LCLS-II Tuner LLRF Controls Issues

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Tuner and microphonics history

Cornell tuner dynamics measurement

LQGR controller

Limited success reducing audio excursions

Tuners, Microphonics, and Control Systems in Superconducting Accelerating Structures

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Tuners, Microphonics, and Control Systems in Superconducting Accelerating Structures

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Introduction

In the textbook image of an accelerating cavity, superconducting or not, the axial electric field in the cavity is a sine wave with constant magnitude and phase. The field is timed (phased) so that the bunches of charged particles which pass through the cavity each receive the desired acceleration. Often the bunches are synchronized to be at the position of maximum field when the sine wave reaches its maximum, so that the greatest average acceleration is achieved. When longitudinal focussing is needed, the beam is retarded somewhat.

Manufacturing tolerances, thermal stresses, acoustic noise, and cooling fluid pressure fluctuations all conspire to make the field in the cavity not precisely what the accelerator physicist has in mind. Tuners and control systems are the tools used to fight back: they regulate the field in the cavity to the desired magnitude and phase.

Amplitude and phase stability are usually of greater concern in superconducting cavities than in copper cavities. The reasons are many:

1. Superconducting cavities allow, and often have, much higher loaded Q's.
2. Superconducting cavities are more conducive to continuous operation, and energy stability is more meaningful in a continuous beam machine; therefore the requirements on phase control are often more stringent.

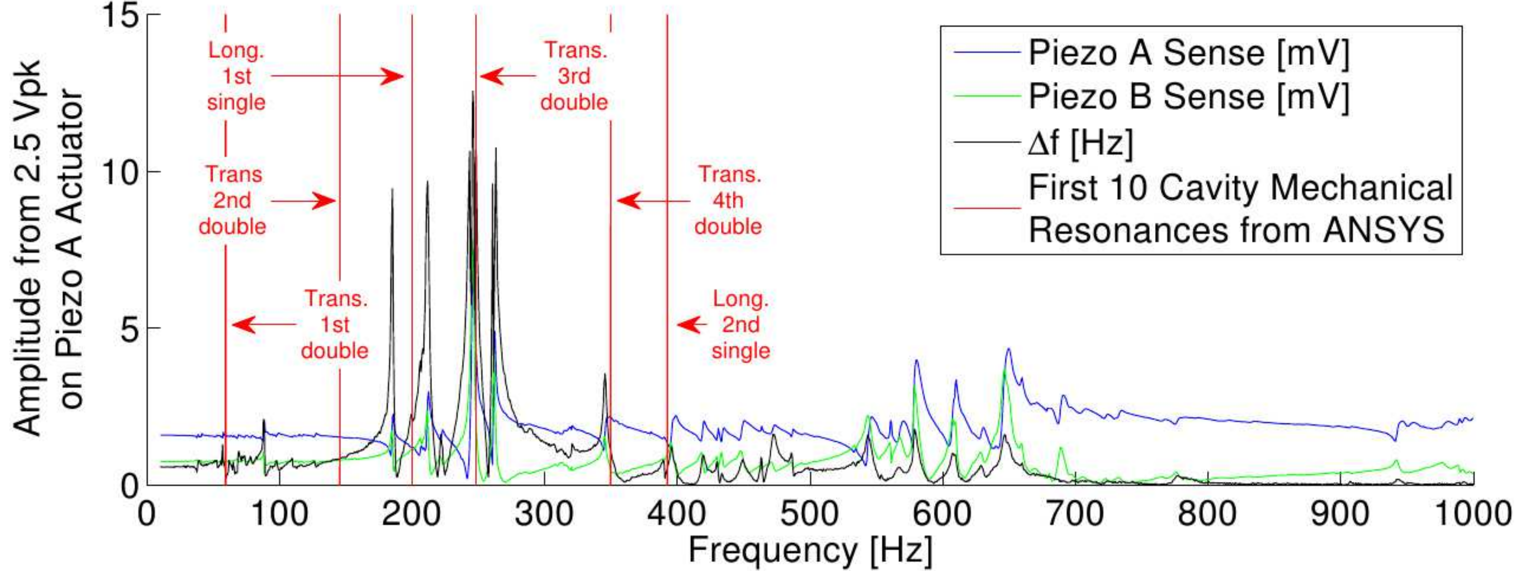
Reference	p-p noise	Center freq.	Resonator	Laboratory
Dick '72 [10]	400 Hz	30 MHz	Helix	Caltech
Fricke '72 [11]	24000 Hz	90 MHz	Helix	Karlsruhe
Benaroya '72 [14]	500 Hz	63 MHz	Helix	Argonne
Dick '76 [19]	600 Hz	238 MHz	Split Ring	Caltech, Stony Brook
Benaroya '77 [21]	120 Hz	97 MHz	Split Ring	Argonne
Hochschild '77 [25]	350 Hz	108 MHz	Helix	Karlsruhe
Shepard '77 [24]	80 Hz	98 MHz	Split Ring	Argonne
Delayen '77 [26]	100 Hz	150 MHz	Split Ring	Caltech
Zieher '81 [28]	350 Hz	142 MHz	Mod. Helix	Karlsruhe
Doolittle '88 [42]	30 Hz	1497 MHz	High-β	CEBAF

