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Combining Test and Simulation to tackle boundary condition mismatches in Environmental Testing

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Product Line Manager Structures & Environmental Testing

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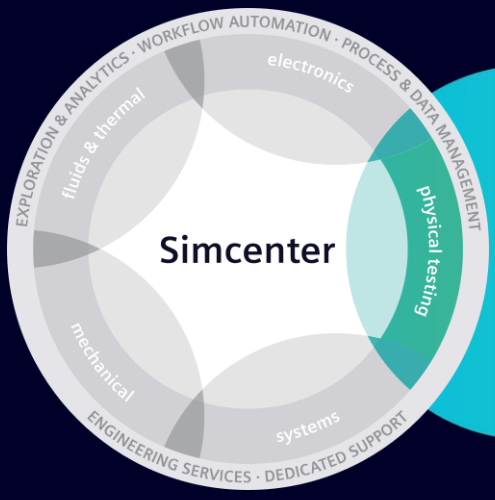
Physical testing



Drive innovation and productivity in test-based engineering

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Main motivation for this work

- Current practices of component environmental vibration testing
  - Non-realistic excitation
  - Mechanical impedance mismatch due to differences between the operational and the test boundary conditions
- Concern: real failure modes of the component are not correctly replicated

- How can we improve it?
  - Can we provide guidelines?
  - Can we use simulation to support the testing practice?

Service environment replication at the component level

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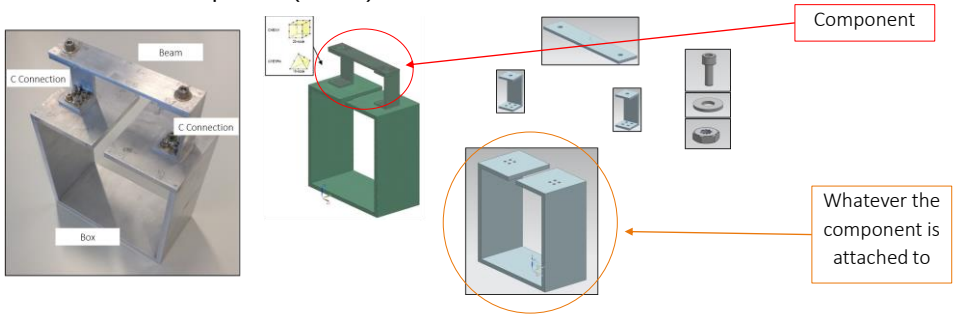
The Boundary Condition Challenge

- Initiated by Kansas City National Security Campus (Honeywell) & Sandia
- The challenge: replicate service environment responses at a component-level (shock & vibration tests)
- Demo hardware design: an easy-to-model structure, complicated enough for environmental testing
- Box Assembly with Removable Component (BARC)



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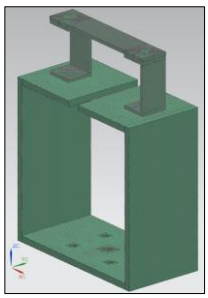
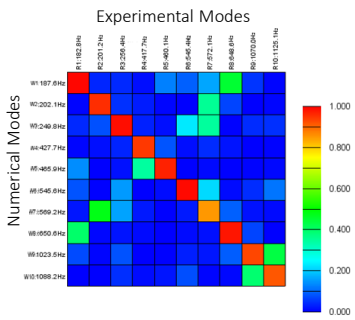
FE modelling and model validation
Free-free boundary conditions

- Modelled using Simcenter 3D (Nastran solver used for modal analysis)
- Model validation using Simcenter Testlab
  - Impact testing
  - Experimental modal analysis (EMA)
- Correlation and updating using Simcenter 3D



Mode	Exper. f_n [Hz] (1)	Num. f_n [Hz] Before Update (2)	Num. f_n [Hz] After Update (3)	Error [%] (1) - (2)	Error [%] (1) - (3)
1	182.84	185.32	187.57	-1.35	-2.59
2	201.22	199.84	202.008	0.69	-0.39
3	256.40	246.28	249.680	3.95	2.62
4	417.72	422.85	427.528	-1.22	-2.34
5	460.10	460.00	465.833	0.02	-1.25
6	545.44	538.45	545.449	1.28	0.00
7	572.07	561.29	569.197	1.89	0.50
8	648.57	641.55	650.517	1.08	-0.30
9	1069.98	1000.85	1023.110	6.46	4.38
10	1125.11	1068.49	1087.678	5.03	3.33



