Microphonic Noise Suppression in Superconducting Cavity with observer based Feedback

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Motivation

In particle accelerators it's important to have a stable accelerating system for the beams of particles. The detuning of superconducting radio frequency (SRF) cavities is mainly caused by the Lorentz force. The detuning is the radiation pressure induced by a high radio frequency (RF) field, and microphonic noise are environmental vibrations that induce undesirable unwanted signals.
Here the three dominant mechanical vibration modes 39 Hz, 157 Hz and 224 Hz for the system has been considered, then an observer based feedback control scheme has been designed based on input-output linearization.
It is shown through simulation studies that the proposed control technique can successfully the suppress the microphonics due to the SRF cavity's dynamic.

State Space Model of the cavity

Electrical Model of the Cavity

$$\ddot{V}_{cav}(t)+\frac{\omega_0}{Q_L}\dot{V}_{cav}(t)+\omega_0^2 V_{cav}(t)=\frac{R_L\omega_0}{Q_L}(\dot{I}_g(t)-\dot{I}_b(t)),$$

$$\begin{bmatrix}\dot{V}_{cav,re}\\ \dot{V}_{cav,im}\end{bmatrix}=\begin{bmatrix}-\omega_{\frac{1}{2}} & -\Delta\omega_m\\ \Delta\omega_m & -\omega_{\frac{1}{2}}\end{bmatrix}\begin{bmatrix}V_{cav,re}\\ V_{cav,im}\end{bmatrix}+\omega_{1/2}R_L\begin{bmatrix}I_{re}\\ I_{im}\end{bmatrix}.$$

Mechanical Model of the Cavity

$$\Delta\ddot{\omega}_{m,i}(t)+\frac{\omega_{m,i}}{Q_{m,i}}\Delta\dot{\omega}_{m,i}(t)+\omega_{m,i}^2\Delta\omega_{m,i}(t)=-k_{LFi}2\pi\omega_{m,i}^2F(t).$$

$$\begin{bmatrix}\Delta\dot{\omega}_{m,1}\\ \Delta\ddot{\omega}_{m,1}\\ \vdots\\ \vdots\\ \Delta\dot{\omega}_{m,n}\\ \Delta\ddot{\omega}_{m,n}\end{bmatrix}=\begin{bmatrix}0 & 1 & \cdots & 0 & 0\\ -\omega_{m,1}^2 & -\frac{\omega_{m,1}}{Q_{m,1}} & \cdots & 0 & 0\\ \vdots & \vdots & \vdots & \vdots & \vdots\\ \vdots & \vdots & \vdots & \vdots & \vdots\\ 0 & 0 & \cdots & 0 & 1\\ 0 & 0 & \cdots & -\omega_{m,n}^2 & -\frac{\omega_{m,n}}{Q_{m,n}}\end{bmatrix}\times\begin{bmatrix}\Delta\omega_{m,1}\\ \Delta\dot{\omega}_{m,1}\\ \vdots\\ \vdots\\ \Delta\omega_{m,n}\\ \Delta\dot{\omega}_{m,n}\end{bmatrix}+2\pi\begin{bmatrix}0\\ -k_{LF1}\omega_{m,1}^2\\ \vdots\\ \vdots\\ 0\\ -k_{LFn}\omega_{m,n}^2\end{bmatrix}(V_{cav}^2+V_{mic})$$

Controller Designing

Step 1:

$$\begin{aligned}\Delta\ddot{\omega}_i=&-\frac{\omega_{m,i}}{Q_{m,i}}\Delta\dot{\omega}_i-\omega_{m,i}^2\Delta\omega_i\\ &-2\pi k_{LFi}\omega_{m,i}^2(V_p^2+V_{mic}+u_p)\\ =&f_i(\Delta\omega_i,u_p),\ i=1,\dots,N;\end{aligned}$$

Step 2:

$$y_p=\Delta\omega=\sum_{i=1}^{N}\Delta\omega_i,$$

$$\ddot{y}_p=\sum_{i=1}^{N}\Delta\ddot{\omega}_i.$$

$$k_p v_p+k_v v_v=\sum_{i=1}^{N}f_i(\Delta\omega_i,u_p),$$

Step 3:

$$\begin{bmatrix}\Delta\dot{\omega}_m(t)\\ \Delta\ddot{\omega}_m(t)\end{bmatrix}=\begin{bmatrix}0 & 1\\ -\omega_m^2 & -\frac{\omega_m}{Q_m}\end{bmatrix}\begin{bmatrix}\Delta\omega_m(t)\\ \Delta\dot{\omega}_m(t)\end{bmatrix}+\begin{bmatrix}0\\ -k_{LF}2\pi\omega_m^2\end{bmatrix}\times u,$$

$$u=\begin{bmatrix}k_p & k_v\end{bmatrix}\begin{bmatrix}\Delta\omega_m(t)\\ \Delta\dot{\omega}_m(t)\end{bmatrix}$$

