Reshaping SRF Cavity Resonance Management with Smart Techniques

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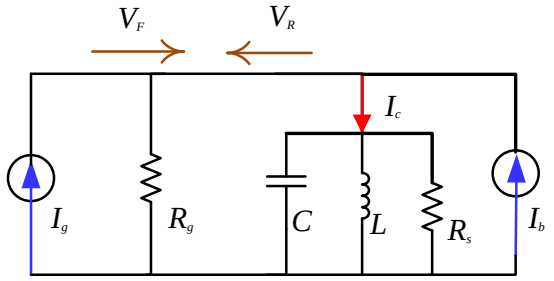
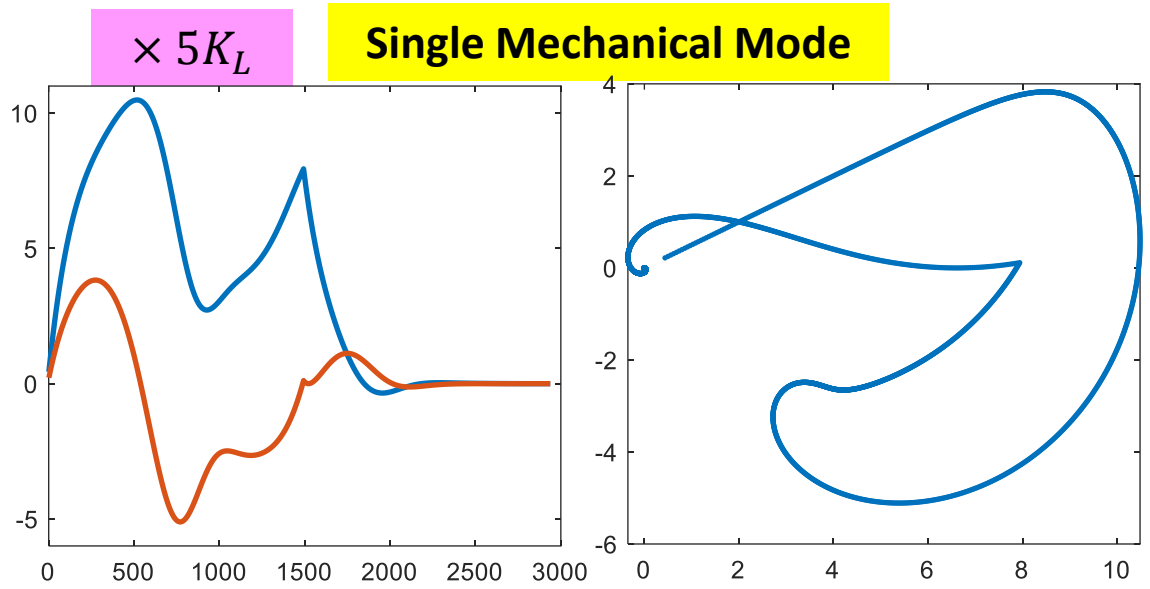
SRF Cavity

