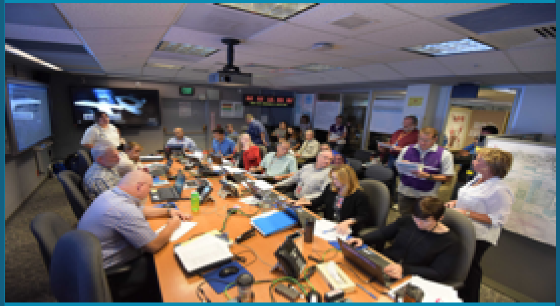
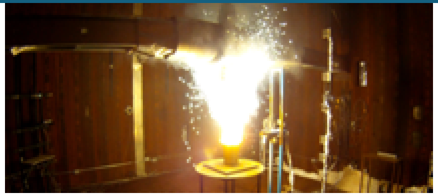
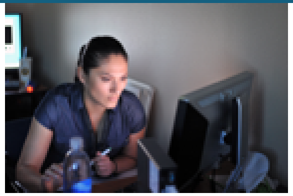
SAND2022-1033C

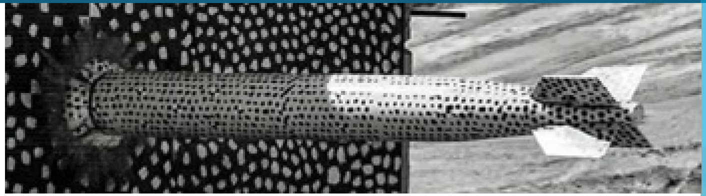
Sandia National Laboratories

Demonstration 2: Multiple-Input, Multiple-Output control









IMAC XL MIMO Vibration Short Course

Dan Rohe

U.S. Department of Energy ENERGY NNSA

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Outline

Test Setup

Description of Control Laws

Test Demonstration

Results Comparison

Test Specification Generation

Creating the Specification

Four shakers applied uncorrelated inputs to the “system” portion of the demo test article

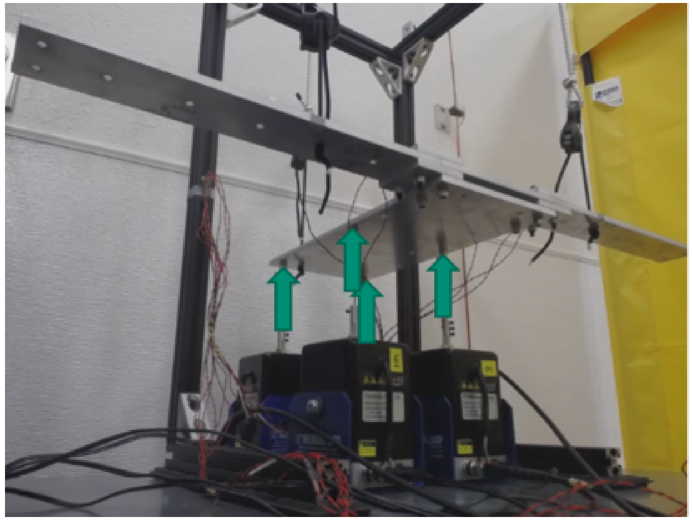
Six accelerometers measured response on the “component” portion of the system.

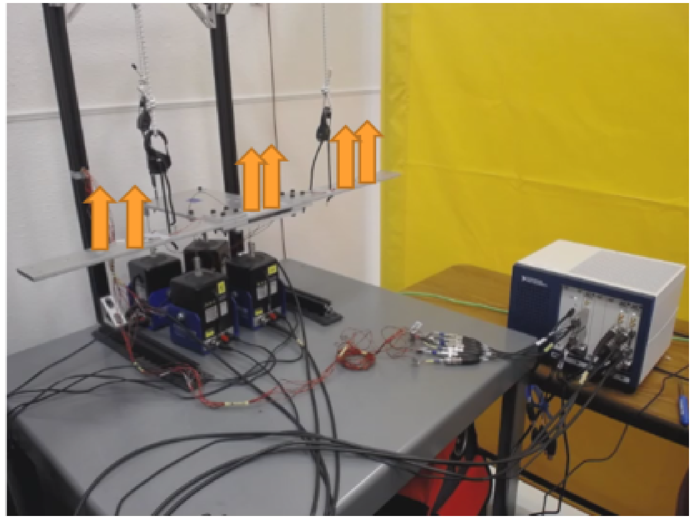
Test controlled using NI data acquisition system with Rattlesnake software.