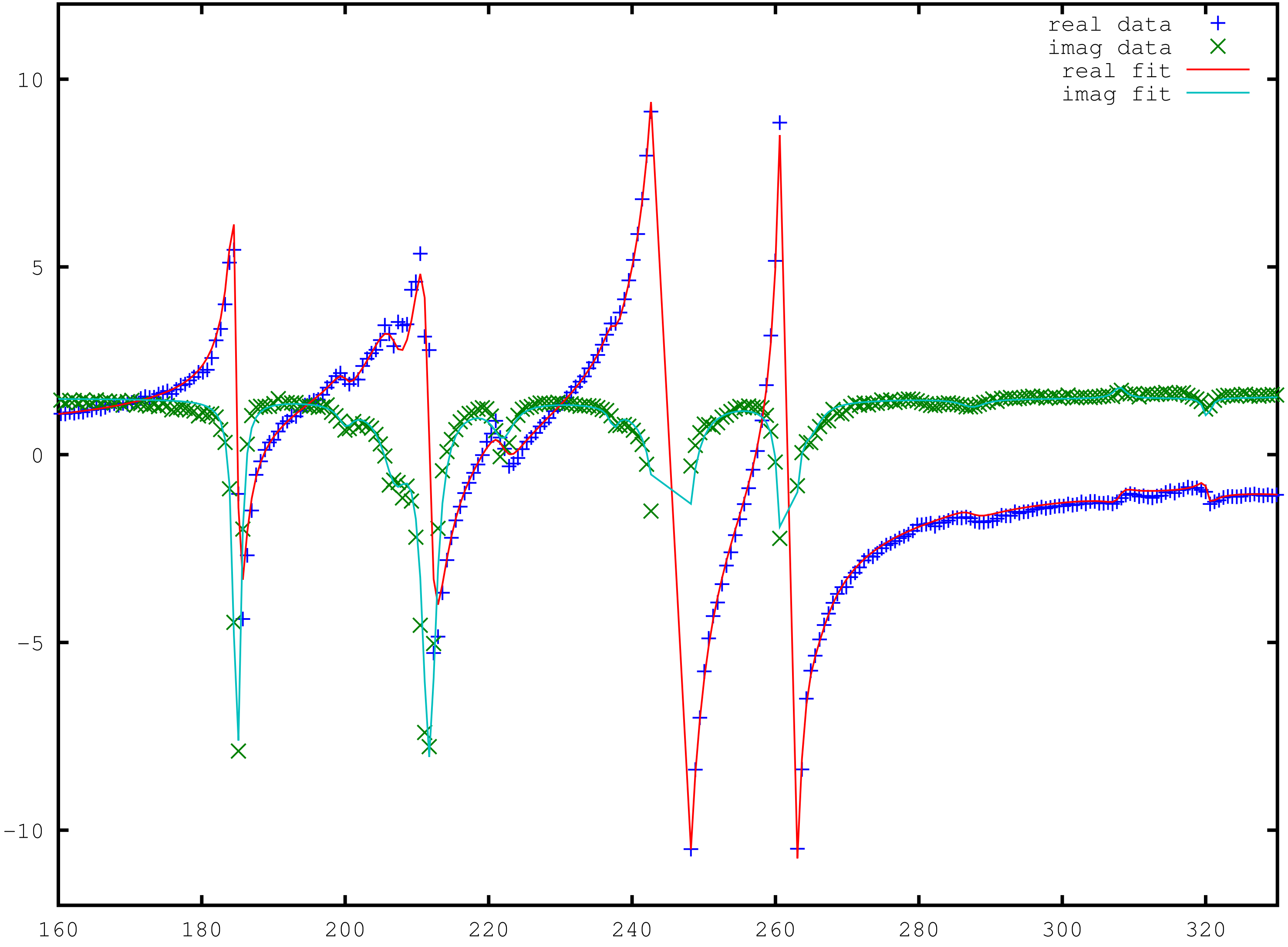
Table 2. Observed levels of microphonics.