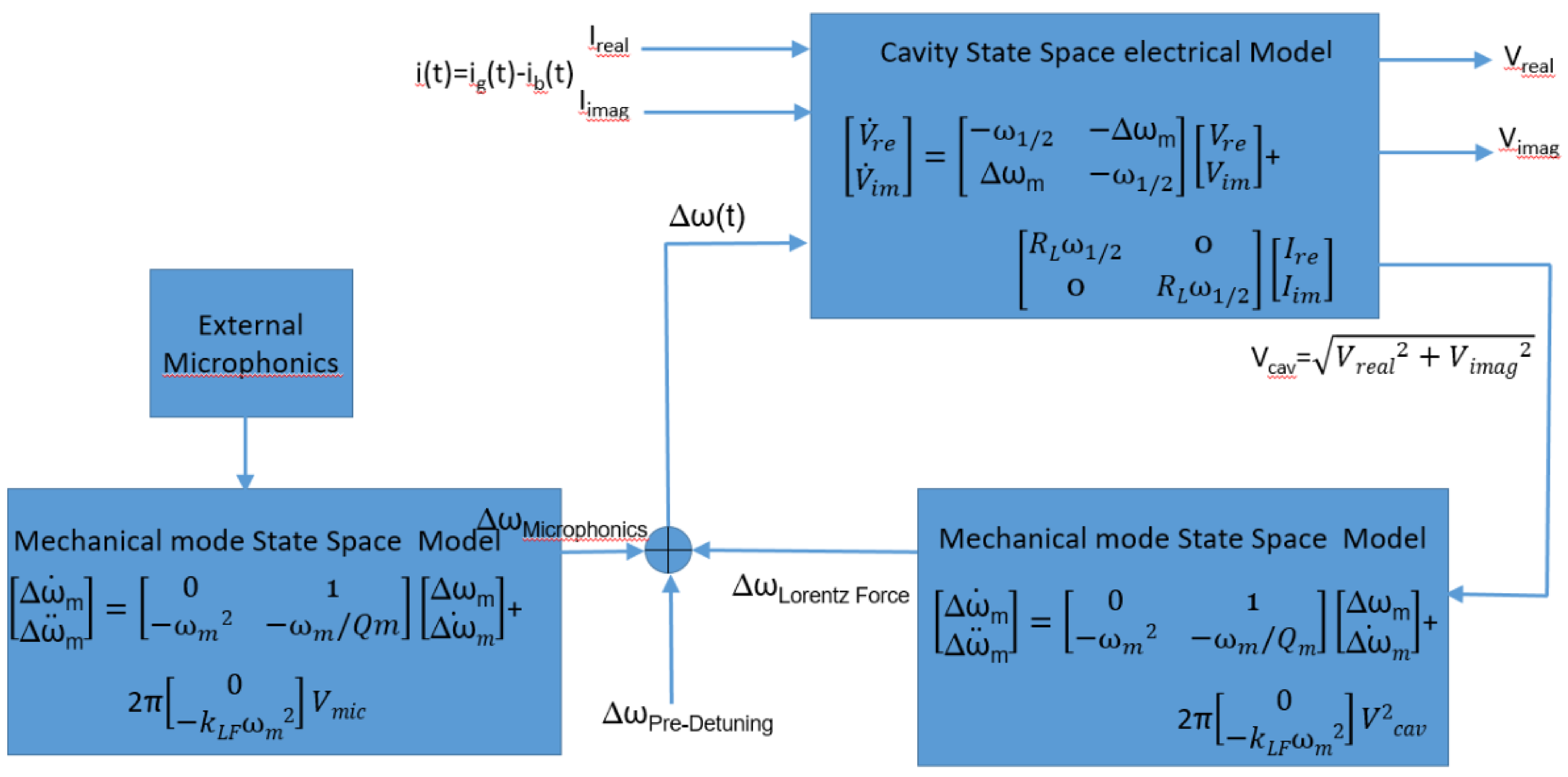
Step 4:

$$\begin{bmatrix}\Delta\dot{\omega}_m(t)\\ \Delta\ddot{\omega}_m(t)\end{bmatrix}=\begin{bmatrix}0 & 1\\ -\omega_m^2 & -\frac{\omega_m}{Q_m}\end{bmatrix}\begin{bmatrix}\Delta\omega_m(t)\\ \Delta\dot{\omega}_m(t)\end{bmatrix}+2\pi\begin{bmatrix}0\\ -k_{LF}\omega_m^2\end{bmatrix}\times\begin{bmatrix}0 & 0\\ -k_{LF}\omega_m^2k_p & -k_{LF}\omega_m^2k_v\end{bmatrix}\begin{bmatrix}\Delta\omega_m(t)\\ \Delta\dot{\omega}_m(t)\end{bmatrix},$$