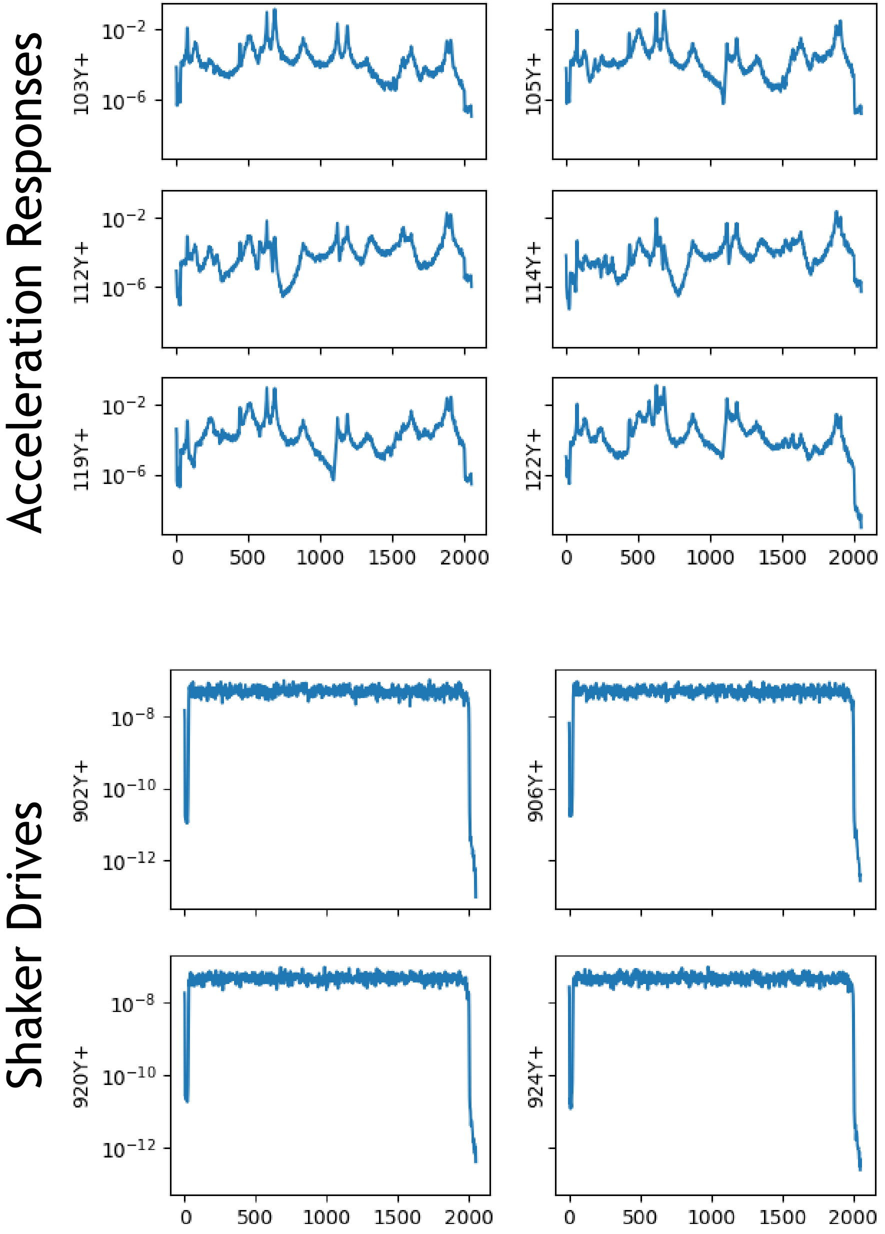
CPSD matrices were computed from the time response of the accelerometers and the voltage signals.