Measurement of the Mechanical Properties of Superconducting Cavities During Operation

S. Posen and M. Liepe

IPAC2012, New Orleans (WEPPC081)


Amplitude from 2.5 Vpk on Piezo A Actuator
Frequency [Hz]
0
5
10
15
0
100
200
300
400
500
600
700
800
900
1000
Long. 1st single
Trans 2nd double
Trans. 1st double
Trans. 3rd double
Trans. 4th double
Long. 2nd single
Piezo A Sense [mV]
Piezo B Sense [mV]
Δf [Hz]
First 10 Cavity Mechanical Resonances from ANSYS

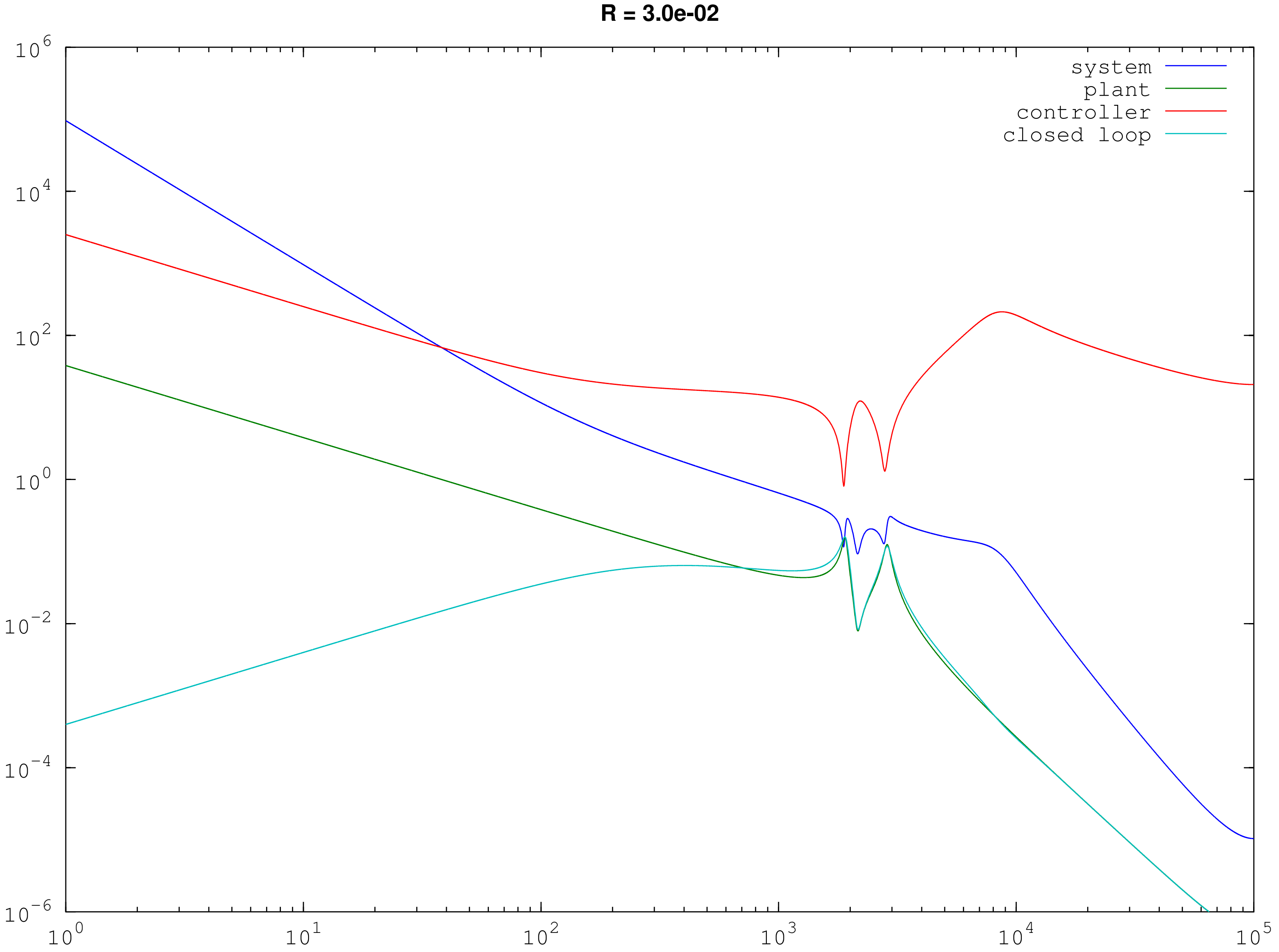

real data +
imag data ×
real fit
imag fit
10
5
0
−5
−10
160
180
200
220
240
260
280
300
320
f (Hz)