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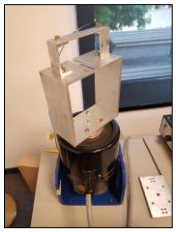
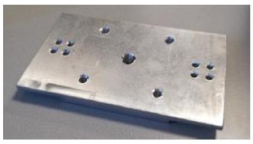
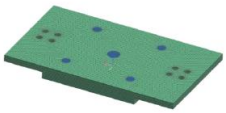
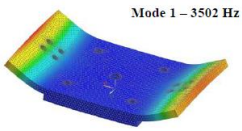
Fixture design

- The fixture is specifically designed for component level testing (without the box)
- The first resonant mode (fixed @ 4 holes) needs to be well above the upper limit of the frequency range of interest (2000 Hz)









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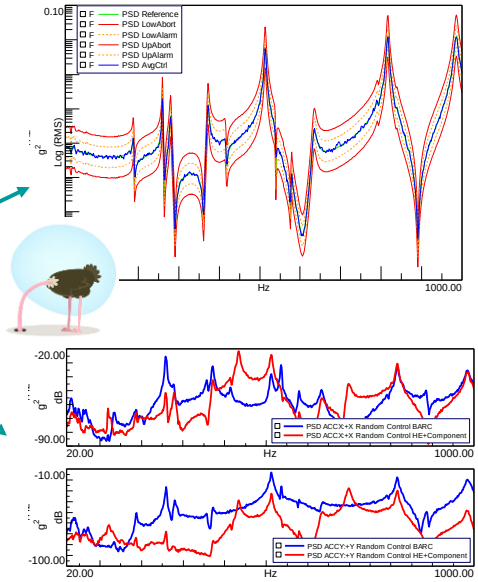
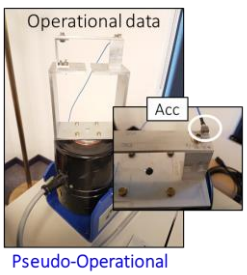
The challenge
Random control - Control channel Acc:+Z

- Target obtained running an open-loop random test on the BARC (next level assembly)
  - (Flat voltage profile -> that's why acc profile is "dynamic")
- Random control on the HE+COMPONENT
  - The control perfectly matches the target in this case….
  - …but responses completely off elsewhere!





Pseudo-Operational

Component test

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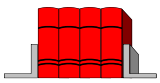
Mission Synthesis / “Test Tailoring”

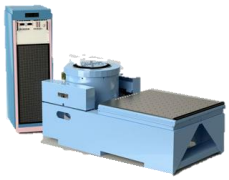
How to derive realistic vibration qualification specifications for complex device-under-test (DUT) mounted on a vibrating structure?

- Based on measurements in the real-life environments (instead of generic standards)
- Principle of “damage equivalence”

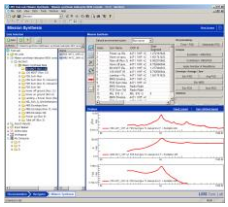
Data acquisition during product mission



Standards



Environmental testing



Mission analysis and test specification synthesis

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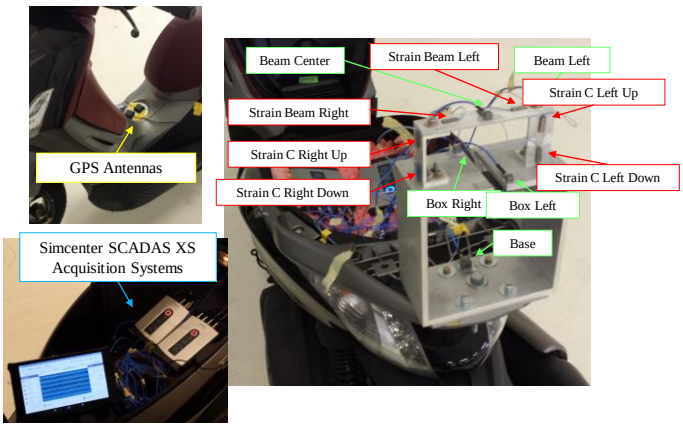
Operational Environment
Road Excitation recordings