Acceleration CPSD matrices are used for the target specification.

For the MIMO case, all six accelerometer were used.







MIMO Test Setup

Goal: Perform a Multi-axis test with modal shakers

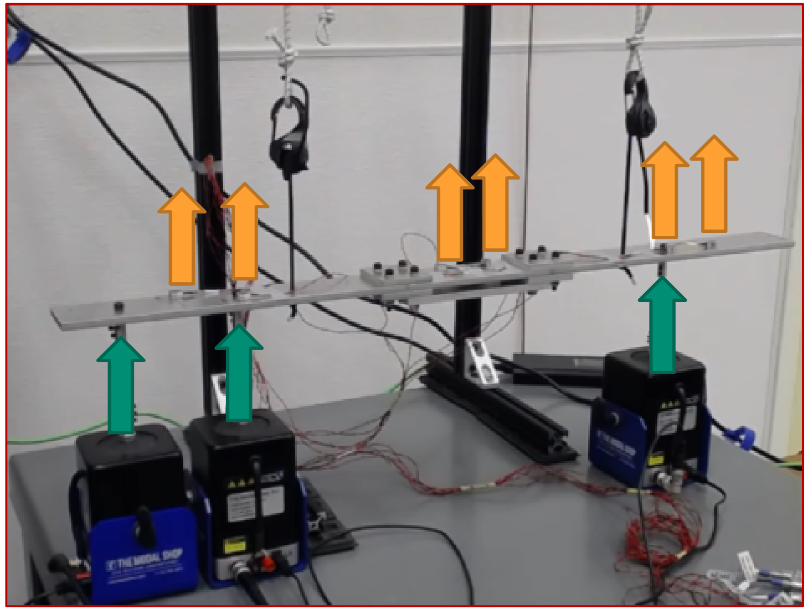
Attach multiple shakers at strategic positions along the test article.

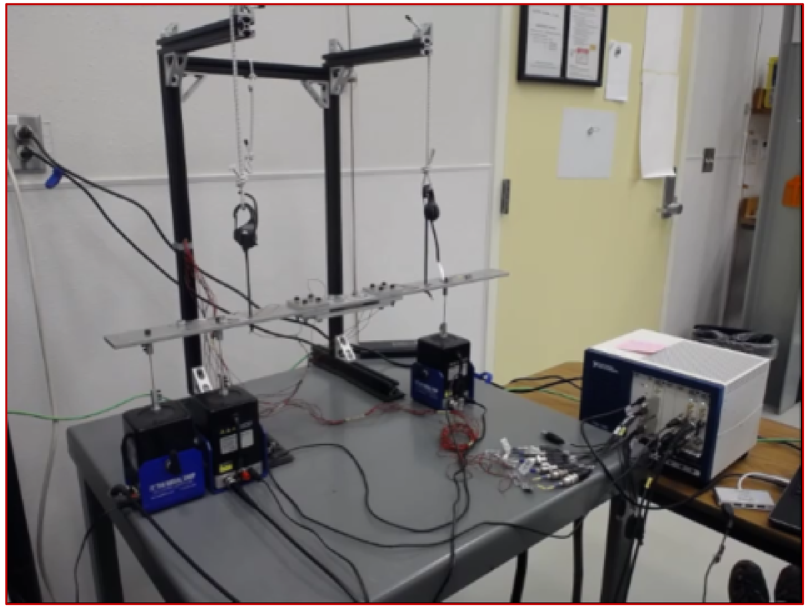
Use Rattlesnake to control responses at control accelerometers to those defined by the specifications.

Use several control laws to generate the output signals:

- Pseudoinverse
- Buzz Test
- Match Trace
- Shape Constrained

Explore the differences between the control laws and compare against single axis testing.





