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# MICROPHONICS SIMULATION AND PARAMETERS DESIGN OF THE SRF CAVITIES FOR CiADS

Jinying Ma†, Guirong Huang
Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China

## *Abstract*

The CiADS (China initiative Accelerator Driven System) proton linac is designed to accelerate CW beams of up to 500 MeV and 5mA, which is delivered to the spallation target. Since the beam power will eventually reach 2.5 MW, the beam loss should be restricted, which is sensitive to the SC cavity stability. On CW operating mode, the main perturbation to the cavity is microphonics. This paper will describe a set of tools developed to simulate performance of the cavity and its LLRF control system in order to ensure proper cavity operation under microphonics. The simulation tools describe a relationship between microphonics and the RF parameters. The microphonics effect to the cavity is simulated. The tolerated intensity of microphonics is determined by simulation, in order to satisfy the stability of amplitude and phase with 0.1% and 0.1 degree respectively.

## INTRODUCTION

Cavities of CiADS with a high external quality factor, which means a narrow bandwidth, any disturbance resulting in a cavity detuning leads to instability in amplitude and phase. A major instability source is the mechanical microphonics detuning. However, it is required to maintain field stability less than 0.1% in amplitude and 0.1° in phase [1]. The instability element of microphonics need to be evaluated initially at the phase of engineering design to satisfy the high stability requirements of the proton Linac for CiADS. We constructed a simulation program in MATLAB with the method of the discretized iterative algorithm to analyse the stability of the resonant system.

This paper analysed the microphonics effect on stability of the amplitude and phase in resonant cavity, compared the microphonics relevance factors such as the resonant frequency and bandwidth according to the results of simulation. Finally, the limitation of microphonics oscillation was presented to satisfy the requirements of stability for CiADS Linac.

## MICROPHONICS

Microphonics is the time domain variation in cavity frequency driven by external vibrational sources [2].

Microphonics caused the oscillation frequency of the resonant cavity can be written as follow equation:

$$\omega(t)=\omega_0+\omega_\mathrm{d}\cdot\sin(\omega_\mathrm{m}\cdot t) \tag{1}$$

Here, $\omega_0$ is the frequency of the cavity fundamental mode, $\omega_\mathrm{d}$ is the frequency shift due to microphonics, and $\omega_\mathrm{m}$ is the oscillation frequency of microphonics.

The detuning angle $\varphi$ caused by microphonics is [3]

$$\tan\varphi=\frac{\omega_\mathrm{d}}{\omega_{HBW}} \tag{2}$$

Here, $\omega_\mathrm{HBW}$ is the half bandwidth of cavity.

The case shown in Fig. 1. is one of the instability cavities of the test facility caused by external vibrational sources.

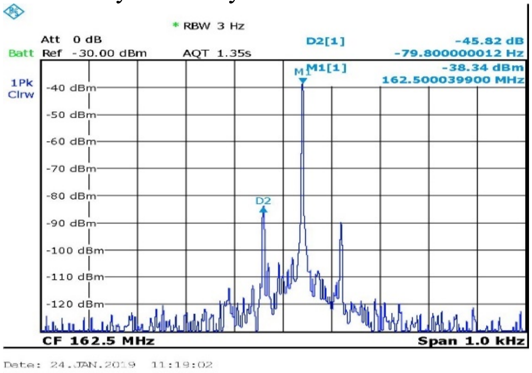

Figure 1: The microphonics of the test facility's cavity.

## CONCEPTUAL DESIGN

The concept of the analysis tool for the stability of cavity is based on library of sub-system blocks used in SIMULINK, to simulate how the cavity will behave when a RF-signal is applied. A mathematical description of the cavity must be used to make a model in Simulink, so the discretized iterative algorithm is developed in this paper to analyze the time-varying dynamical process of superconductive cavity under the microphonics, based on the impulse response model of the resonant system.

### *Equivalent Circuit*

The RF cavity can be represented by the equivalent circuit with an inductance *L*, a capacitance *C*, and a resistor *R* as shown in Fig. 2. [4].

The relationship between R, L, C and the characteristic parameters of resonant cavity are given by

$$\omega_0^2=\frac{1}{LC}\qquad\frac{R}{Q}=\omega_0 L\qquad\tau=\frac{2Q}{\omega_0} \tag{3}$$

Where $\omega_0$ is the resonant frequency, Q is the quality factor, $\tau$ is the attenuation coefficient.

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† majinying@impcas.ac.cn

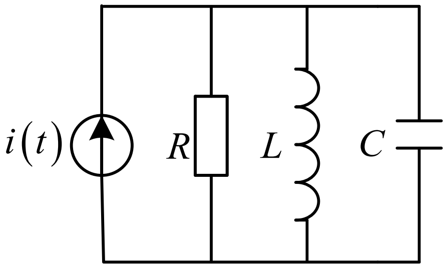


Figure 2: Equivalent circuit of RF cavity.

