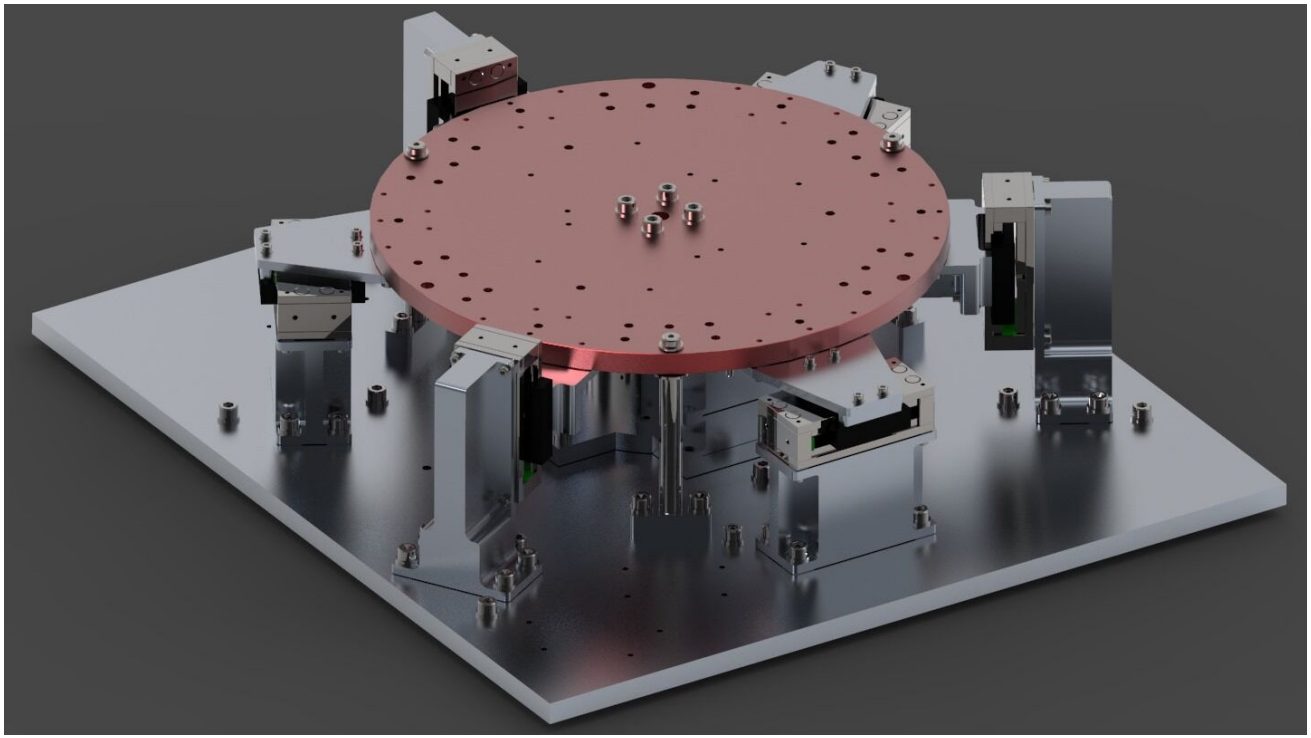
MAGLEV ON A BUDGET: *A STUDENT DISCOUNT*

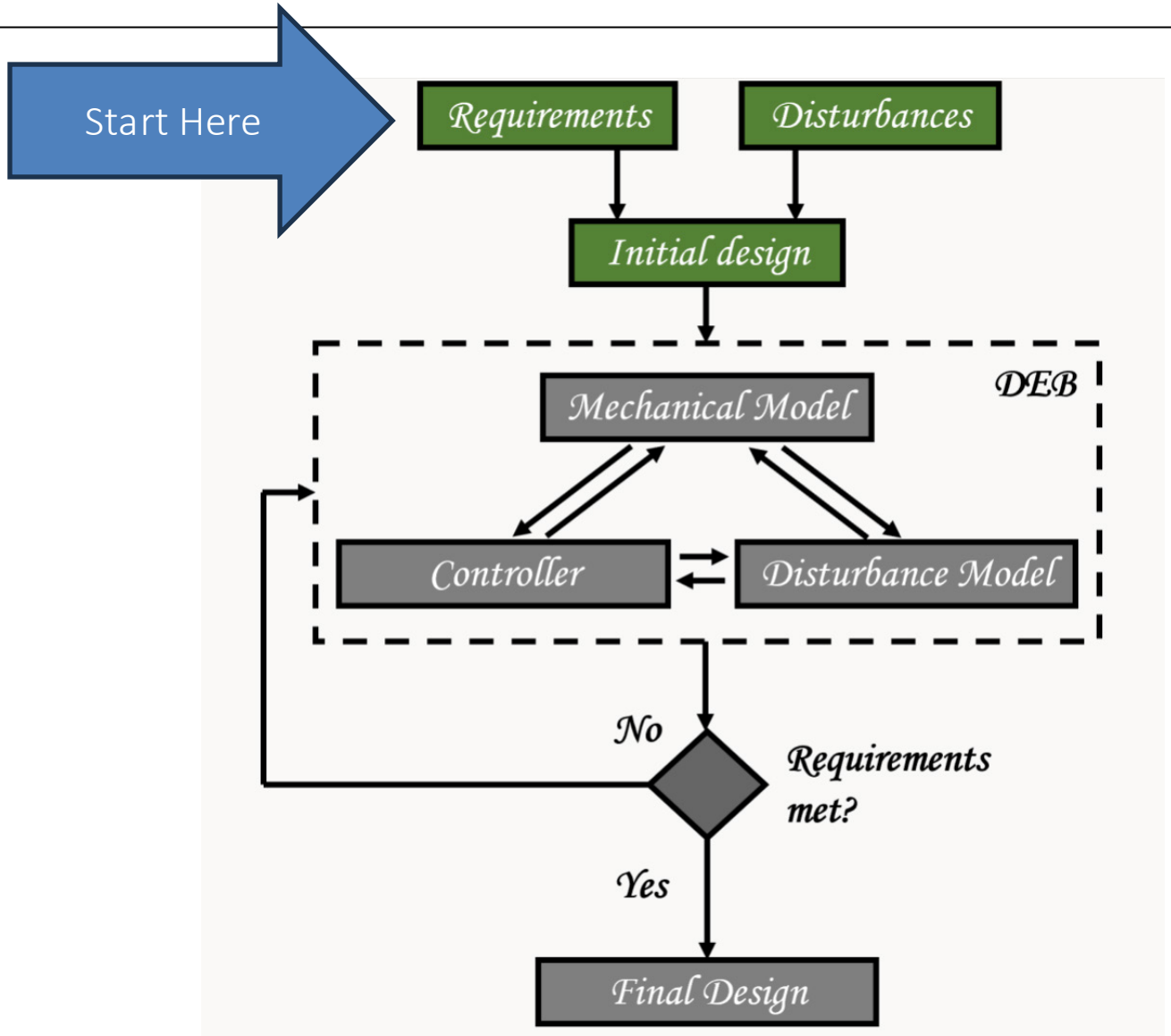


Dr Jon Kelly
The Diamond Light Source
UK

Motivation: Why Build A Maglev?

- Proof-of-concept Vibration Isolation for Endstations
- A step in my campaign to embrace Mechatronics
- A vehicle for training, creating MATLAB tools and gaining experience
- Cost effective R & D using talented students
- **It sounded really cool!**

Mechatronics Process



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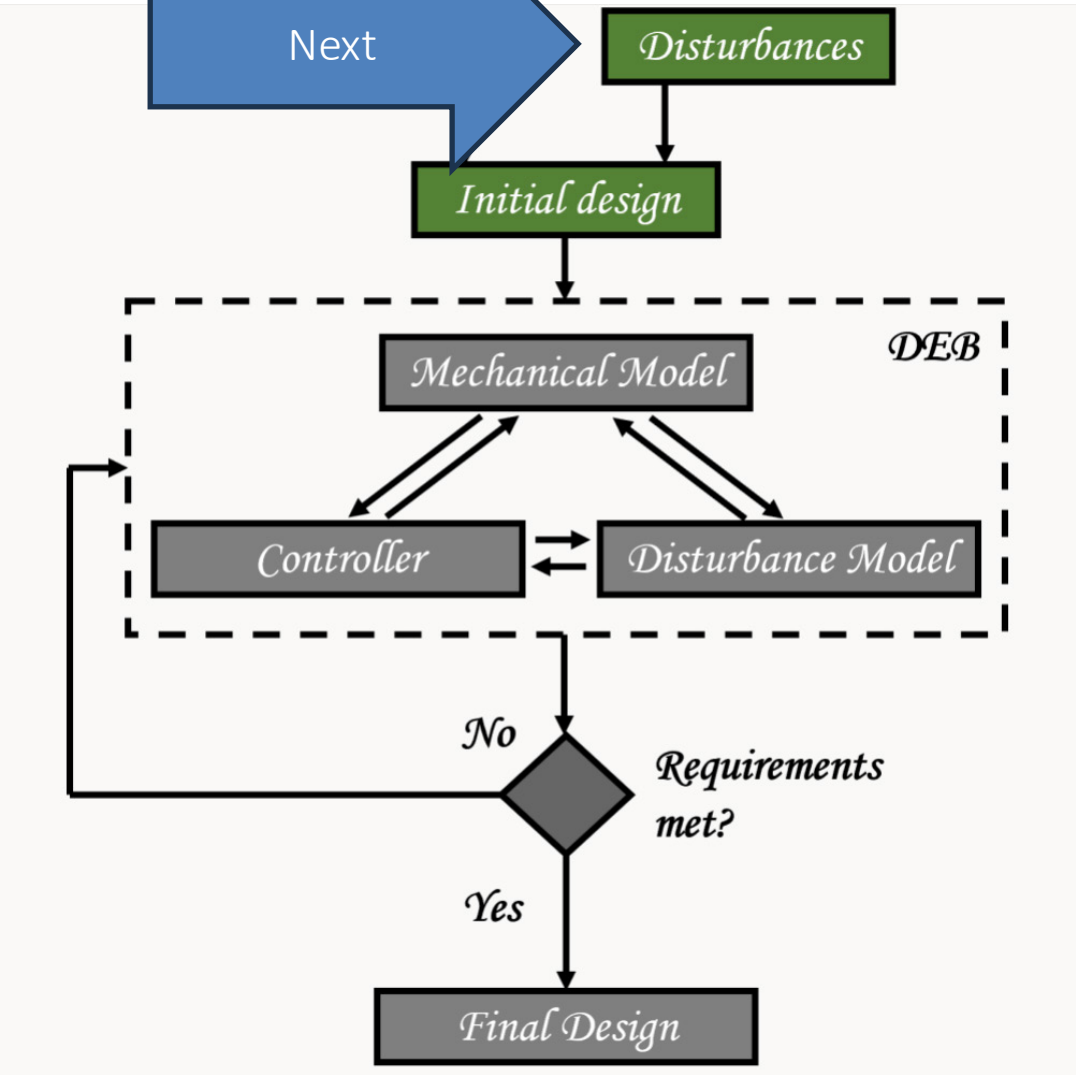
Requirements