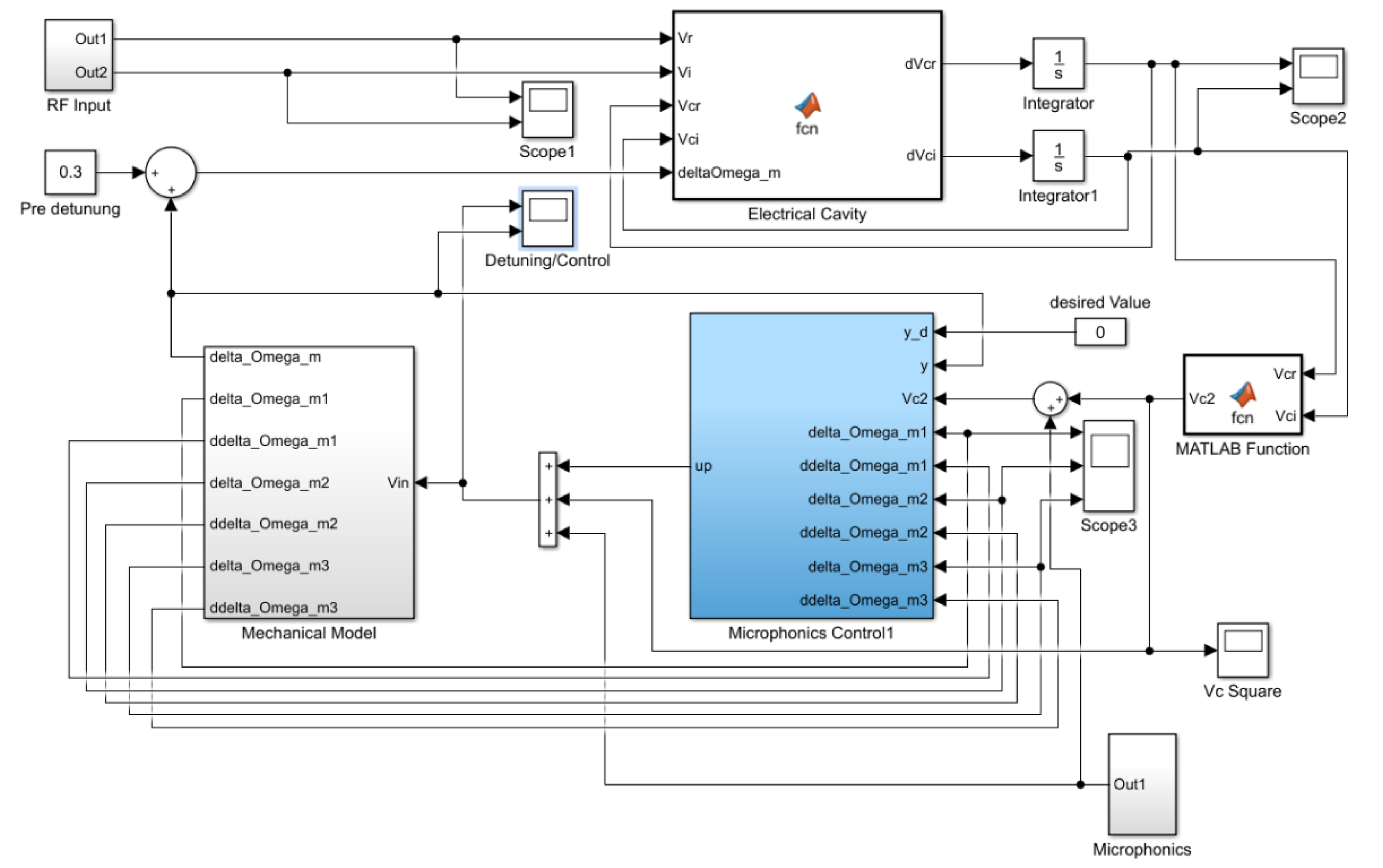
Controller Output signal:

$$u_p=k_pv_p+k_vv_v-\frac{\sum_{i=1}^{N}(2\zeta_{m,i}\omega_{m,i}\Delta\dot{\omega}_i+\omega_{m,i}^2\Delta\omega_i)}{\sum_{i=1}^{N}2\pi k_{LFi}\omega_{m,i}^2}-(V_p^2+V_{mic})$$