### *Mathematical Deduction of the Cavity Model*

In accelerator, we see that both the beam current $I_b$ and the generator current $I_g$ are loading on the resonant cavity, and $I_b$ is a narrow pulse signal of periodically while $I_g$ is a continuous cosine signal.

Based on the impulse response model of the resonant system, the discretized iterative algorithm of the resonant cavity voltage is developed. We can get expressions for $V_b$ using this theory, where $V_b$ is the beam loading voltage at the cavity resonant frequency. The equation is given by

$$V_{\mathrm{b},n+1} = V_n \cdot e^{-T/\tau} \cdot e^{j\omega(nT)\cdot T} + \frac{I_{\mathrm{b},n+1} \cdot T}{C} \tag{4}$$

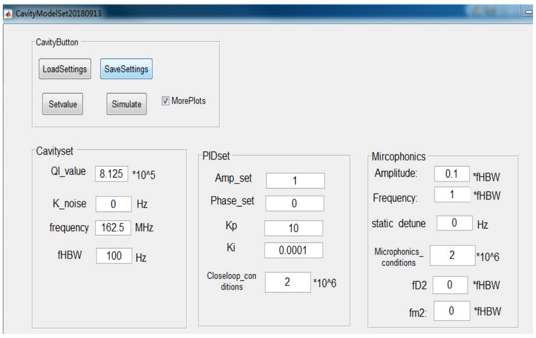
The generator current is discretized into a series of pulse signals, and then it is easy to obtain $V_g$ using the same theory as the beam loading voltage $V_b$, which turns out to be

$$V_{\mathrm{g},n+1} = V_n \cdot e^{-T/\tau} \cdot e^{j\omega(nT)\cdot T} + \frac{I_{\mathrm{g},n+1} \cdot T}{2C} \tag{5}$$

We see that both the beam loading voltage and the generator voltage are loading on the accelerator. Since these two voltages are added up, we must have

$$\begin{aligned} V_{n+1} &= V_{\mathrm{b},n+1} + V_{\mathrm{g},n+1} \\ &= V_n \cdot e^{-T/\tau} \cdot e^{j\omega(nT)\cdot T} + \frac{T}{C}\left(\frac{1}{2} I_{\mathrm{g},n+1} + I_{\mathrm{b},n+1}\right) \end{aligned} \tag{6}$$

Where Eq. (6) is the total cavity voltage. This equation makes the model easier to implement in Simulink and the simulation model of superconducting resonant cavity is developed according to it. The simulation library blocks include models for the superconducting cavities, the RF feedback system, microphonics and so on. The simulation interface is shown in Fig. 3.



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QI_value: 8.125 *10^5
K_noise: 0 Hz
frequency: 162.5 MHz
fHBW: 100 Hz

Amp_set: 1
Phase_set: 0
Kp: 10
Ki: 0.0001
Closeloop_conditions: 2 *10^6

Amplitude: 0.1 *fHBW
Frequency: 1 *fHBW
static detune: 0 Hz
Microphonics_conditions: 2 *10^6
fD2: 0 *fHBW
fm2: 0 *fHBW

Figure 3: The interface of Simulation.

## SIMULATION ANALYSIS

Figure 4 depicts the effect of microphonics to the resonant cavities in open loop mode and closed loop mode. The system is in open loop mode before point B while in close loop mode after point B. Microphonics oscillation is introduced to the system after point A. Here, *N* is the number of RF periods.

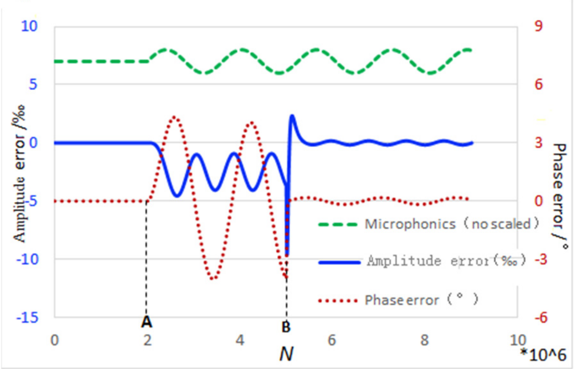

Figure 4: Microphonics in open loop and closed loop mode.

In one period of the oscillation of microphonics, phase changes once while amplitude changes twice as illustrated in Fig. 4. The reason is that both forward detuning and reverse detuning cause amplitude reduction.

It also appears that the phase is much more influenced by the microphonics than the amplitude. Therefore, we will mainly discuss the phase variations in closed loop mode in later sections.

### *Simulation Results*

The simulations have been performed for different type of cavities with 162.5, 325 and 650MHz. In the case shown in Fig. 5. and Fig. 6. are the effect of frequency shift which related to cavities parameters, where $f_0$ is the resonant frequency of cavity, $f_{\mathrm{HBW}}$ is the bandwidth of cavity, $f_{\mathrm{m}}$ is the oscillation frequency of microphonics and $f_{\mathrm{d}}$ is the frequency shift of microphonics.