A bit more on the different control laws

Pseudoinverse Control

Simplest Control Law: Compute the pseudoinverse of the transfer function matrix and multiply by the specification

$$\mathbf{G}_{xx} = \mathbf{H}\mathbf{G}_{vv}\mathbf{H}^*$$
$$\mathbf{G}_{vv} = \mathbf{H}^+\mathbf{G}_{xx}\mathbf{H}^{+*}$$

Pros:

- Simple to implement

Cons:

- Can be inaccurate if problem is not well-posed
- Can suffer ill-conditioning

Buzz Test Method

Update the specification to match the dynamics of the unit under test [1].

$$\gamma_{ij}^2 = \frac{\left|B_{xx,ij}\right|^2}{B_{xx,ii}B_{xx,jj}}$$

$$\theta_{ij} = \angle B_{xx,ij}$$

$$\tilde{G}_{xx,ij} = e^{\mathrm{i}\theta_{ij}}\sqrt{\gamma_{ij}^2 G_{xx,ii} G_{xx,jj}}$$

$$\mathbf{G}_{vv} = \mathbf{H}^{+}\tilde{\mathbf{G}}_{xx}\mathbf{H}^{+^*}$$

Pros:

- Takes into account variations between the field test article and lab test article; doesn't force field article's dynamics on lab article.

Cons:

- Changing the specification *may* remove some important characteristics of it

[1] Daborn, Smarter Dynamic Testing of Critical Structures, PhD Thesis, University of Bristol, 2014

Match Trace Method

Simple closed-loop control law to scale each frequency line to match the sum of ASDs

$$\mathbf{G}_{vv,k} = \mathbf{G}_{vv,k-1} \frac{\sum_i G_{xx,ii}}{\left(\sum_i \hat{G}_{xx,ii}\right)_{k-1}}$$

Pros:

- Can typically match the sum of the diagonals of the CPSD matrix

Cons:

- Often requires more force to achieve than the buzz test approach
- Matching overall system response can sacrifice individual gauge accuracy

Shape Constrained Approach

If struggling to hit a test level, constrain shakers to work together rather than fight against each other [2]

$$\mathbf{USV}^H = \mathbf{H}$$
$$\mathbf{S}_{keep} = \mathbf{S}[\mathbf{S} > threshold]$$
$$\mathbf{V}_{keep} = \mathbf{V}[\mathbf{S} > threshold]$$
$$\mathbf{H}_c = \mathbf{HV}_{keep}$$
$$\mathbf{G}_{vv,c} = \mathbf{H}_c^+ \mathbf{G}_{xx} \mathbf{H}_c^{+*}$$
$$\mathbf{G}_{vv} = \mathbf{V}_{keep} \mathbf{G}_{vv,c} \mathbf{V}_{keep}$$

Pros:

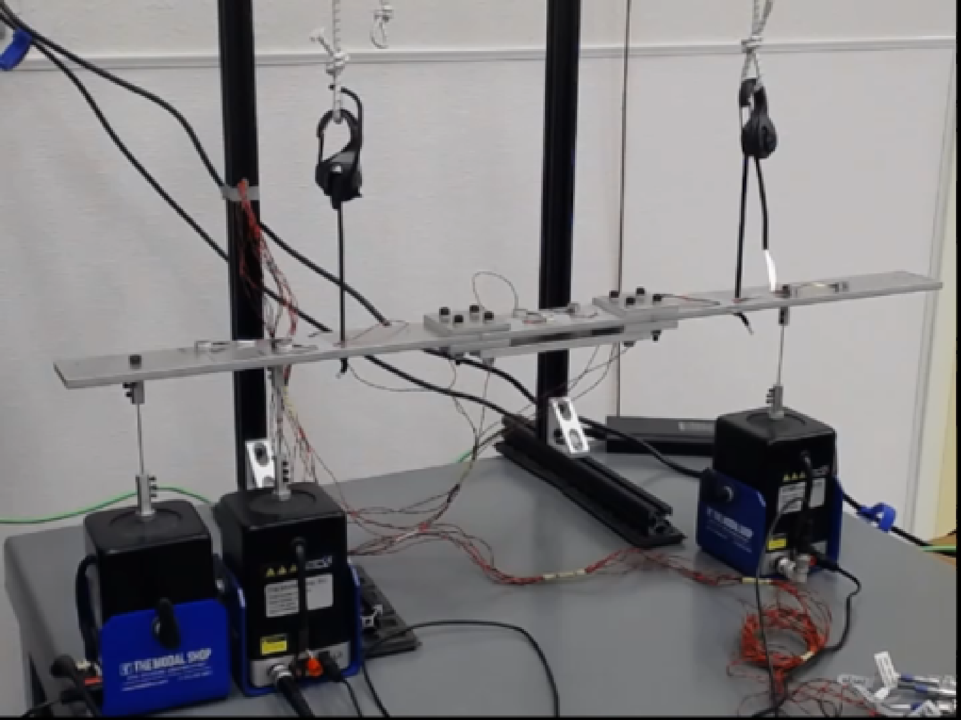
- Can significantly reduce force/voltage/current required to run a test