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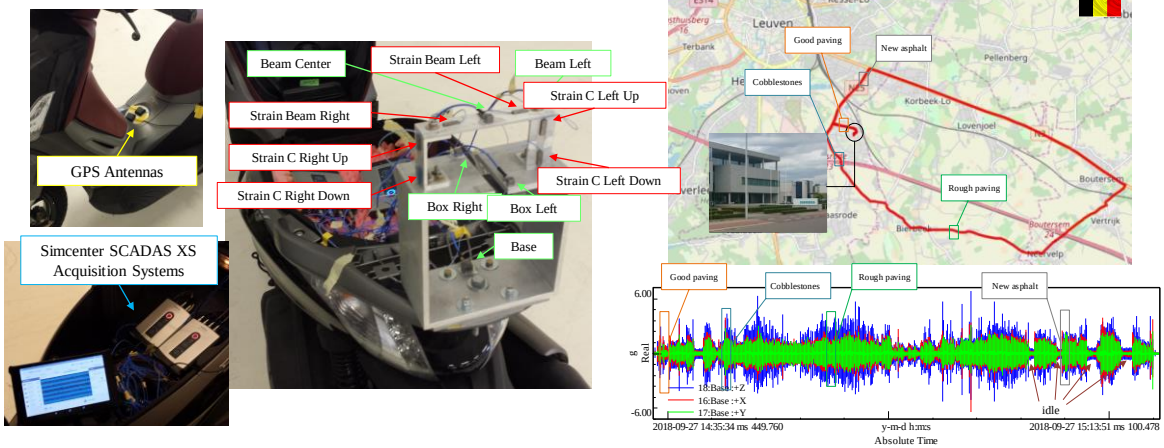
Operational Environment
Road Excitation recordings



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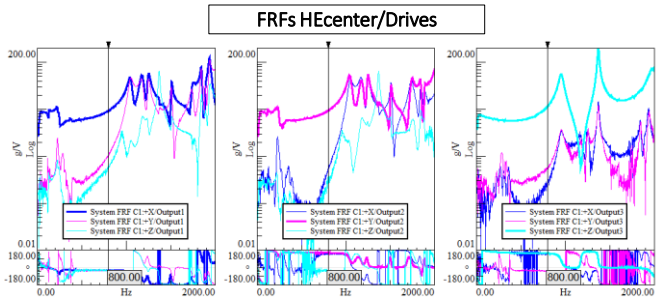
MIMO Random Control
3D Excitation with a 10-kN three-axis shaker

- 10 kN Dongling Shaker (courtesy of University of Ferrara)
- 21 ICP Channels (5 Accels + 6 strain sensors)
- 3 Drives
- Simcenter SCADAS Mobile SCM05V
- Simcenter Testlab Environmental Testing



Fully 3D coupled empty shaker

MIMO Control needed

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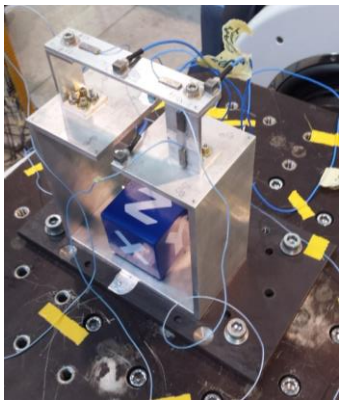
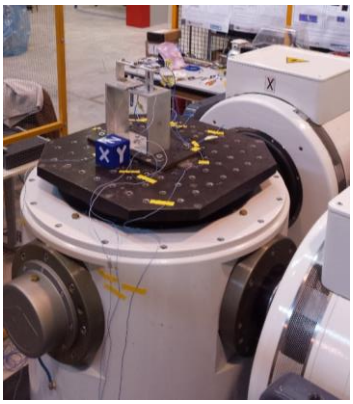
MIMO Random Control
Test Setup