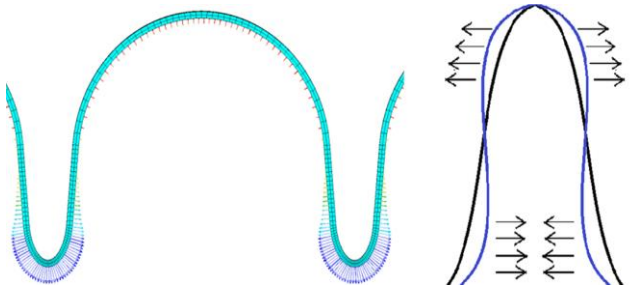
- **Cavity Circuit model**



Linear System

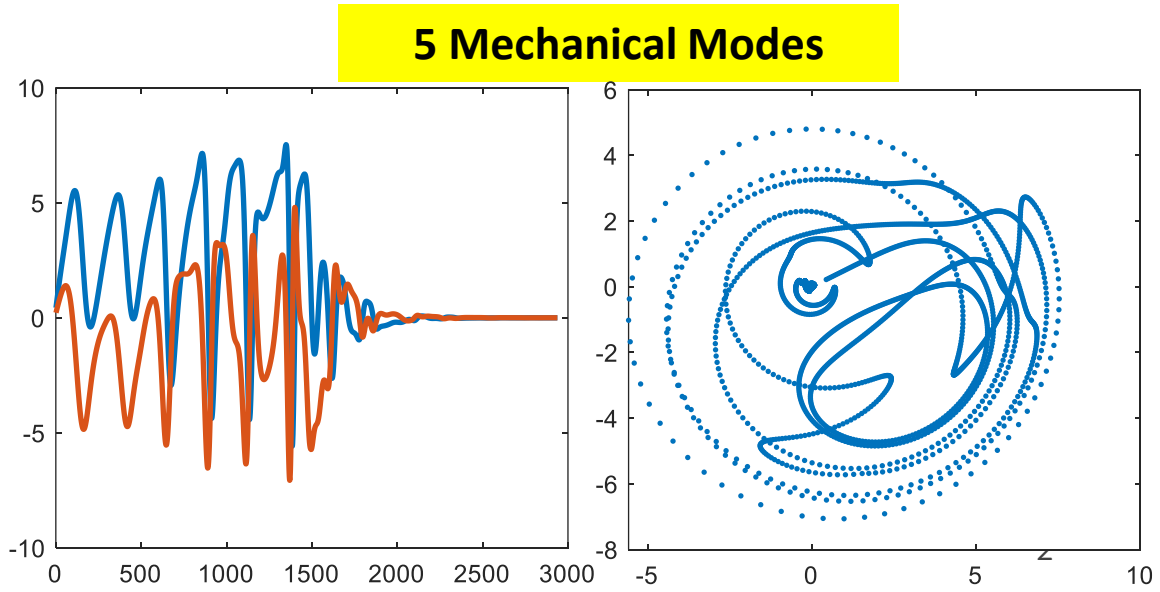


- **Lorentz pressure distribution on cavity wall**

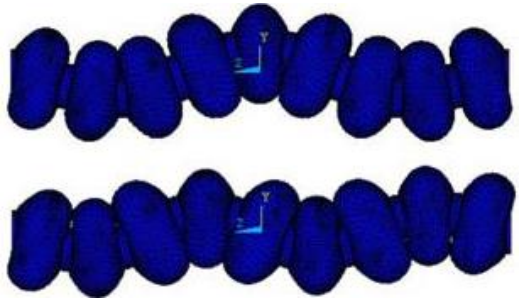


Nonlinear Force

$$P = \frac{1}{4}(\varepsilon_0 E^2 - \mu_0 H^2)$$



- **Mechanical Modes: ω_m, Q_m, K_m**



Electromagnetic field

Vibration

SRF Cavity DMD Test Results

- **DMD: Dynamic Mode Decomposition**

$$\frac{d}{dt}\boldsymbol{x}(t) = F(\boldsymbol{x}(t)) \qquad \boldsymbol{x_{k+1}} = \boldsymbol{F(x_k)} \qquad F \approx f \text{ based on data}$$

