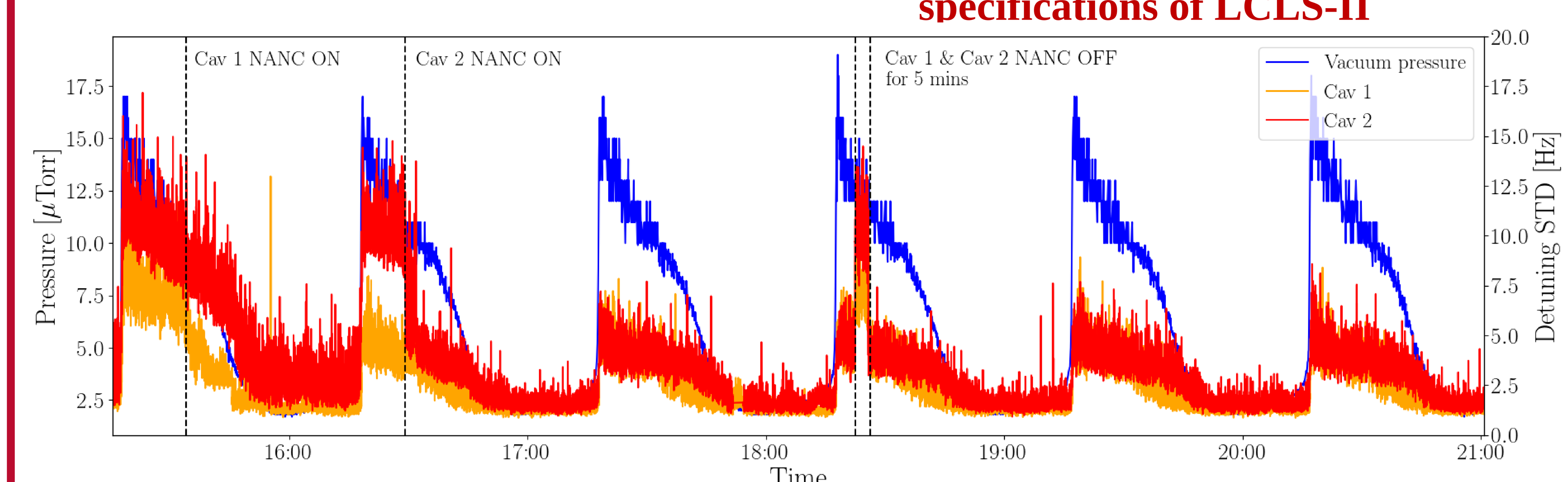
- No need to characterize the tuner-detuning transfer function beforehand.
- Fast (~1s) settling time.
- Accounts for drifts in the disturbance parameters over time.
- Minimal expertise required to use the algorithm once set up.
- Reduces the amount of RF power required to drive a cavity.
- Allows to drive SRF LINACs in mechanically noisy environments efficiently.

RESULTS



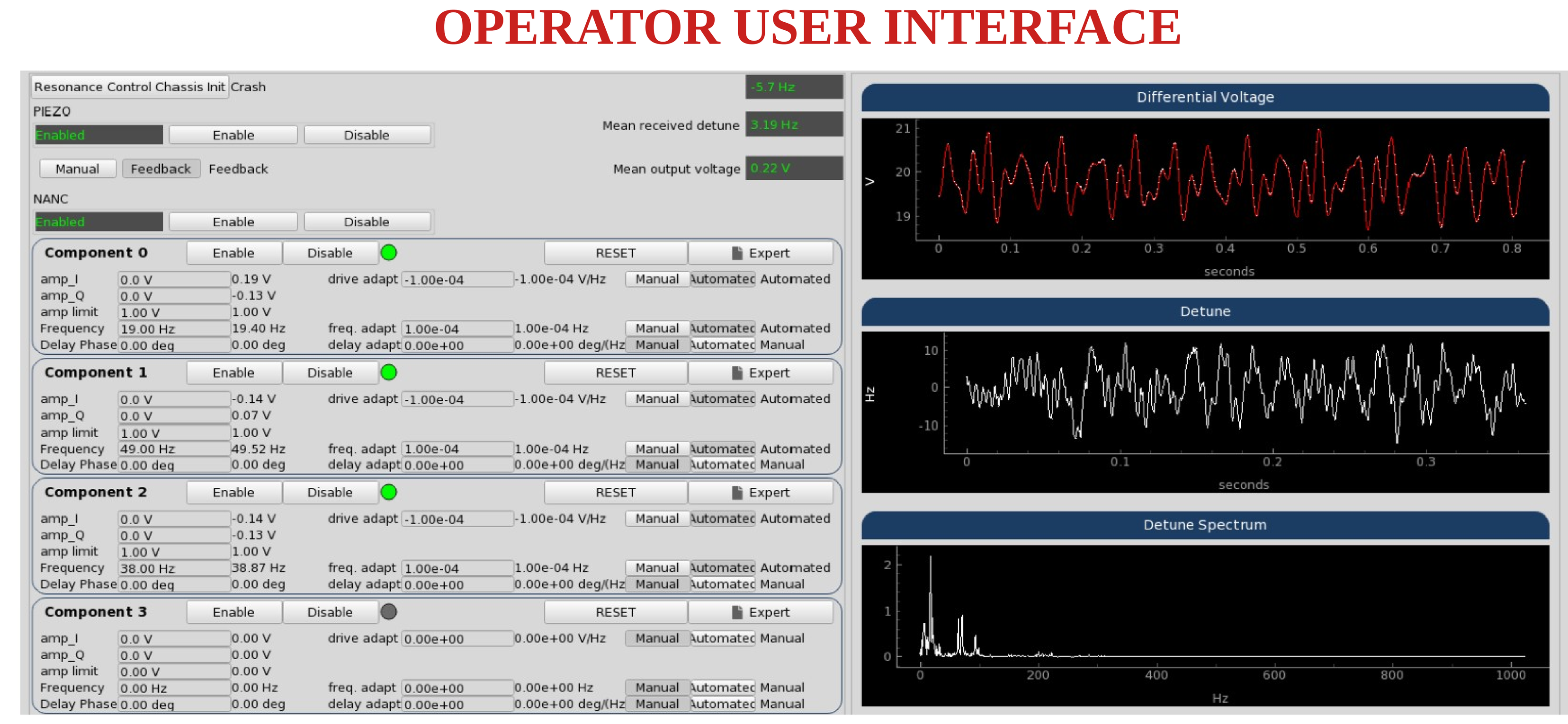


- Integrated detuning standard deviation.
- When the NANC is switched on, the **reduction in cavity detuning is ~12 dB**
- Detuning distribution.
- With the NANC is possible to **drive the cavities within the +/- 10 Hz specifications of LCLS-II**



- **6 hour test for cavities 1&2 of CM31.**
- Isolation vacuum pressure oscillations tell us that microphonics is driven by an external source. It does not imply that this pressure is the source of microphonics.
- **NANC adapts automatically for drifts and changes in microphonics disturbances.**

OPERATOR USER INTERFACE



Up to 4 different microphonics frequencies can be compensated using totally independent NANC components.

CONCLUSIONS AND FUTURE WORK

The NANC previously implemented at DESY and CORNELL has now been implemented at SLAC for the LCLS-II LINAC in CW operation, with the addition of the frequency follower feature. The controller is able to compensate for narrowband microphonics and reduces cavity detuning by a factor of 3. With this microphonics compensation, detuning of noisy cavities is reduced and reaches LCLS-II specifications. More cavities should be tested to have a better understanding of the performance of the controller.

REFERENCES

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Proceeding link

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