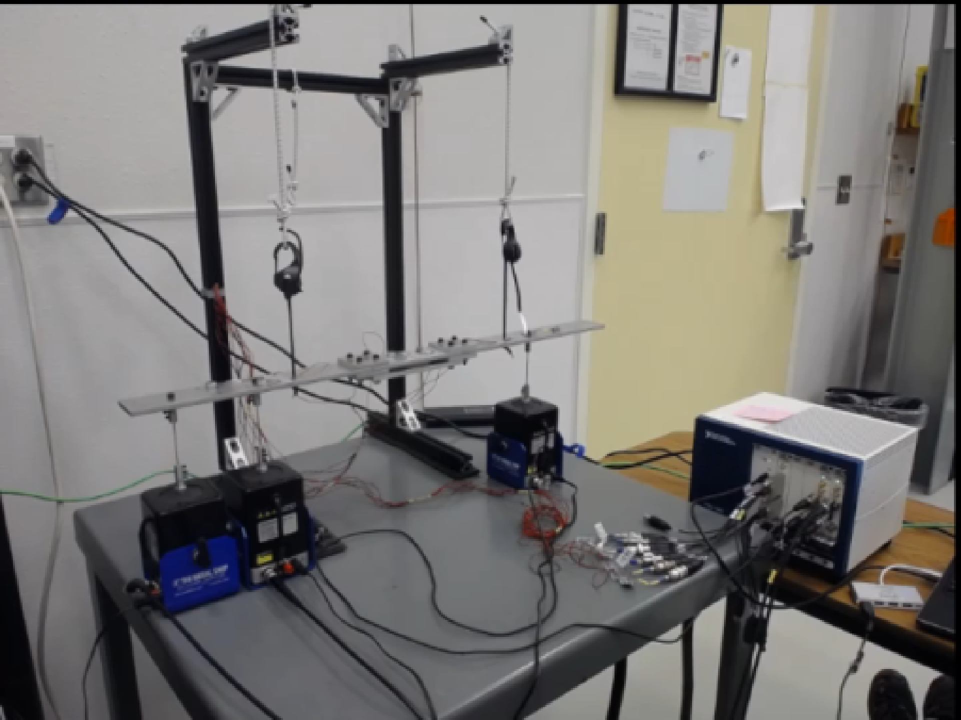
Cons:

- Accuracy of response is degraded

[2] Schultz, Shape-constrained Input Estimation for Efficient Multi-shaker Vibration Testing, Experimental Techniques, 2020