- 15kg off-the-shelf head expander
- 20x30 iron plate to fix the BARC on the HE (holes compatibility)





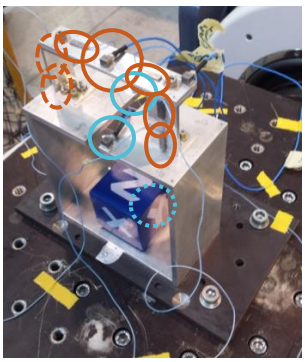
MIMO Random Control
Test Setup and planning

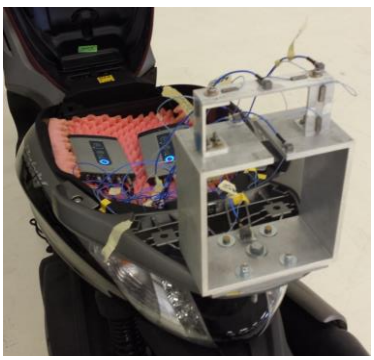
Test run using different control strategies

- SISO Z-dir (same conclusions with X and Y)
- MIMO controlling the Base (X, Y, Z) (3x3 --> square control)
- MIMO controlling the Base and the Box (9x3 --> rectangular control)

The idea is to look what happens **<u>at the component level</u>**

- Monitoring acceleration channels
- Monitoring ICP strain sensors





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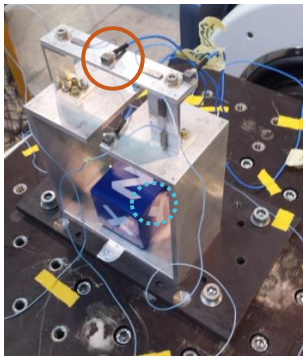
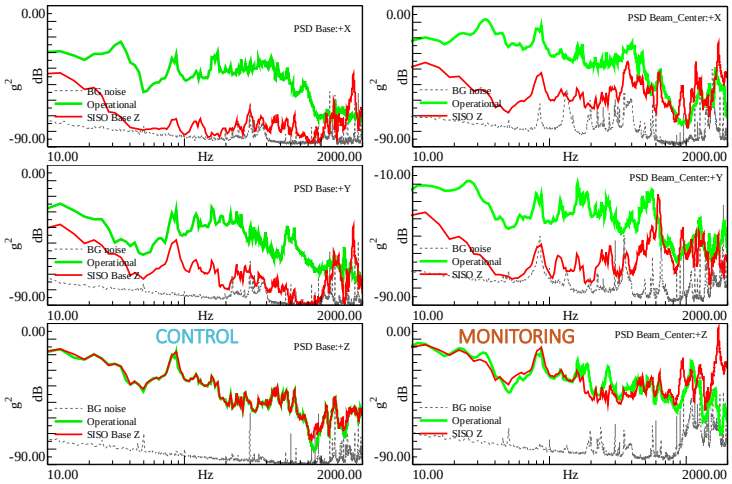
SISO Random Control with shaker of comparable size Controlling the Base (Z only)

Monitoring (Z) +/-OK, except over-testing @1700 Hz



CONTROL

MONITORING



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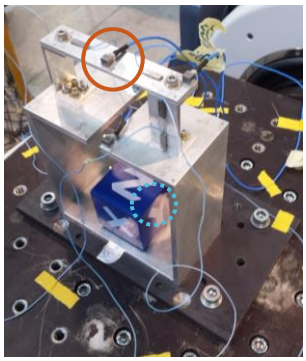
MIMO Random Control Controlling the Base (Square control)