The top-level requirements defined for the project were:

- Vibration transmission < 10% from 10 – 500 Hz
- Load capacity >10 kg
- Low profile ~ 0.5 x 0.5 x 0.2 m maximum envelope
- Provide 6 DOF motorised alignment
- Position Stability ± 0.5 µm, 1-1000 Hz Peak-Peak
- Angular Stability ± 0.5 µrad, 1-1000 Hz Peak-Peak
- Travel Range XYZ ± 1 mm
- Pitch/Roll/Yaw ± 1 mrad
- Low budget & Delivered within 1 year

All this was based on a beamline endstation application

Mechatronics Process



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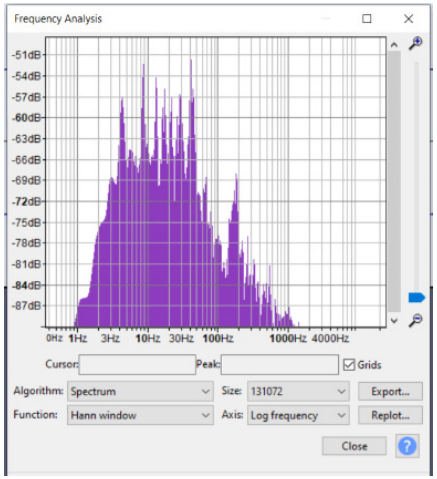
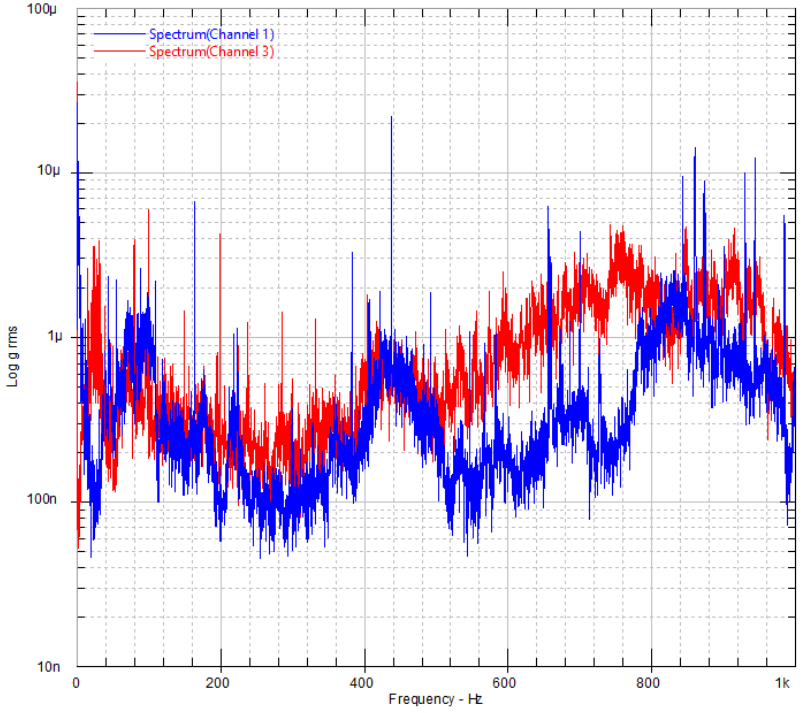
Disturbances

Only considered:

- Table vibration
- Amplifier Noise
- Sensor Noise
- DAC resolution

Ignore acoustic disturbance





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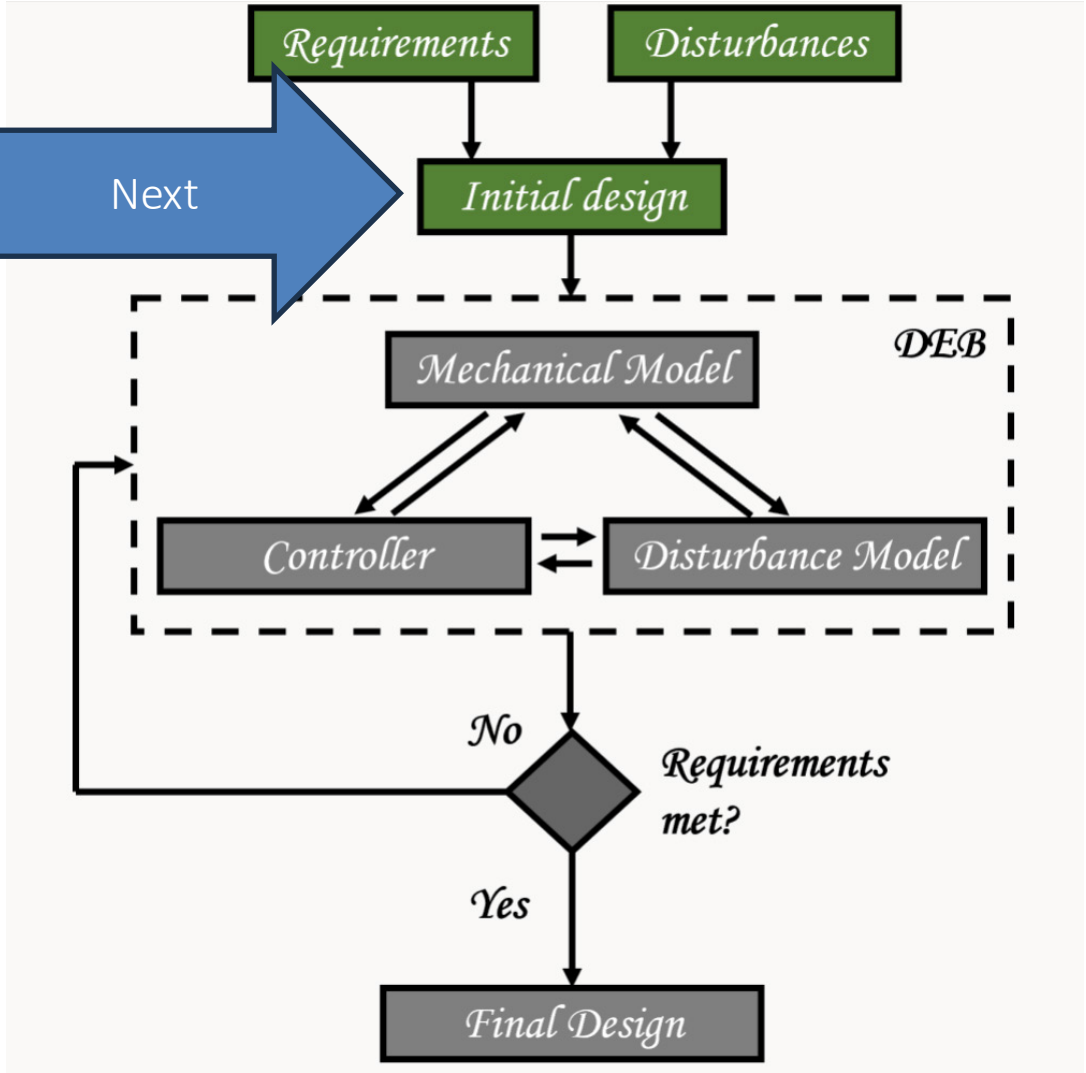
Mechatronics Process



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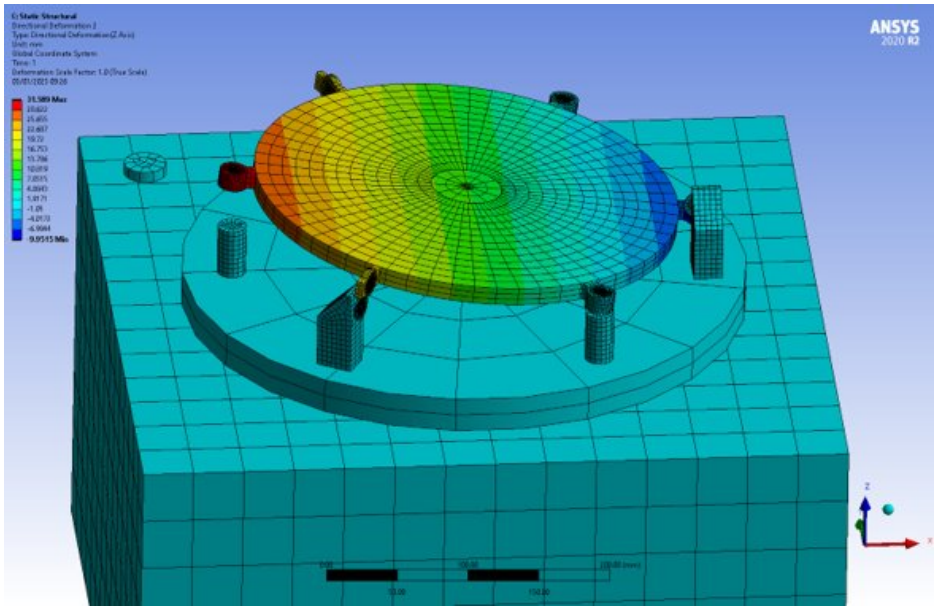
Initial Design