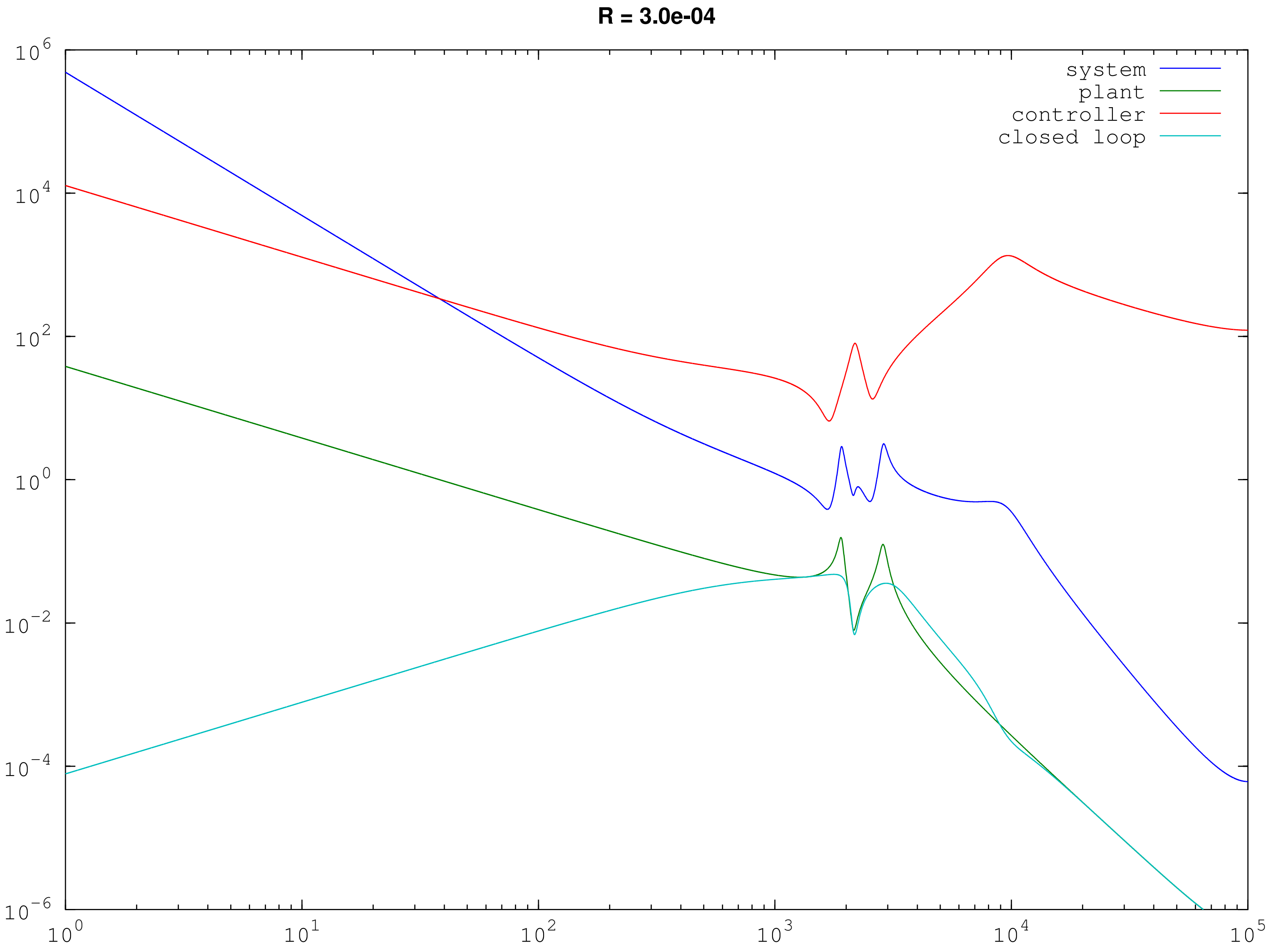
LQGR controller

http://en.wikipedia.org/wiki/Linear-quadratic-Gaussian_control

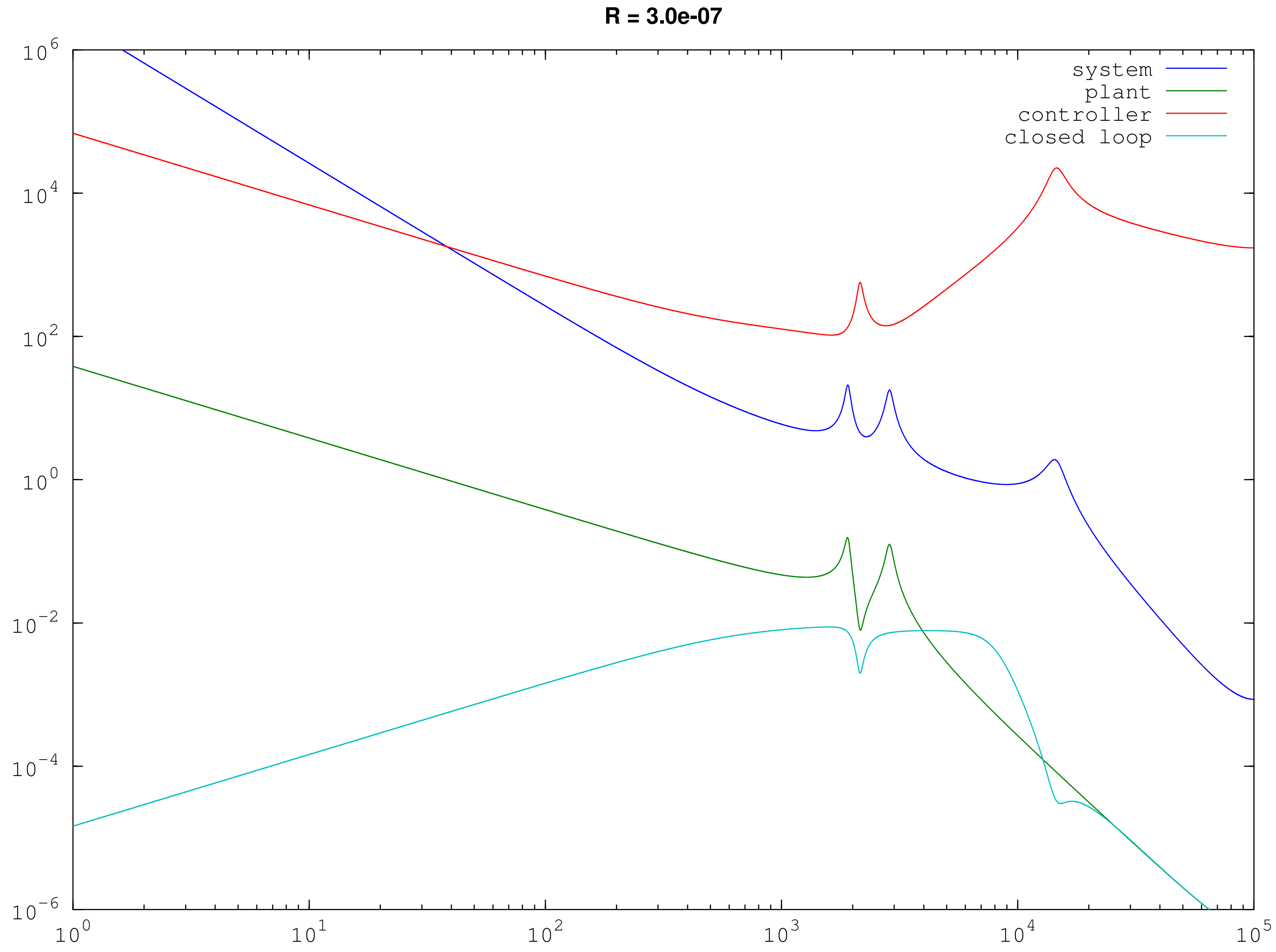
“linear systems disturbed by additive white Gaussian noise”