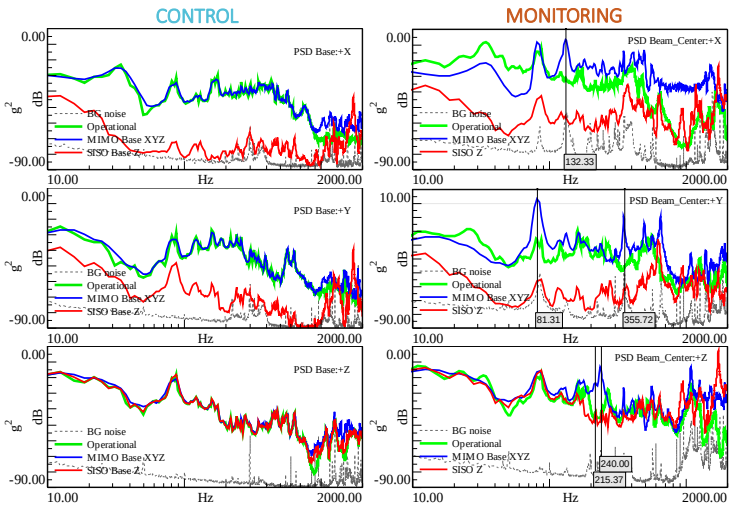
Simultaneous matching of all directions

Significant deviations from field responses



CONTROL

MONITORING



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MIMO Random Control
Using simulation models to enhance understanding

Largest deviations at box resonances

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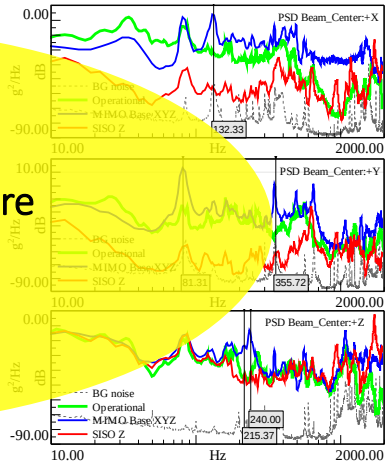
We cannot ignore the fixture resonances!



CONTROL

MONITORING

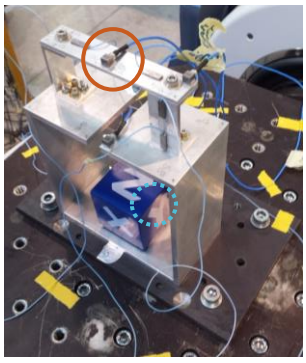
MIMO Random Control
Controlling the Base (Square control)

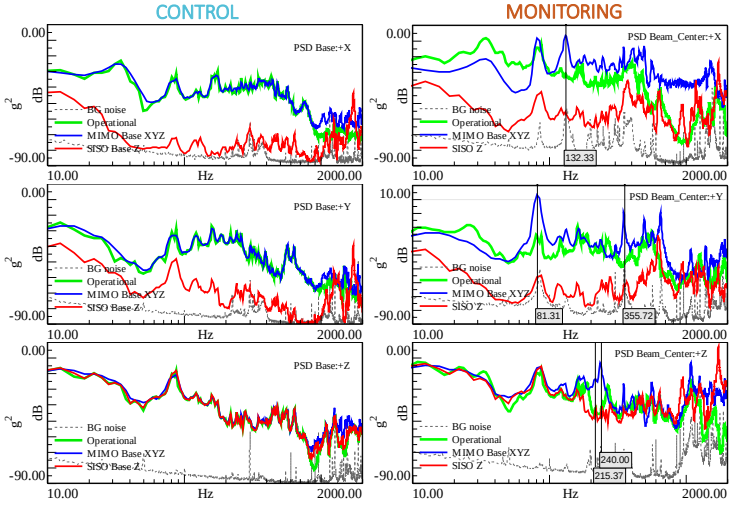
Simultaneous matching of all directions

Significant deviations from field responses

CONTROL

MONITORING





CONTROL

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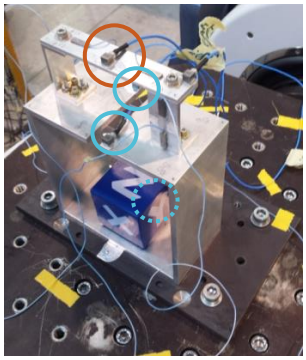
MIMO Random Control
Controlling the Base and the Box
(Rectangular control)