Aim for a symmetric design with a co-incident centre of mass and centre of stiffness

Major Components

- Voice Coils
- Position Sensors
- Control System hardware & software
- Gravity Compensator



Voice Coils

Keep life simple and just order catalogue coils which meet our requirements

- Force
- Size & Shape
- Current

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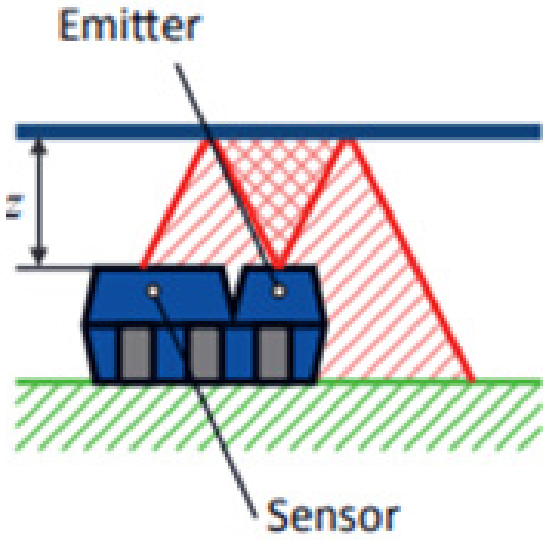
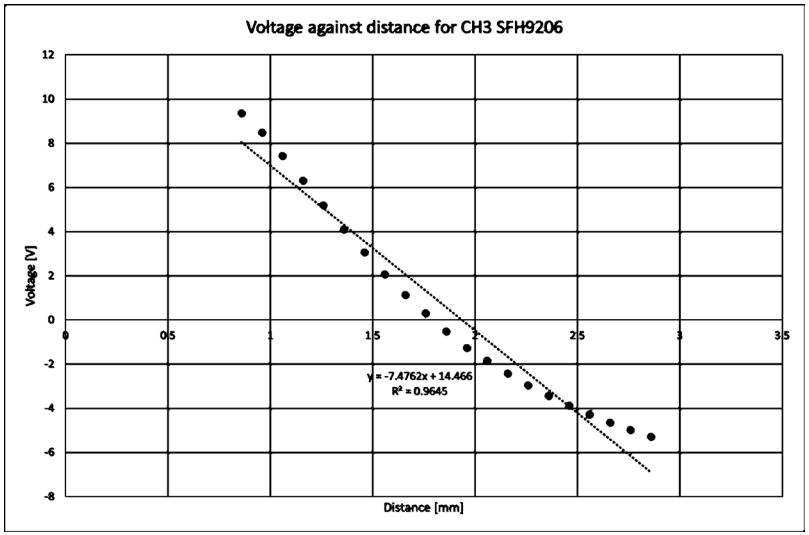
Position Sensors

Retro-reflective phototransistor, OSRAM SFH 9206





Custom PCBs designed to amplify & filter the sensor signals

Calibration assumed to be linear for simplicity

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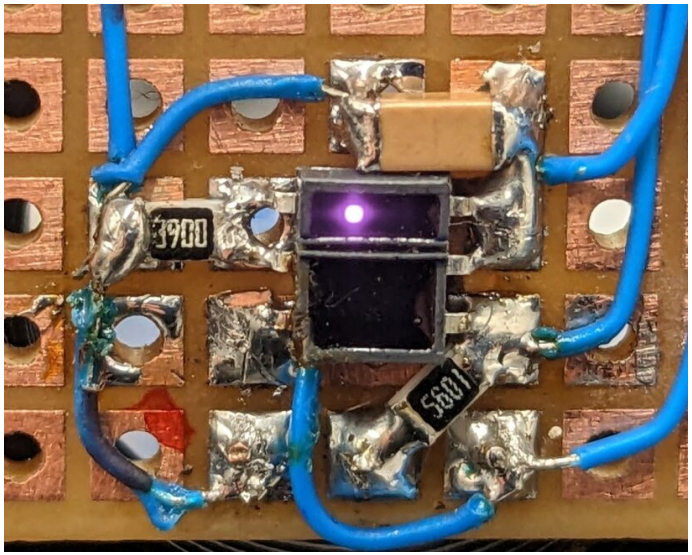
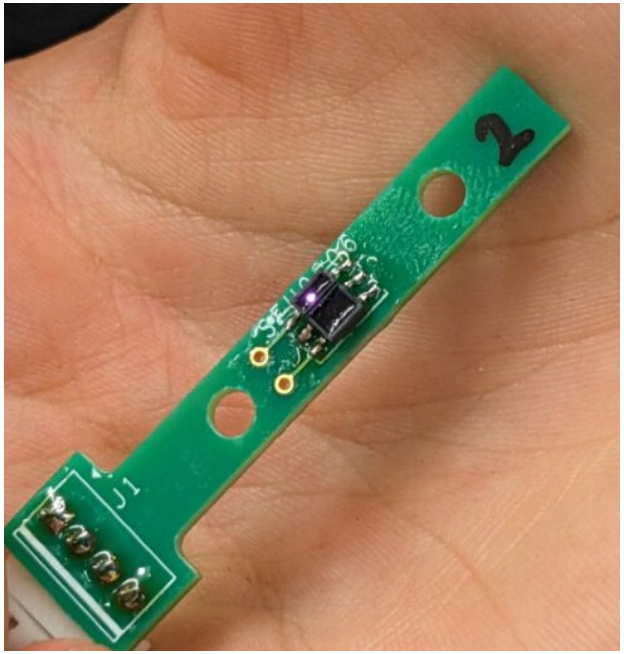
Position Sensors: PCB

Retro-reflective phototransistor, OSRAM SFH 9206



Initial concept test set-up



Final PCB ready to be inserted into the voice coil

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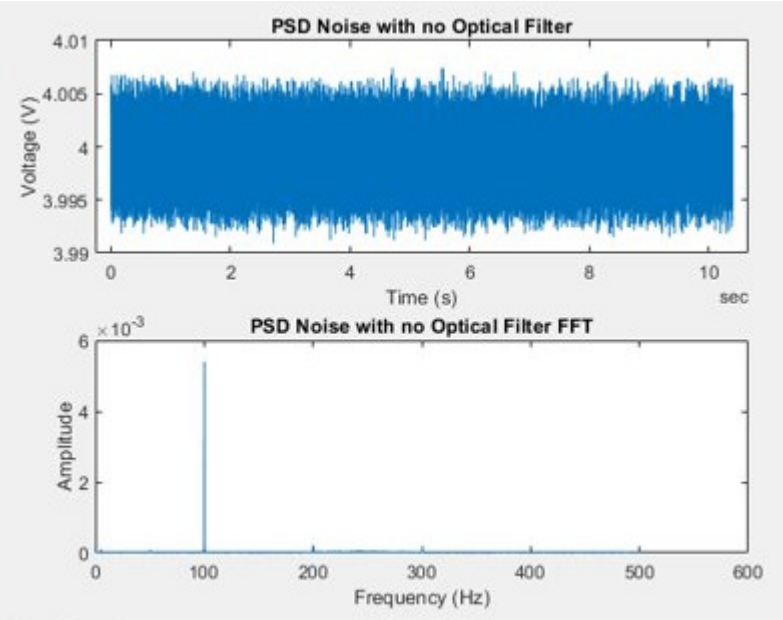
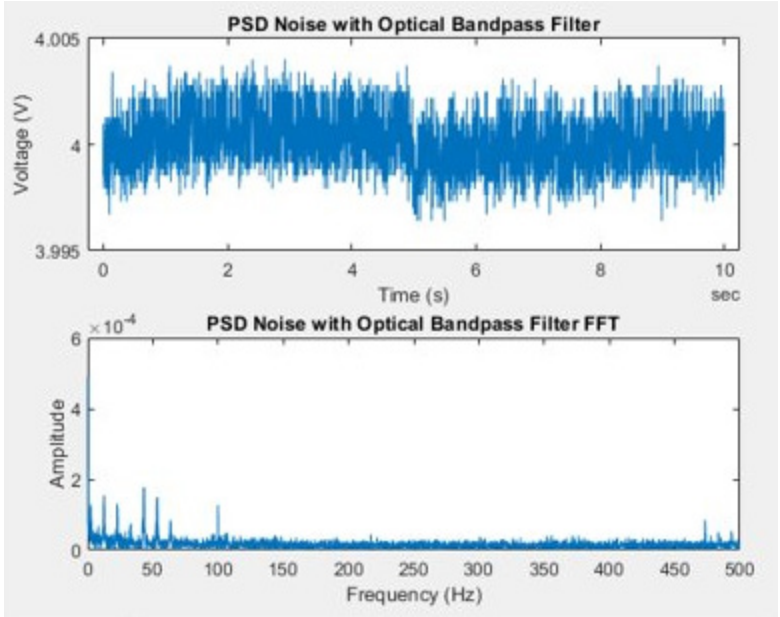
Position Sensors: Filters