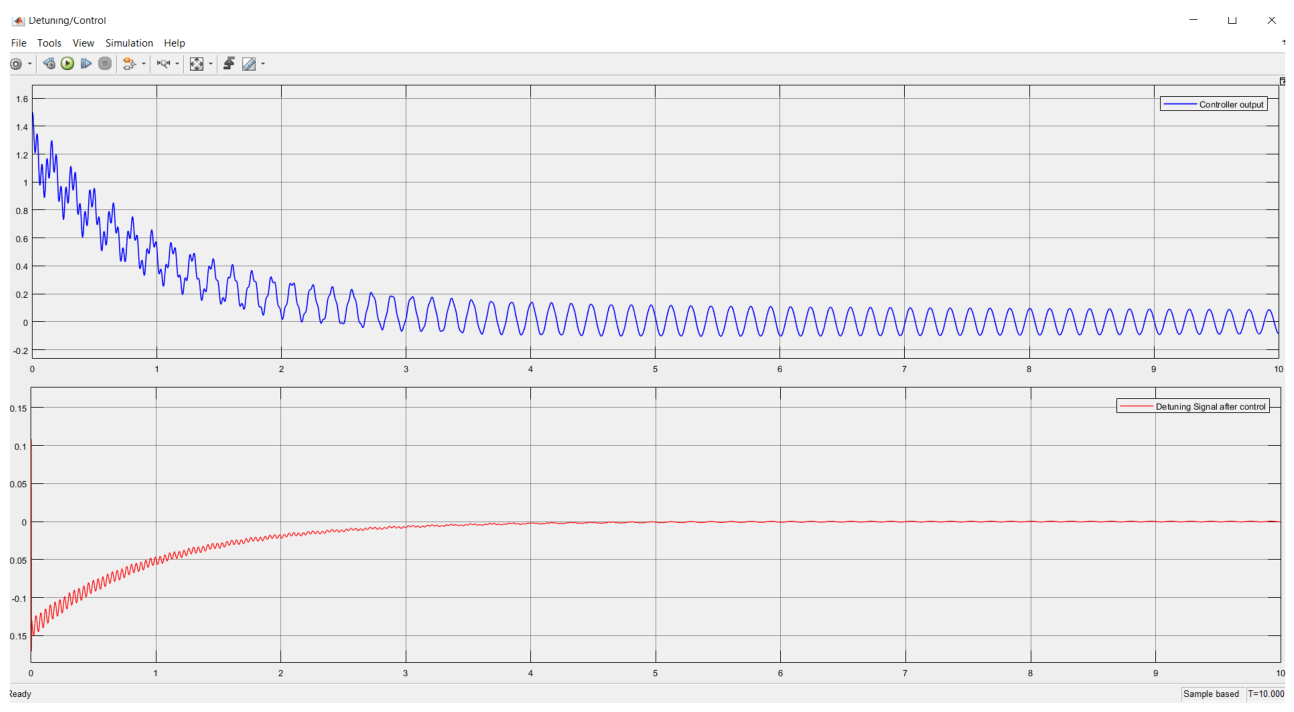
$$u_p=k_pv_p+k_v\dot{v}_p-\frac{\sum_{i=1}^{N}(2\zeta_{m,i}\omega_{m,i}\Delta\dot{\omega}_i+\omega_{m,i}^2\Delta\omega_i)}{\sum_{i=1}^{N}2\pi k_{LFi}\omega_{m,i}^2}-(V_p^2+V_{mic})$$



Block Diagram of the State space model



SIMULINK Model of the Microphonics suppression



Controller Output and Suppressed microphonic signals for 3 dominant modes

Conclusion

This is an efficient algorithm for active noise suppression in superconducting cavities. By applying this feedback method the three dominant microphonic noise has been suppressed in the simulation. The simulation results indicate the effectiveness of the proposed controller that controls the unwanted detuning to the desired value zero. This obtained signal from controller is a voltage that is being applied as input of a piezo which installed to the cavity and the displacement of the piezo electric result from the controller signal suppresses the mechanical vibration.

Acknowledgments

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