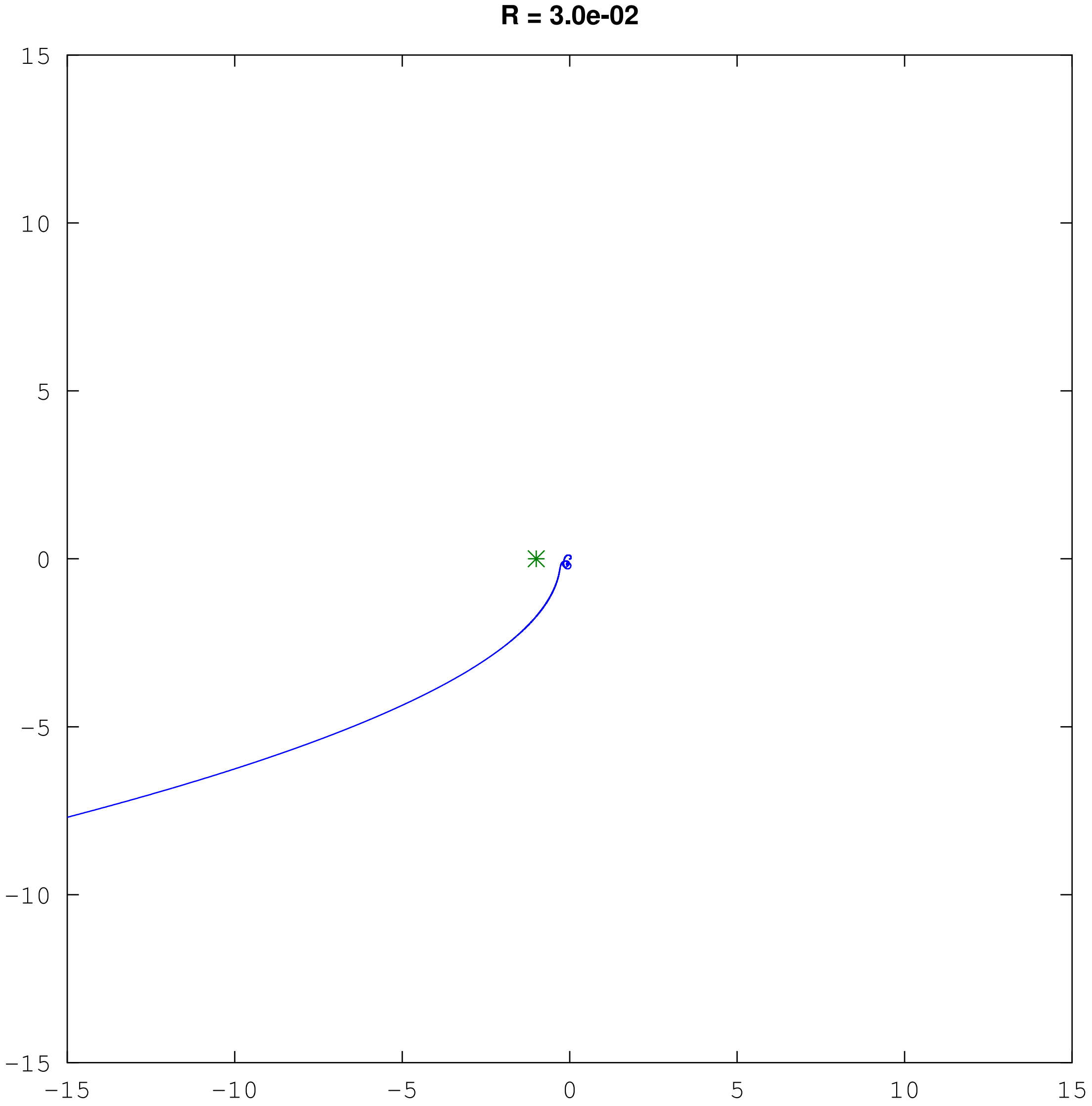
“... subject to quadratic costs” has one limit of nearly zero drive power, turns into (approximately) a slow integrator; at high power it gets into crazy conditionally stable territory