Raw 100Hz Sensor Noise



Tuned Analogue Electronics Low Pass Filter

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GRAVITY COMPENSATOR

Most magnetically levitating motion stages employ a gravity compensator to minimise the power required to resist gravity. There are various published examples such as:

[1] S. A. J. Hol, 'Design and optimization of a magnetic gravity compensator', doi: 10.6100/IR574485.
[2] R. Deng, 'Integrated 6-DoF Lorentz Actuator with Gravity Compensation for Vibration Isolation in In-Line Surface Metrology', 2016, doi: 10.4233/uuid:e8590c25-5cfc-43a9-989e-e98b1ea9a8d8.
[3] A. C. P. De Klerk, G. Z. Angelis, and J. Van Eijk, 'Design of a next generation 6 DoF stage for scanning application in vacuum with nanometer accuracy and mGauss magnetic stray field'. [Online]. Available: https://www.researchgate.net/publication/240624066

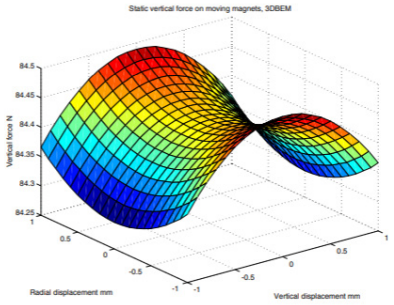
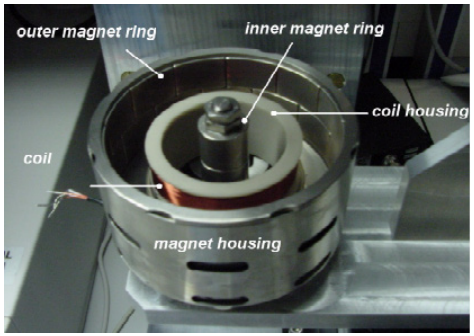


Figure 4.10: Vertical force F_z on moving magnets (3D BEM).



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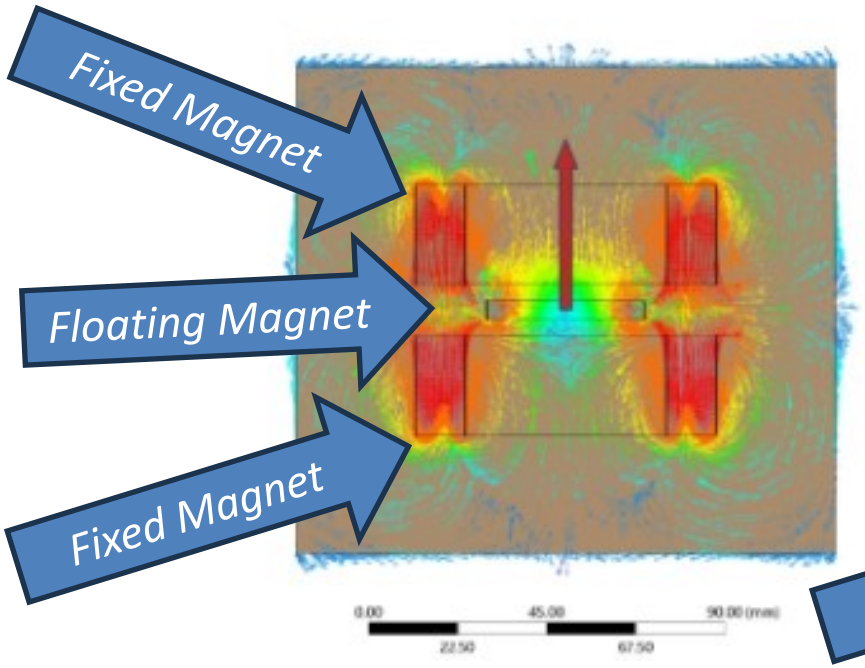
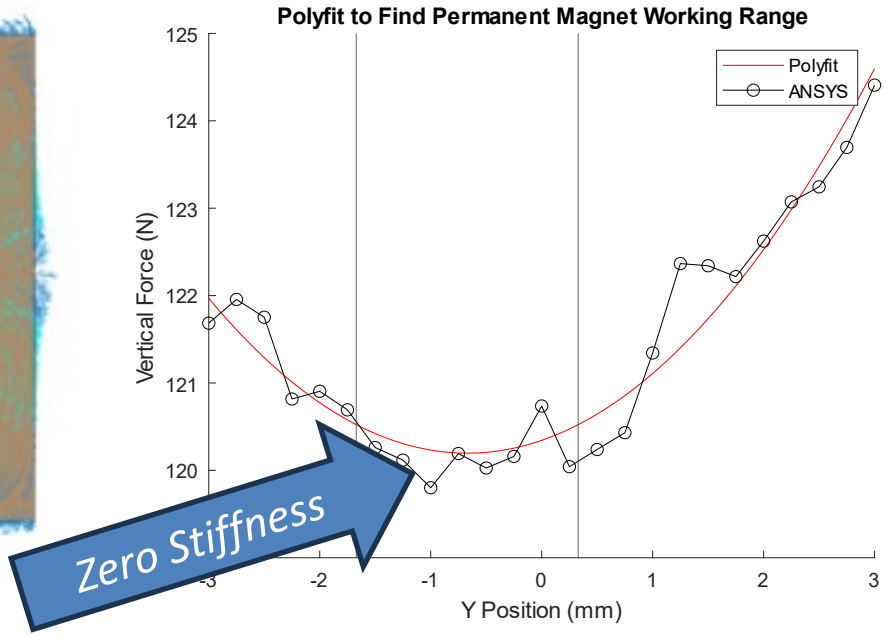
GRAVITY COMPENSATOR

- Design optimised to create a self-contained, shielded module with a low (<3mT) external field to meet the required health & safety regulations
- Custom manufactured fixed 60kg force ring magnets
- Documented assembly procedure with dedicated location, tools & staff