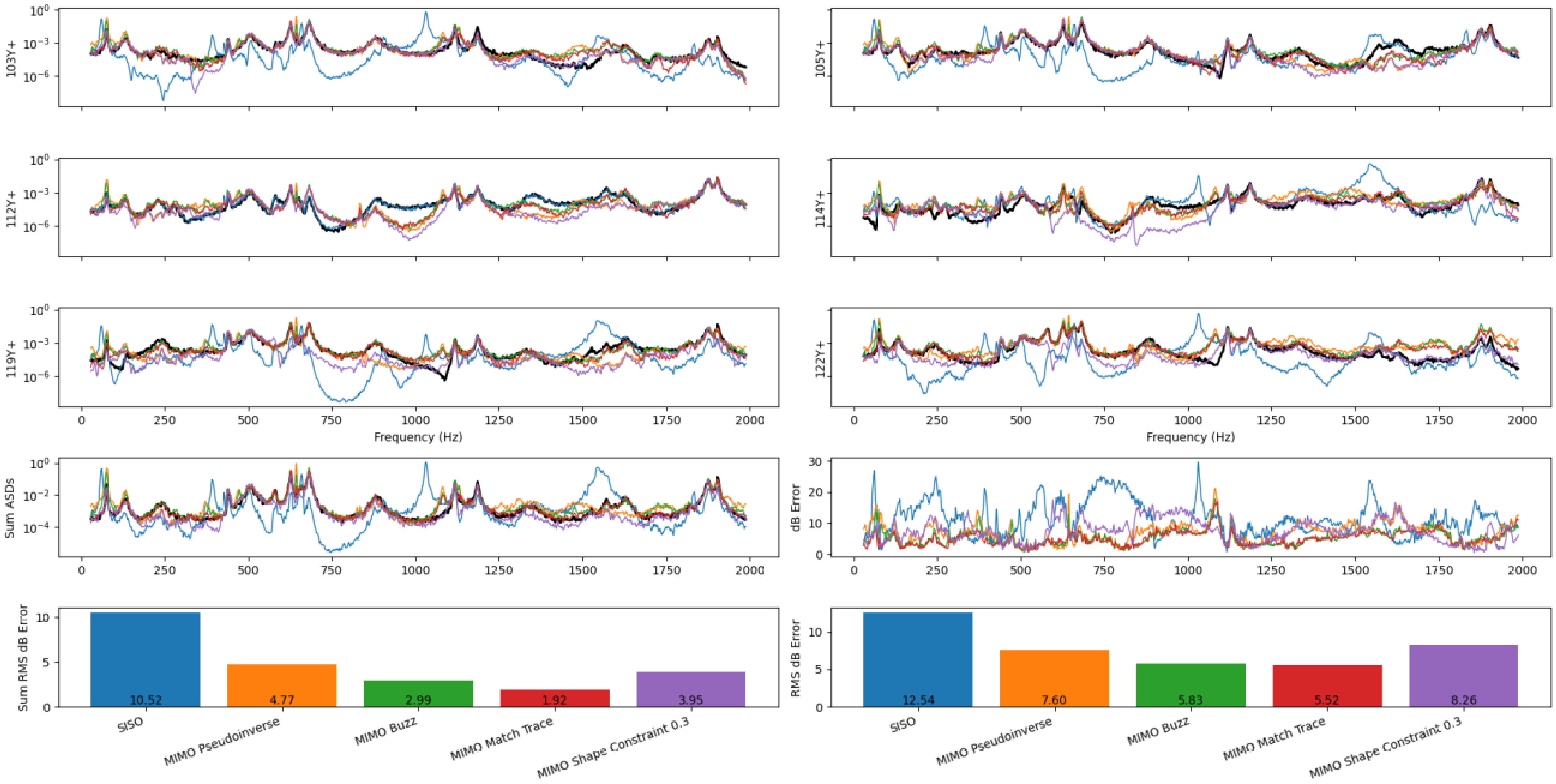
MIMO Test Demonstration


THE MODAL SHOP


THE MODAL SHOP

MIMO Results

MIMO Test Results



Conclusions

Conclusions

MIMO testing offers significant improvements over single axis testing:

- Can control the shape of the response
- More accurate over more of the part than with single axis testing

There are a number of different control laws available depending on goals:

- If force is not limited, a closed loop control law can often get you the best results
- If force is limited, might need to constrain shakers to work together instead of fighting each other.