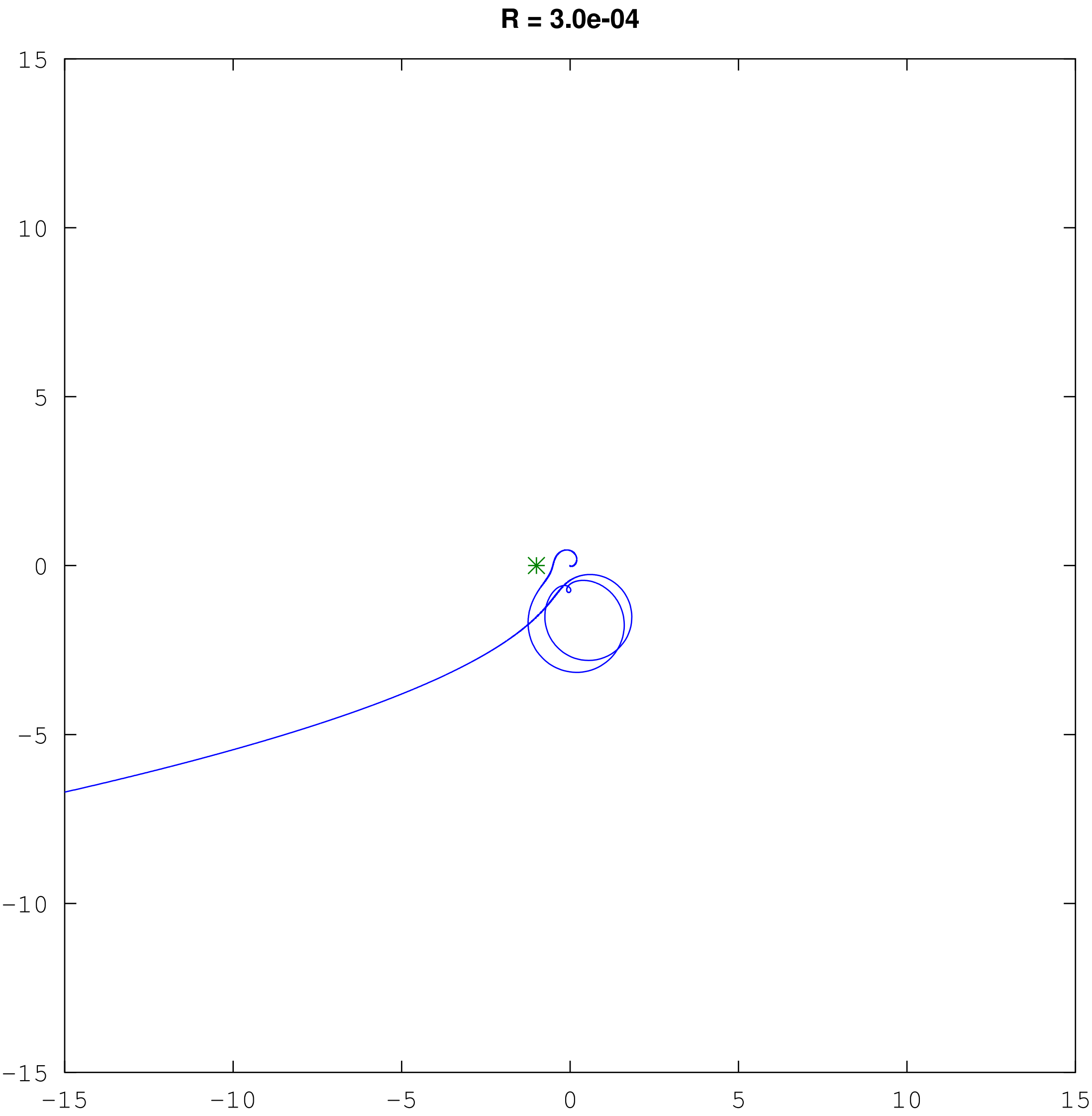

R = 3.0e-02
system
plant
controller
closed loop
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
10^0
10^1
10^2
10^3
10^4
10^5