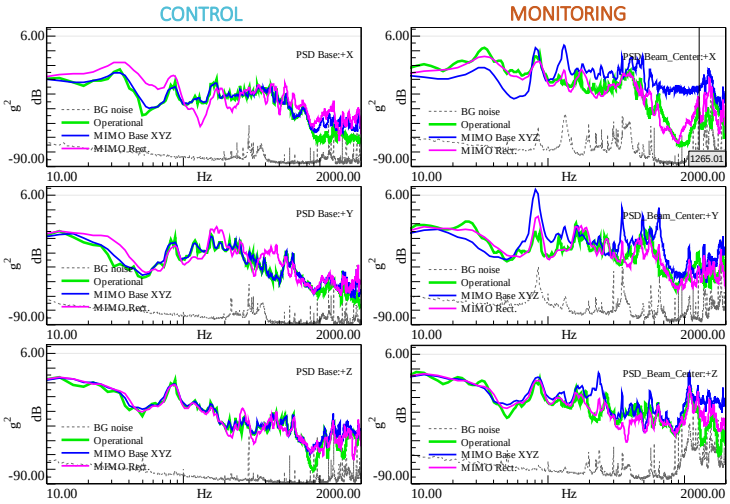
At base, field data less well matched

Much improved component behaviour



CONTROL

MONITORING



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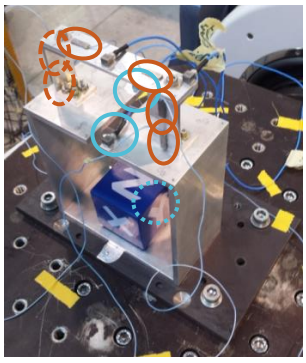
MIMO Random Control
Controlling the Base and the Box
(Rectangular control): strain measurements

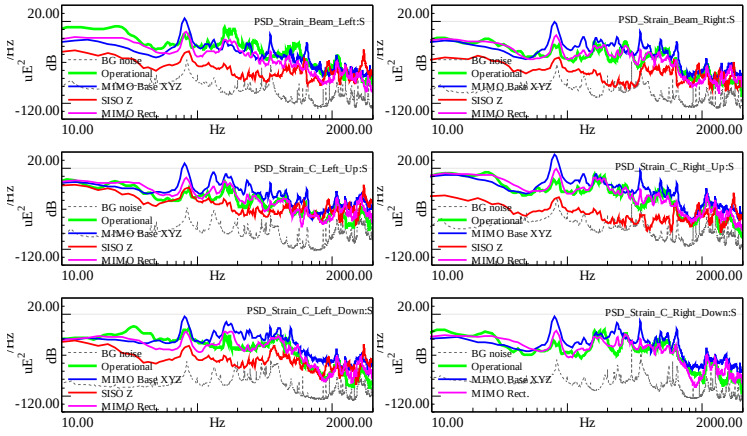
Quality increase: SISO < Square < Rectangular

MONITORING



CONTROL

MONITORING



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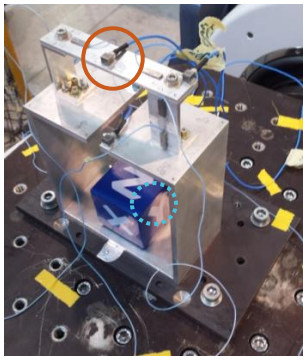
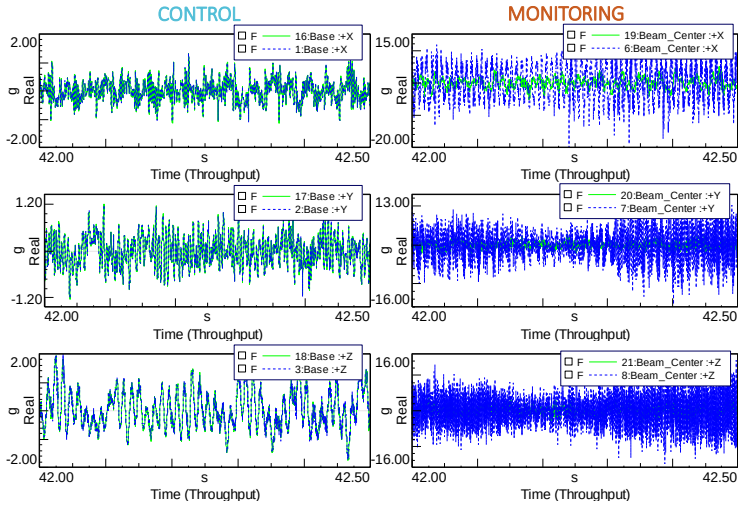
Time Waveform Replication
Square Control