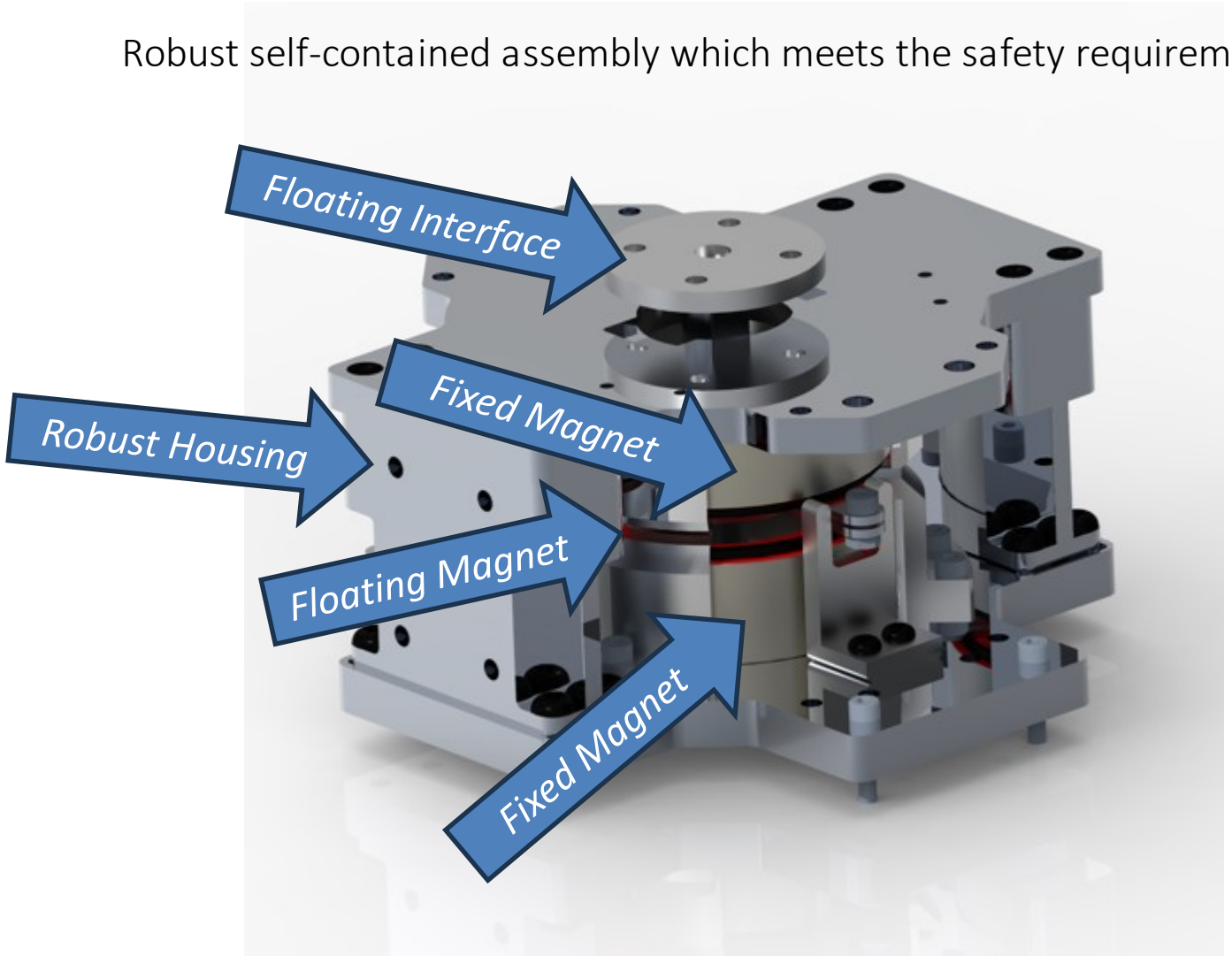
ANSYS Simulation



Vertical Force vs. Position

GRAVITY COMPENSATOR

Robust self-contained assembly which meets the safety requirements



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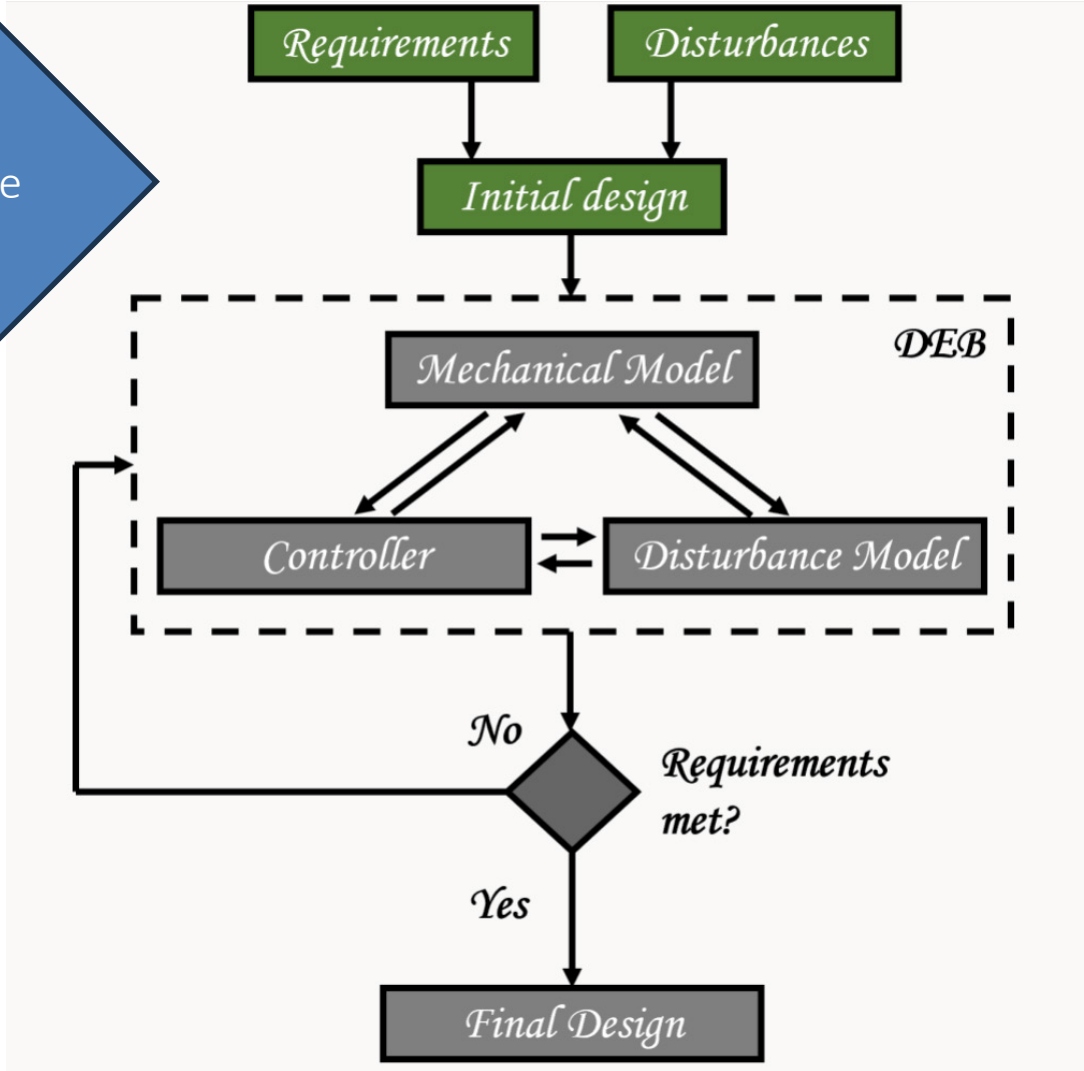
Mechatronics Process

We Have These



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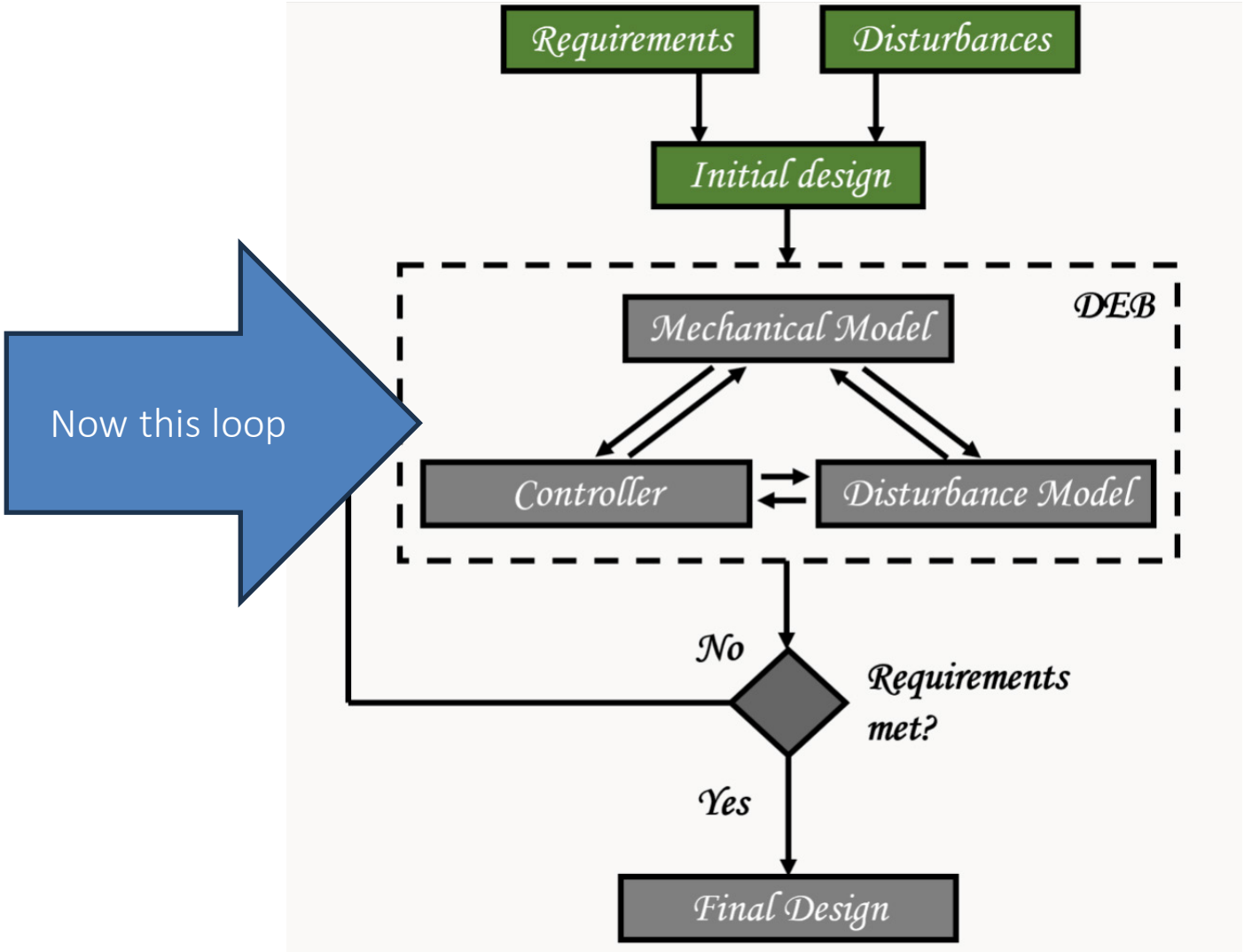
Mechatronics Process



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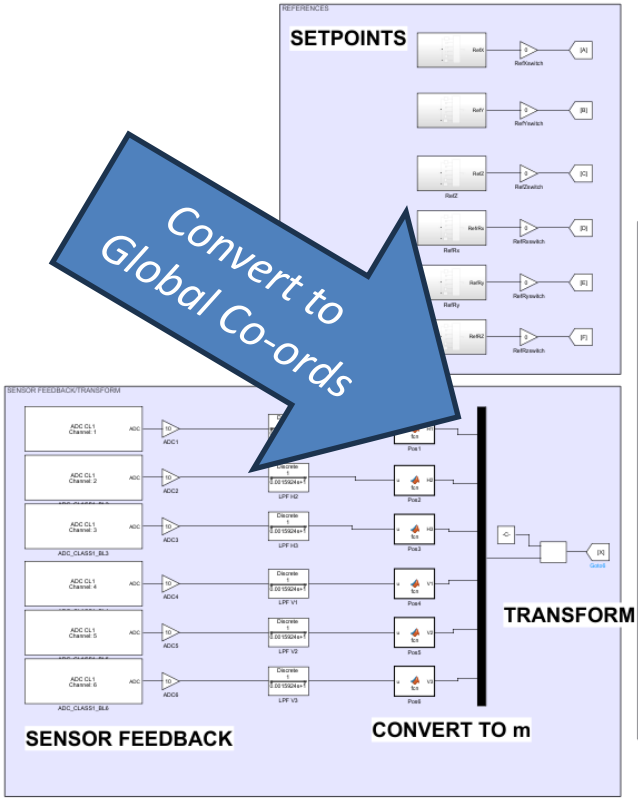
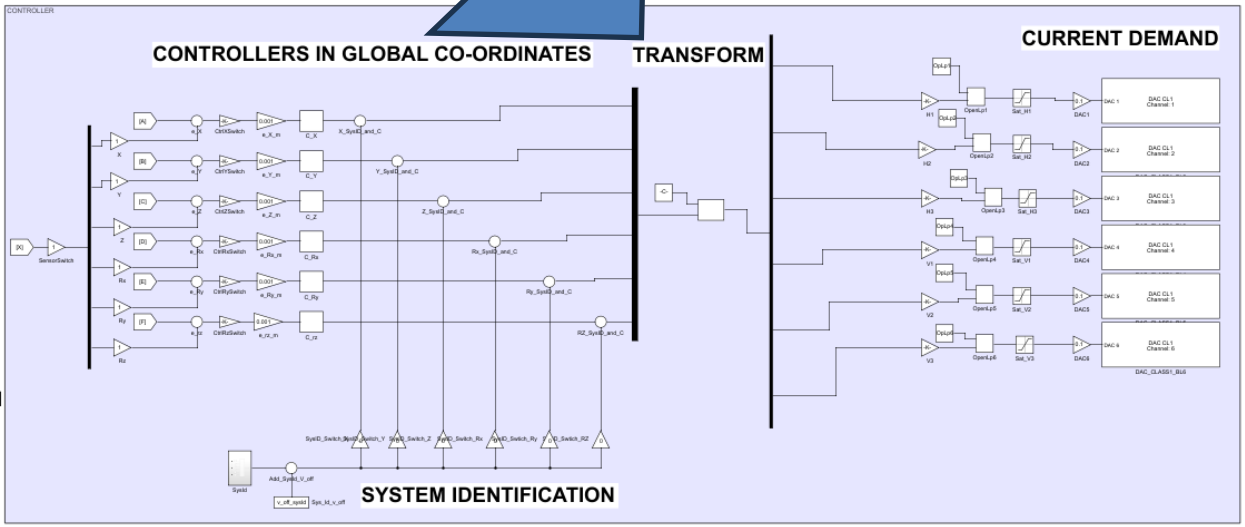
Simulink: MIMO to 6 x SISO