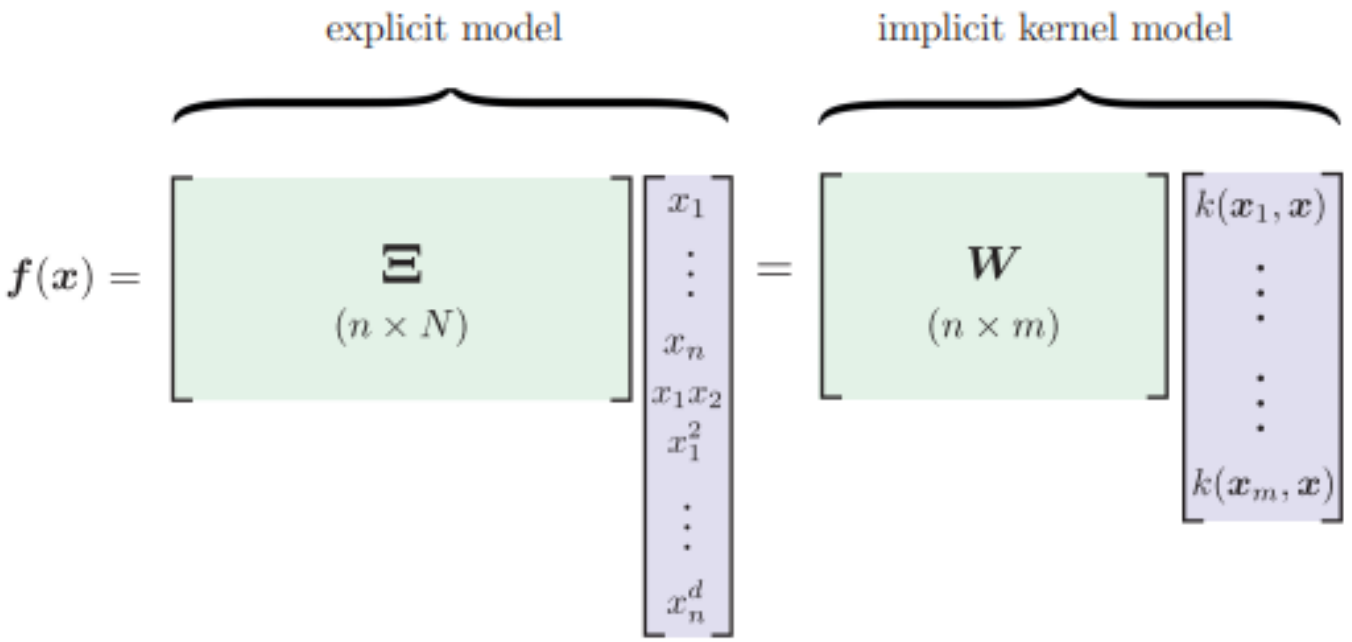
$\boldsymbol{x_k} = [\boldsymbol{a_k}\ \ \boldsymbol{b_k}]^{\boldsymbol{T}}$: system status and actuator inputs

Linear system: $\boldsymbol{x_{k+1}} = \boldsymbol{W x_k}$

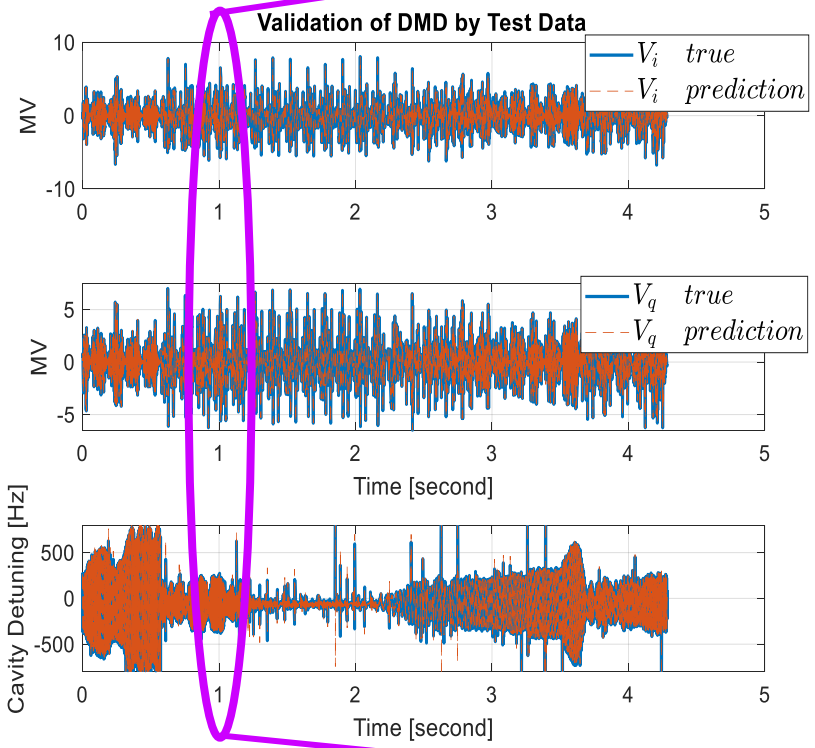
- **Mapping nonlinear problem in large state dimension with kernel function**

$$\boldsymbol{f} \approx \sum_{\boldsymbol{j=1}}^{\boldsymbol{N}} \boldsymbol{\xi_j \phi_j(x)} = \boldsymbol{\Xi \phi(x)} = \boldsymbol{W k(X, x)}$$