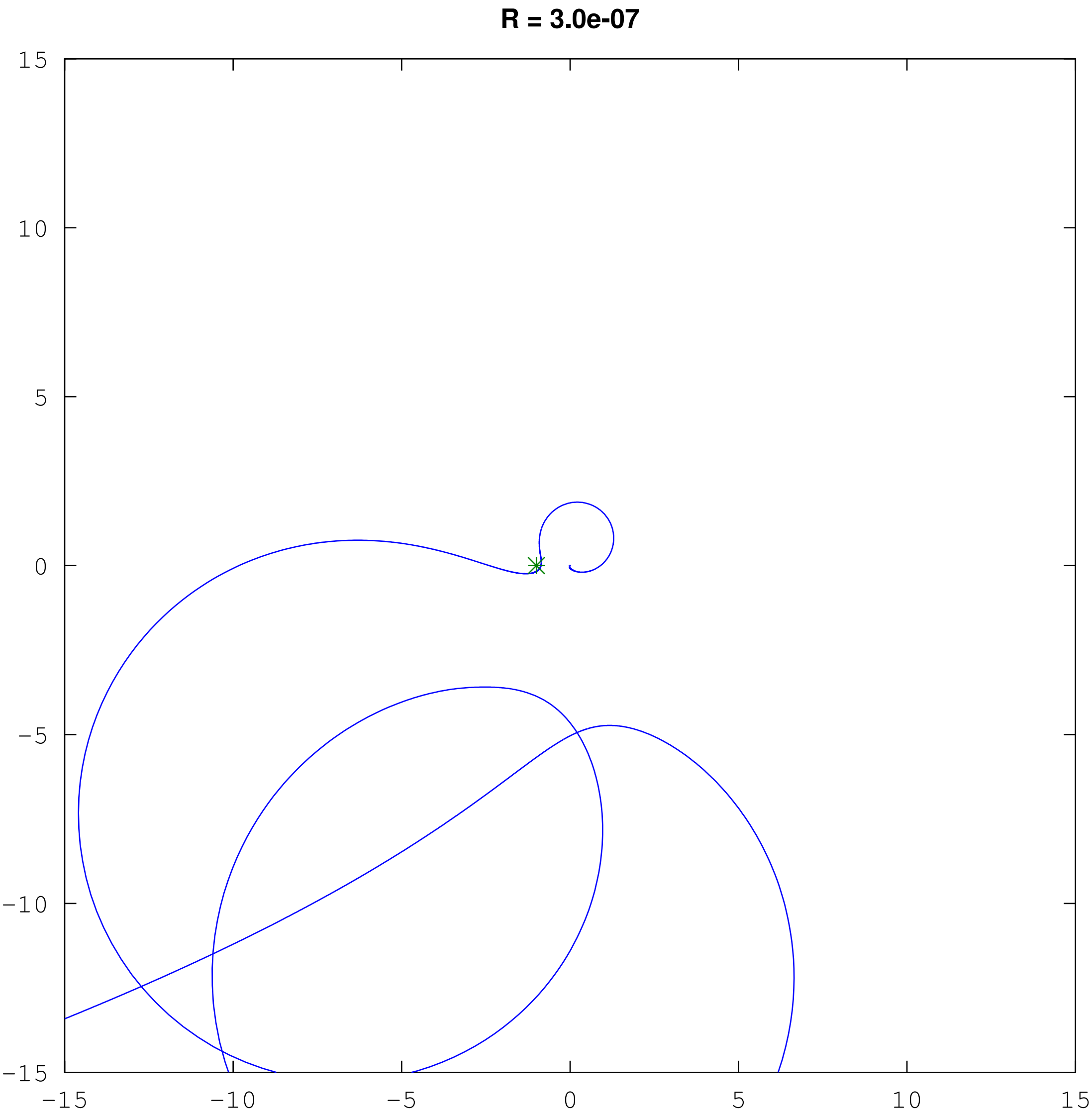


R = 3.0e-04
system
plant
controller
closed loop
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
10^0
10^1
10^2
10^3
10^4
10^5


R = 3.0e-07
system
plant
controller
closed loop
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
10^0
10^1
10^2
10^3
10^4
10^5