Convert to Global Co-ords

Convert back to actuator co-ords



MathWorks®

Simulink

Compile

dSPACE

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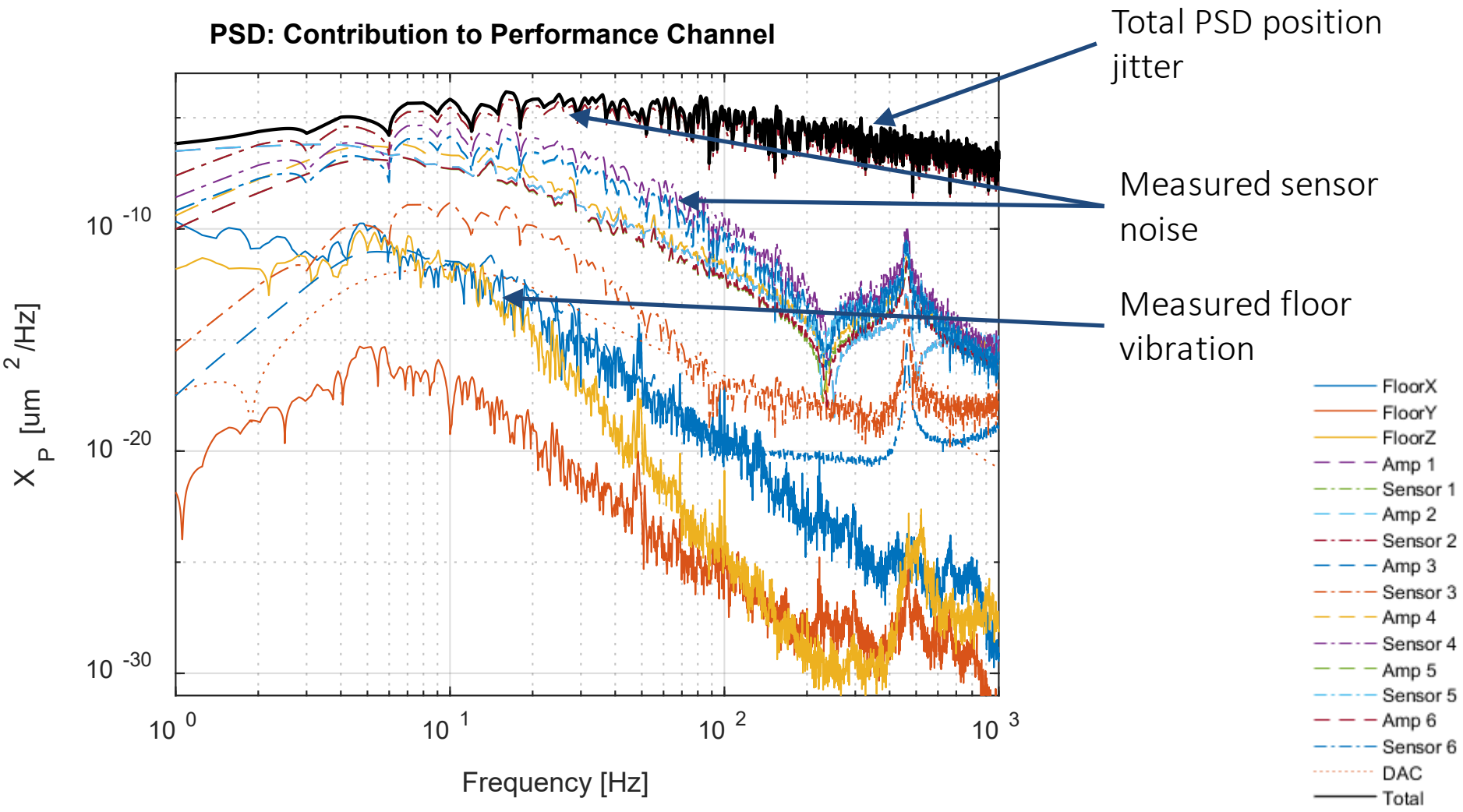
Dynamic Error Budget: What Effects Position Jitter



Ref: Jabben L. Mechatronic design of a magnetically suspended rotating platform. 2007

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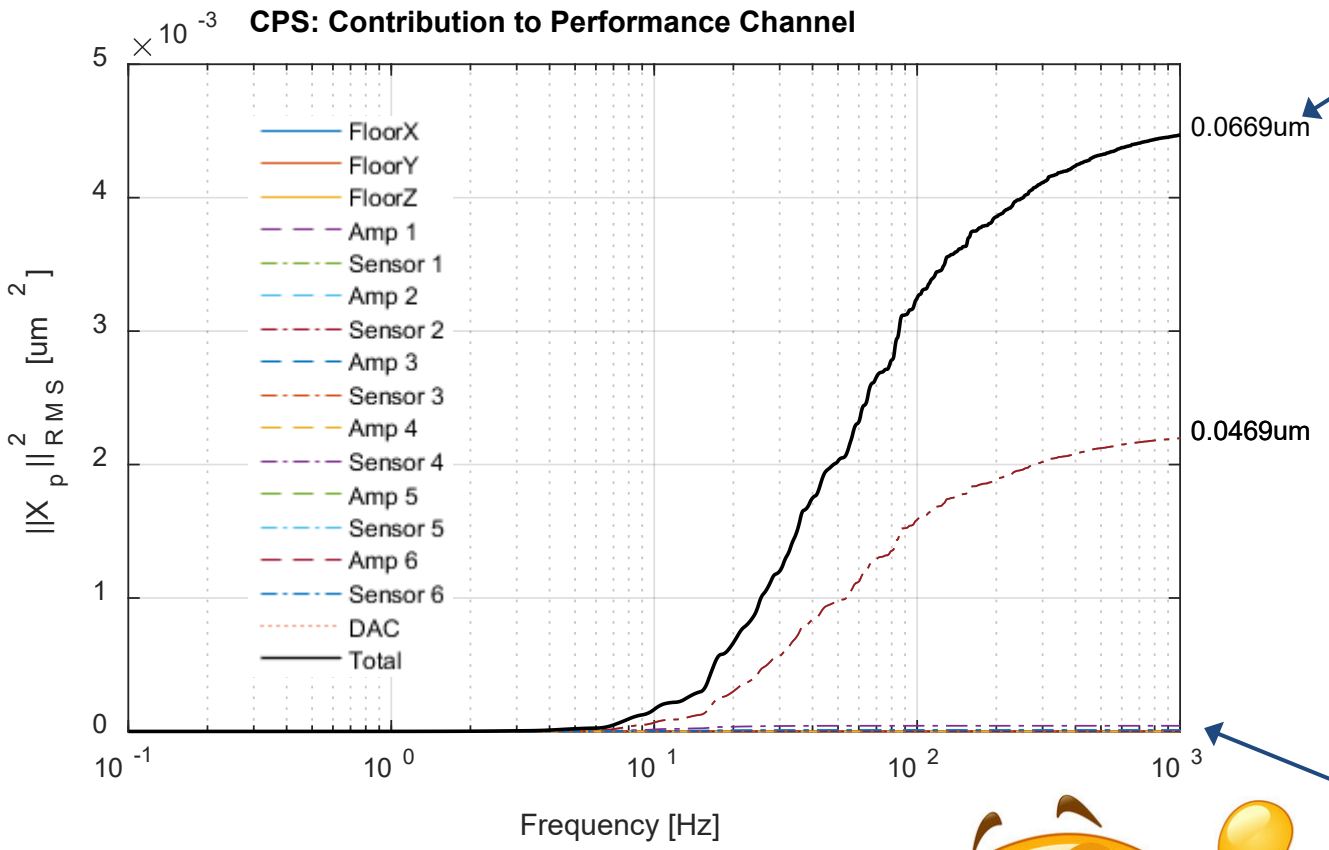
Cumulative Power Spectrum: Predict Jitter



Total RMS x direction position jitter

The 2 symmetric horizontal sensors 1 & 2 contribute the most

The simulation cross coupling is minimal between vertical and horizontal

Spec ± 500 nm so looks good!