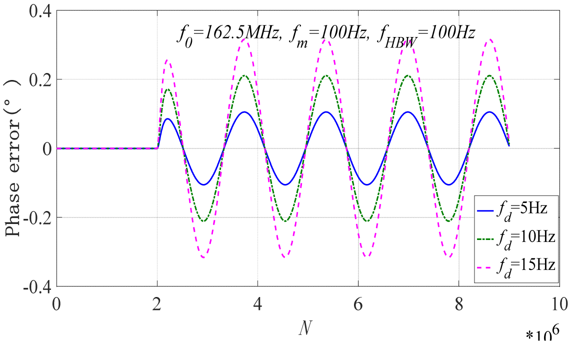

Figure 5: Phase error VS the frequency shift of microphonics.

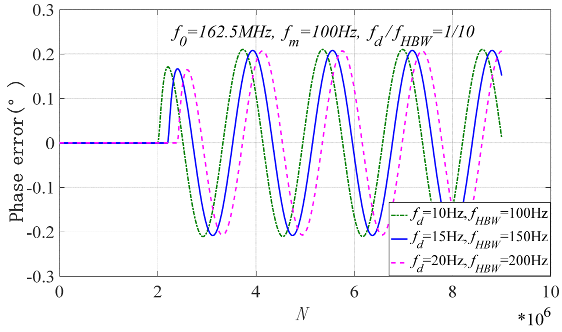

Figure 6: Phase error VS $f_d$ / $f_{HBW}$.

The result of the frequency shift of microphonics to the phase stability is illustrated in Fig. 5. The larger frequency shift of microphonics is set, the worse instability of phase is caused, while the Fig. 6. simulation result shows when the ratio of $f_d$ to $f_{HBW}$ is same and the same effect is observed on instability of phase under otherwise equal conditions. It depicts that the effect of frequency shift depends on the ratio of the frequency shift of microphonics to the bandwidth of the cavity.

Similarly, the larger oscillation frequency of microphonics is set, the worse instability of phase is caused. The approximately same effect is observed on instability of phase under otherwise equal conditions when the ratio of $f_m$ to $f_0$ is same. These simulation results are shown in Fig. 7. and Fig. 8. It depicts that the effect of the oscillation frequency of microphonics depends on the ratio of it to the resonant frequency of the cavity.

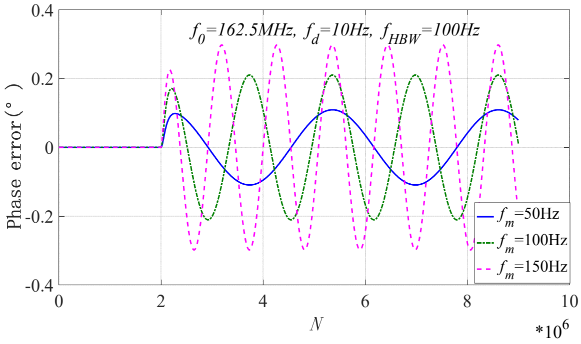

Figure 7: Phase error VS the oscillation frequency of microphonics.

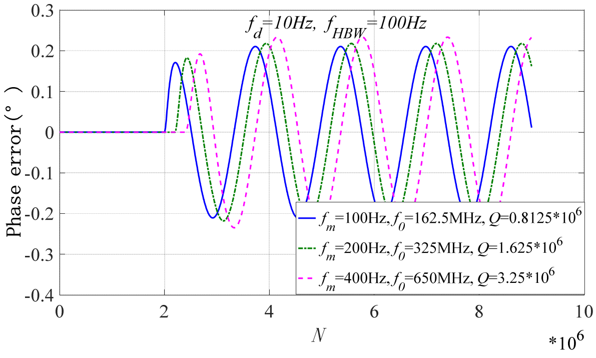

Figure 8: Phase error VS $f_m$ / $f_0$.

Finally, the limitation of microphonics oscillation is given in Table 1 to satisfy the stability of amplitude and phase with 0.1% and 0.1 degree respectively of CiADS cavities.

Table 1: Maximum Frequency Shift of Microphonics Tolerated by CiADS Cavity Stability

| **$f_m$ [Hz]** | **$f_d$ max [Hz]** | | | |
|---|---|---|---|---|
| | $f_0$ [MHz] | 162.5 | 325 | 650 |
| | $f_{HBW}$[Hz] | 100 | 100 | 50 |
| 50 | | 10 | 18 | 18 |
| 100 | | 5 | 10 | 10 |
| 150 | | 4 | 7 | 7 |
| 200 | | 3 | 5 | 5 |

## CONCLUSION

In this paper, based on the impulse response model of the resonant system, the discretized iterative algorithm and corresponsive simulation program are developed to trace the effect of microphonics to the resonant cavity. Finally, the tolerated intensity of microphonics frequency shift which satisfy the stability of CiADS cavities are given.

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