R = 3.0e-02
15
10
5
0
−5
−10
−15
−15
−10
−5
0
5
10
15


R = 3.0e-04
15
10
5
0
−5
−10
−15
−15
−10
−5
0
5
10
15

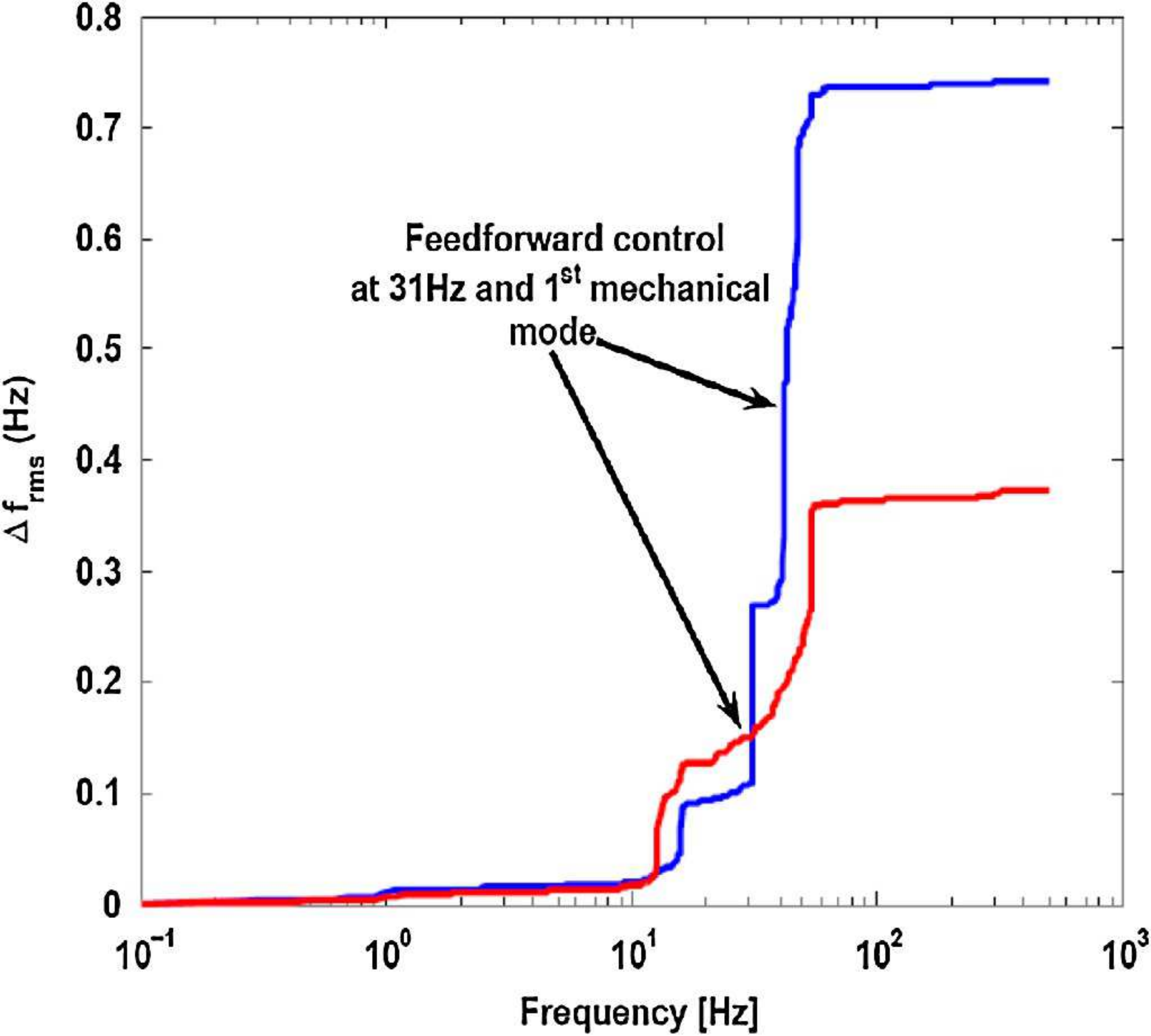

R = 3.0e-07
15
10
5
0
−5
−10
−15
−15
−10
−5
0
5
10
15

Reality

FRIB and HzB show 10 dB to 15 dB reduction (at best) in rms frequency excursions, by extending the bandwidth of tuner control from near-DC into the audio band.

Analysis and Active Compensation of Microphonics in Continuous Wave Narrow-Bandwidth Superconducting Cavities

A. Neumann *et al.*, PRST Accelerators and Beams, 2010


0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Δ f_{rms} (Hz)
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Frequency [Hz]
Feedforward control
at 31Hz and 1st mechanical
mode

Conclusion

If all that is asked of a piezo tuner is eliminating slow frequency drift, all that is needed is “small” backlash.

To reduce audio band excursions, the system has to be linear: zero backlash even when excited by audio signals.

Thank you for your attention!