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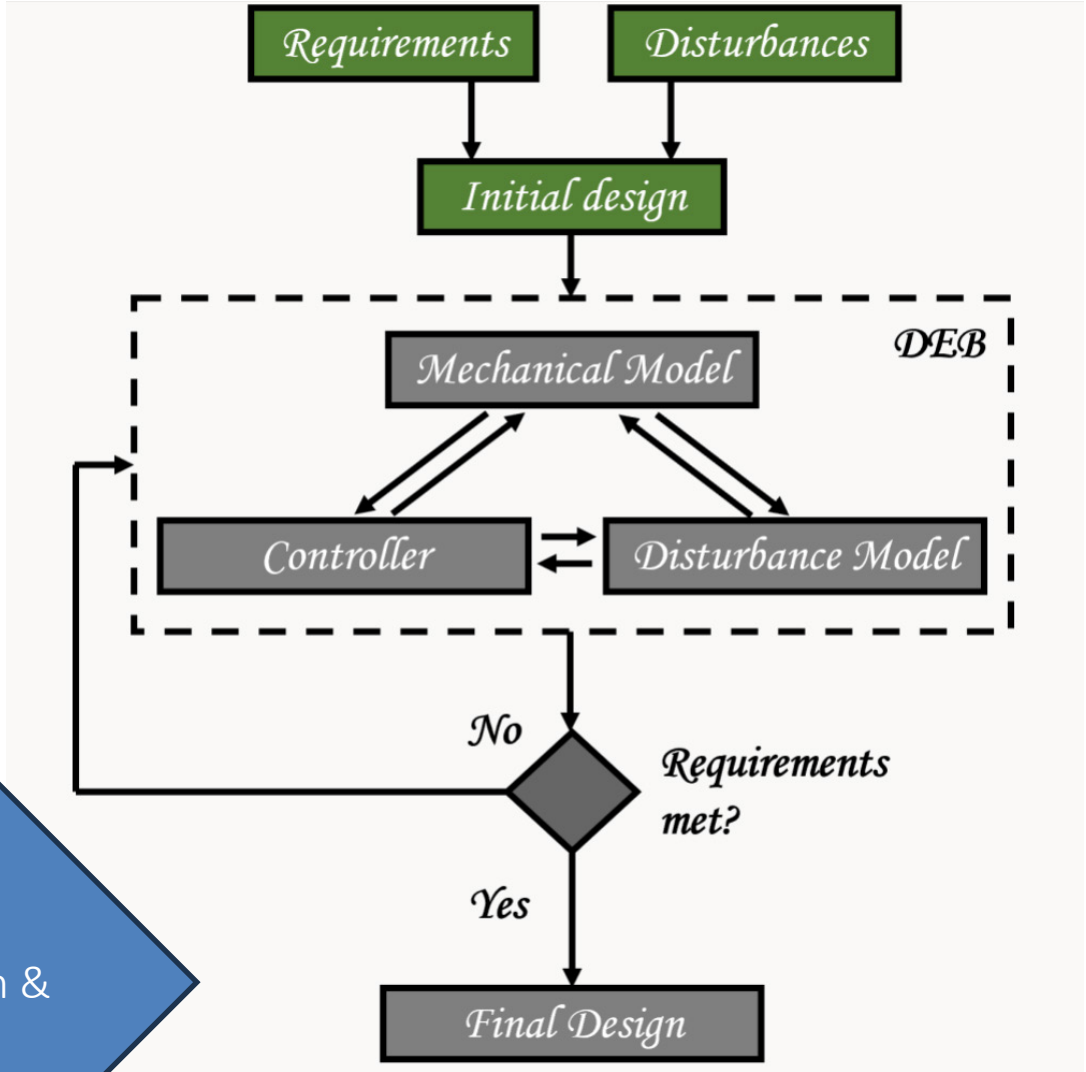
Mechatronics Process



Build, Commission & Test

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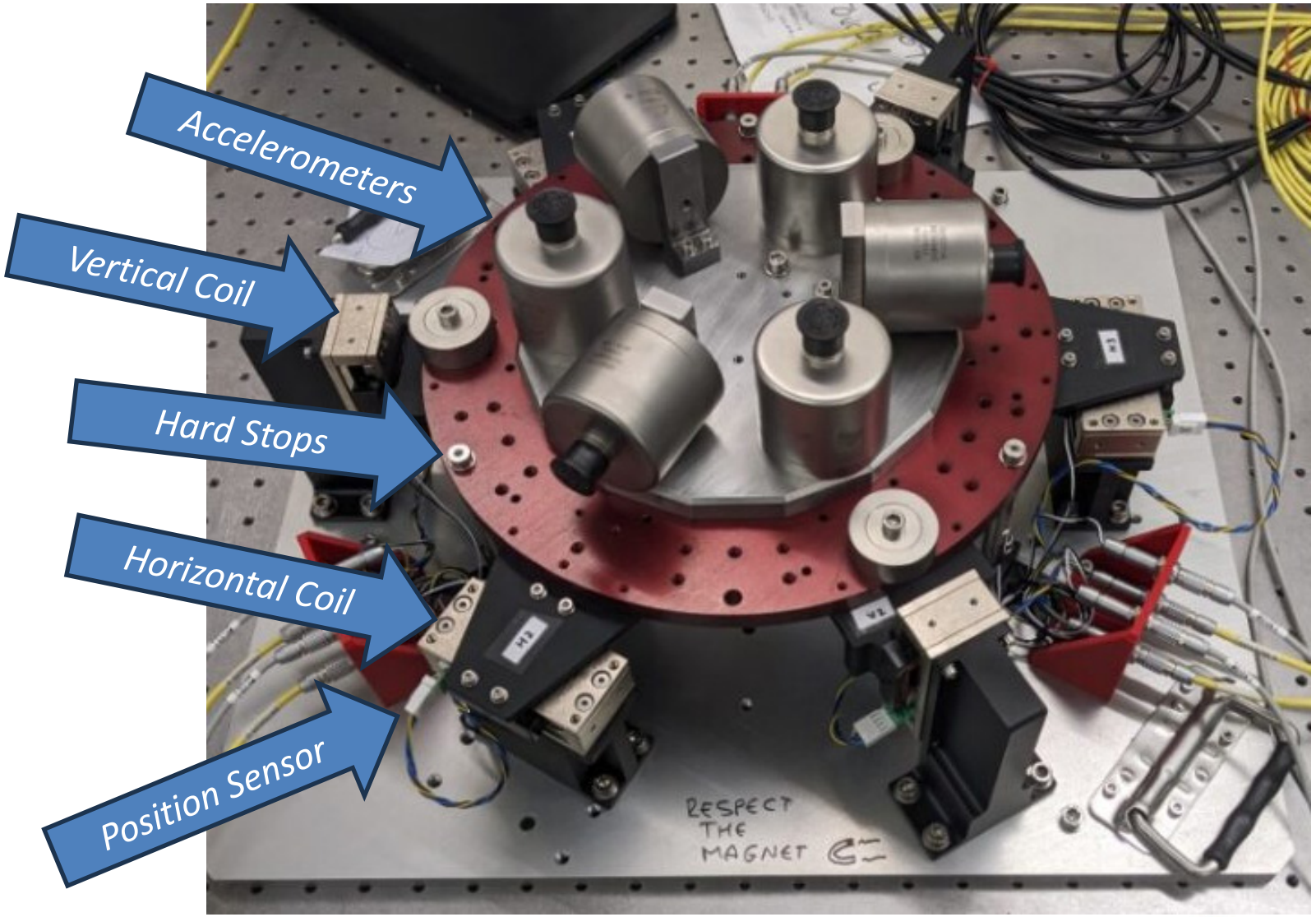
6 DOF Maglev Stage



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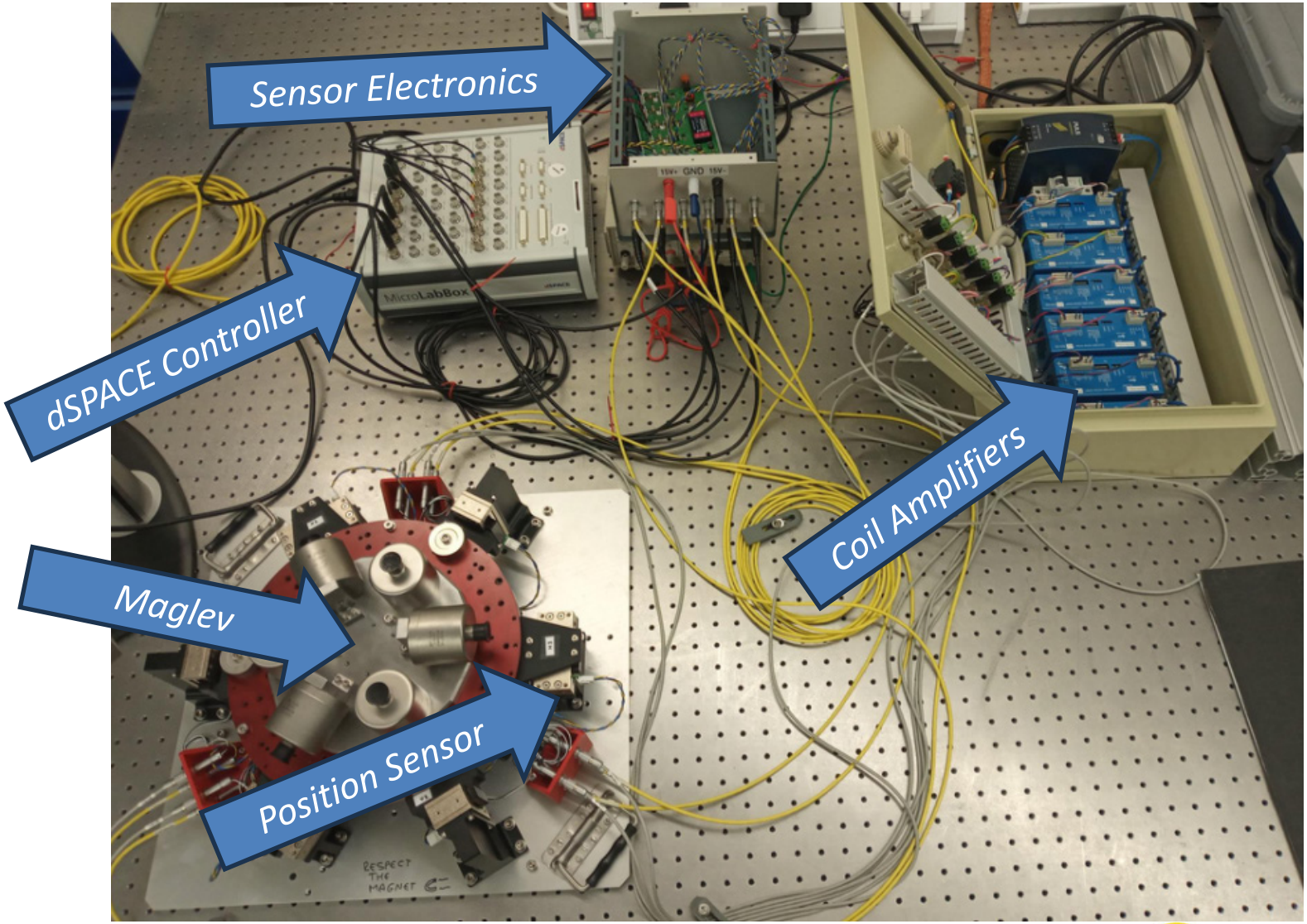
Assembled System