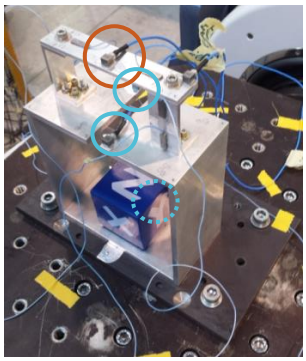


CONTROL

MONITORING

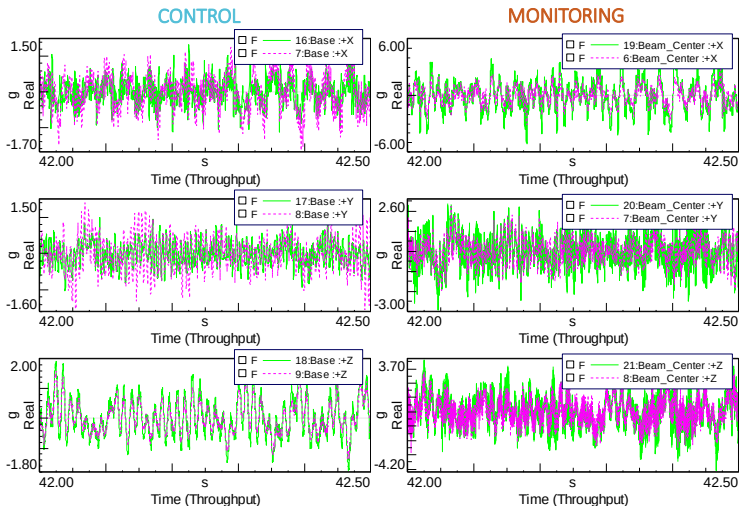


Time Waveform Replication
Rectangular Control



CONTROL

MONITORING



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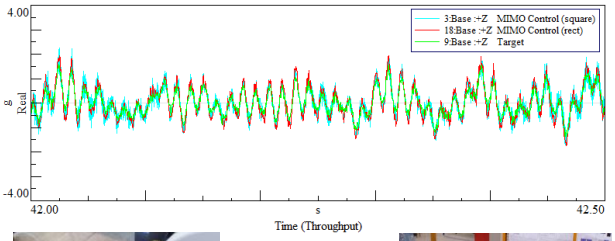
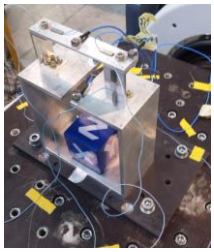
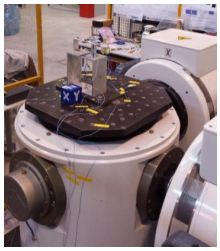
The Boundary Condition Challenge







Operational Environment

MIMO Square

MIMO Rectangular

Conclusions

- The environmental replication in the lab is influenced by the mismatch between the operational and the laboratory impedance and excitation mechanisms
- Very good response replication @ the control channels does not necessarily mean good operational replication
  - **Excitation mechanism**
  - **Impedance mismatch**
- Improvements possible? Conclusions from this introductory study:
  - Try to get as close as possible to the next level assembly during the testing and to the real excitation mechanism (3DOF? 6DOF?)
    - Try to control multiple sensors in the next level assembly during the testing.
  - Main interest lies in the **responses at the component level**
    - Control channels @ Base (rectangular case) may not look as good as the square or SISO case, but we are actually doing better
    - Control channels are matched in a least-square sense (i.e. as good as possible given imperfect fixture/excitation mechanism)

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