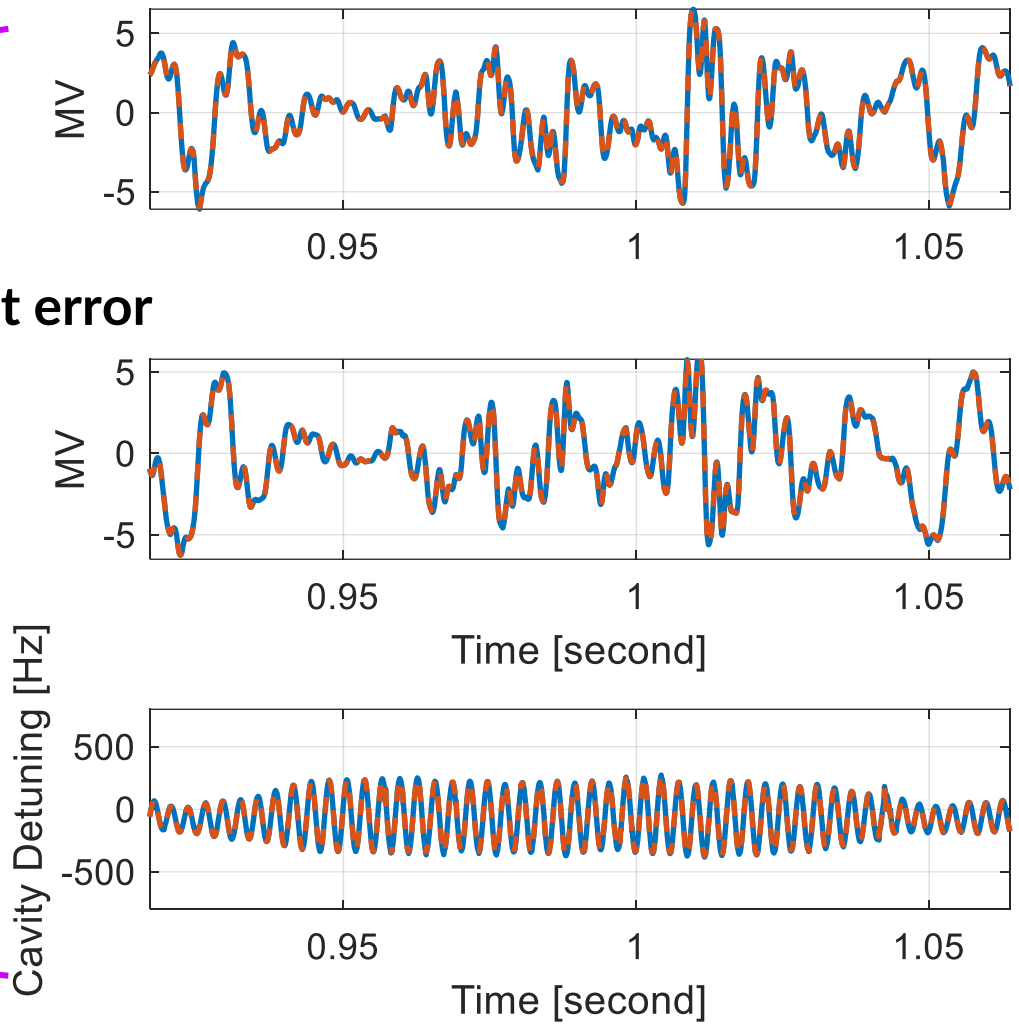
  - $\boldsymbol{\phi}$: the feature library of N candidate term that may describe the dynamics
  - $\boldsymbol{\Xi}$: the coefficients that determine which feature terms are active and what proportions.
  - $\boldsymbol{k}$: kernel function
  - Data matrices: $\boldsymbol{X} = [\boldsymbol{x_1}\ \boldsymbol{x_2}\ \ldots \boldsymbol{x_m}]$



SRF Cavity DMD Test Results



~ 2.5% test error



Faya Wang, "Enhancing SRF cavity stability and minimizing detuning with data-driven resonance control based on dynamic mode decomposition", AIP Advances 13, 075104 (2023)

Active Resonance Controller

- Simulation with 32 mechanical modes
- Cavity half bandwidth: 16.25 Hz
- Detune std: ~ 1 Hz