Results: We Have Lift Off!

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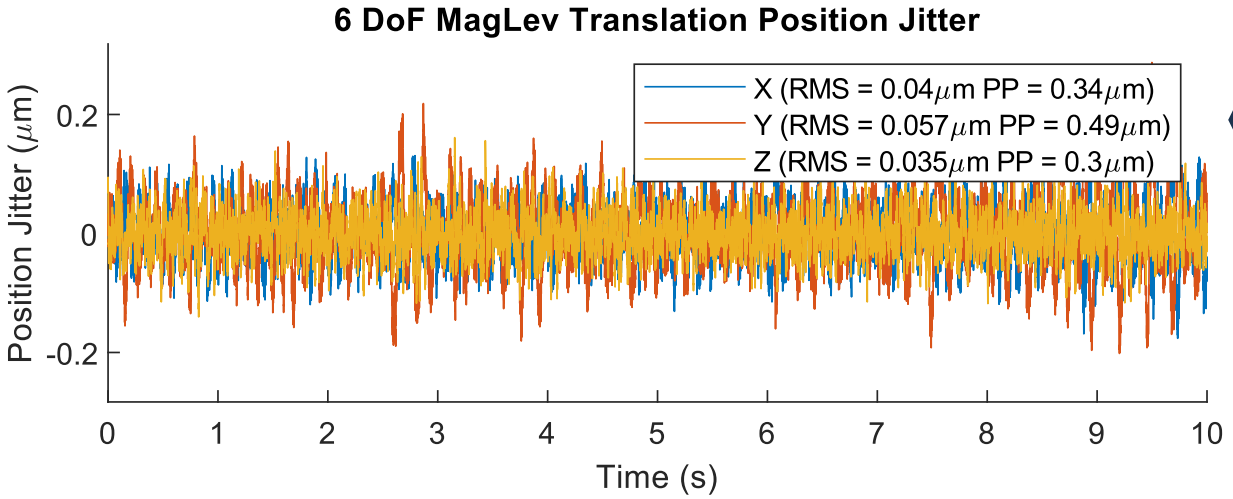
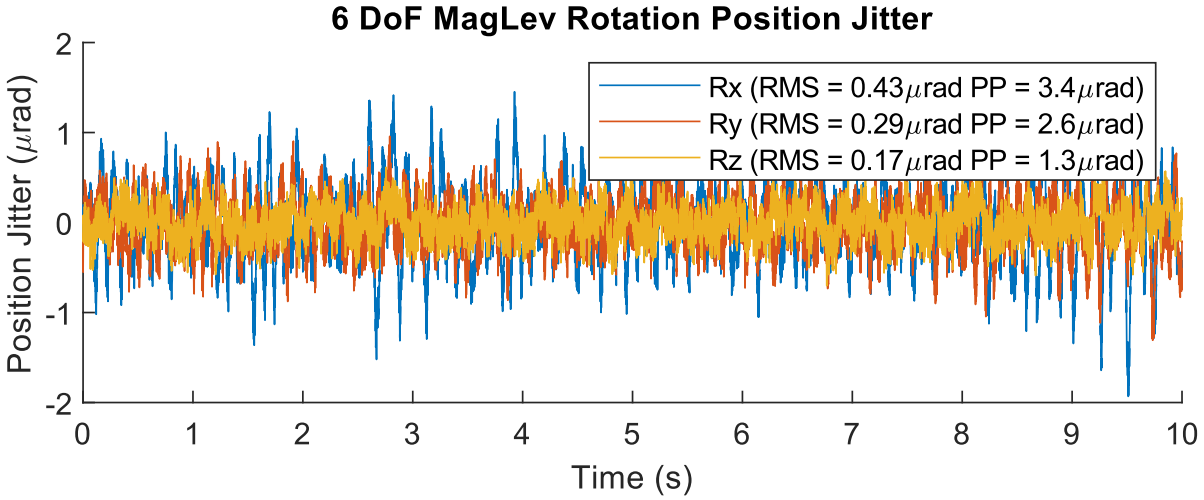
Results: Position Jitter





DEB 70 nm RMS

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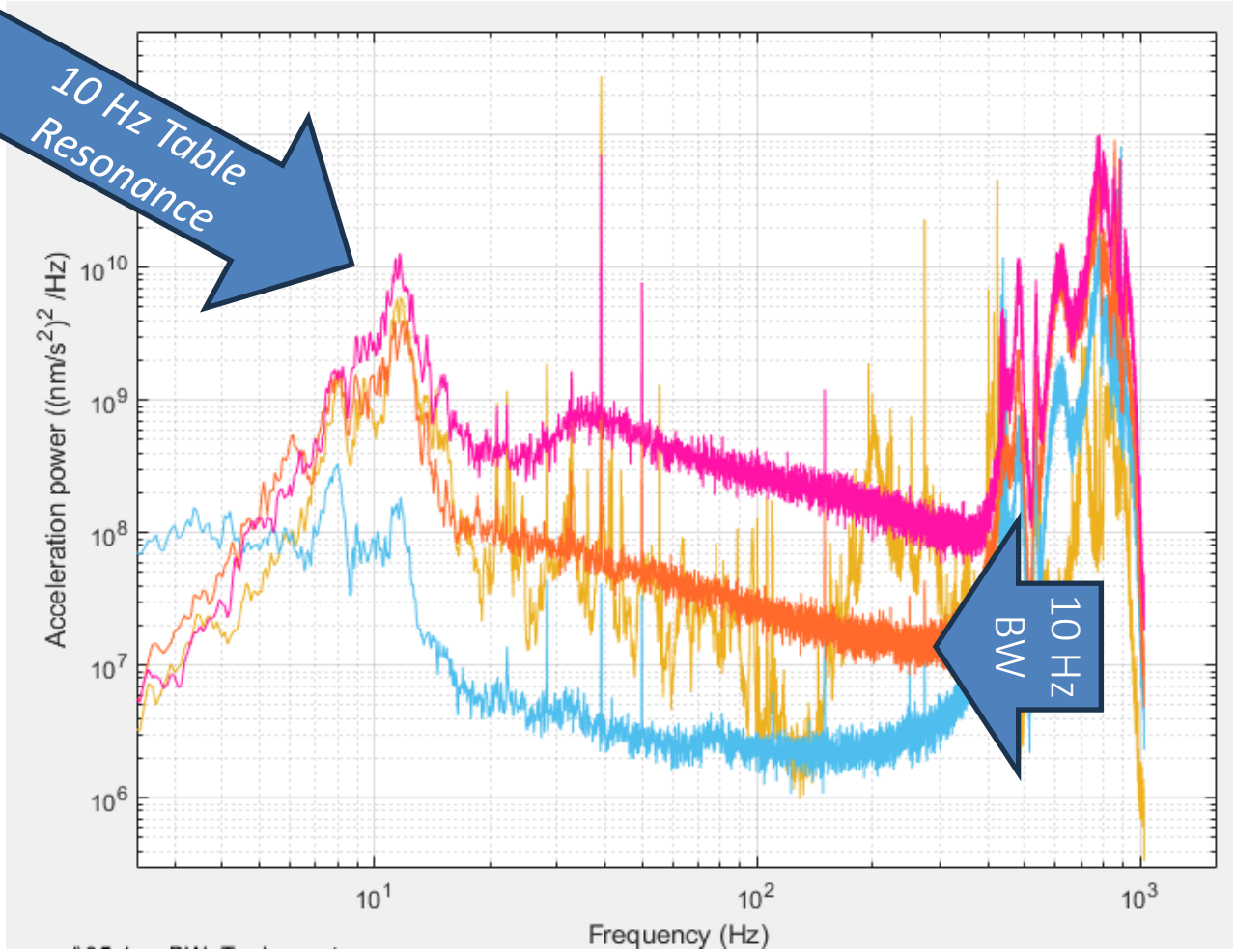
Effect of Control Bandwidth

The bandwidth may be adjusted to give a compromise between vibration isolation and table tracking/alignment



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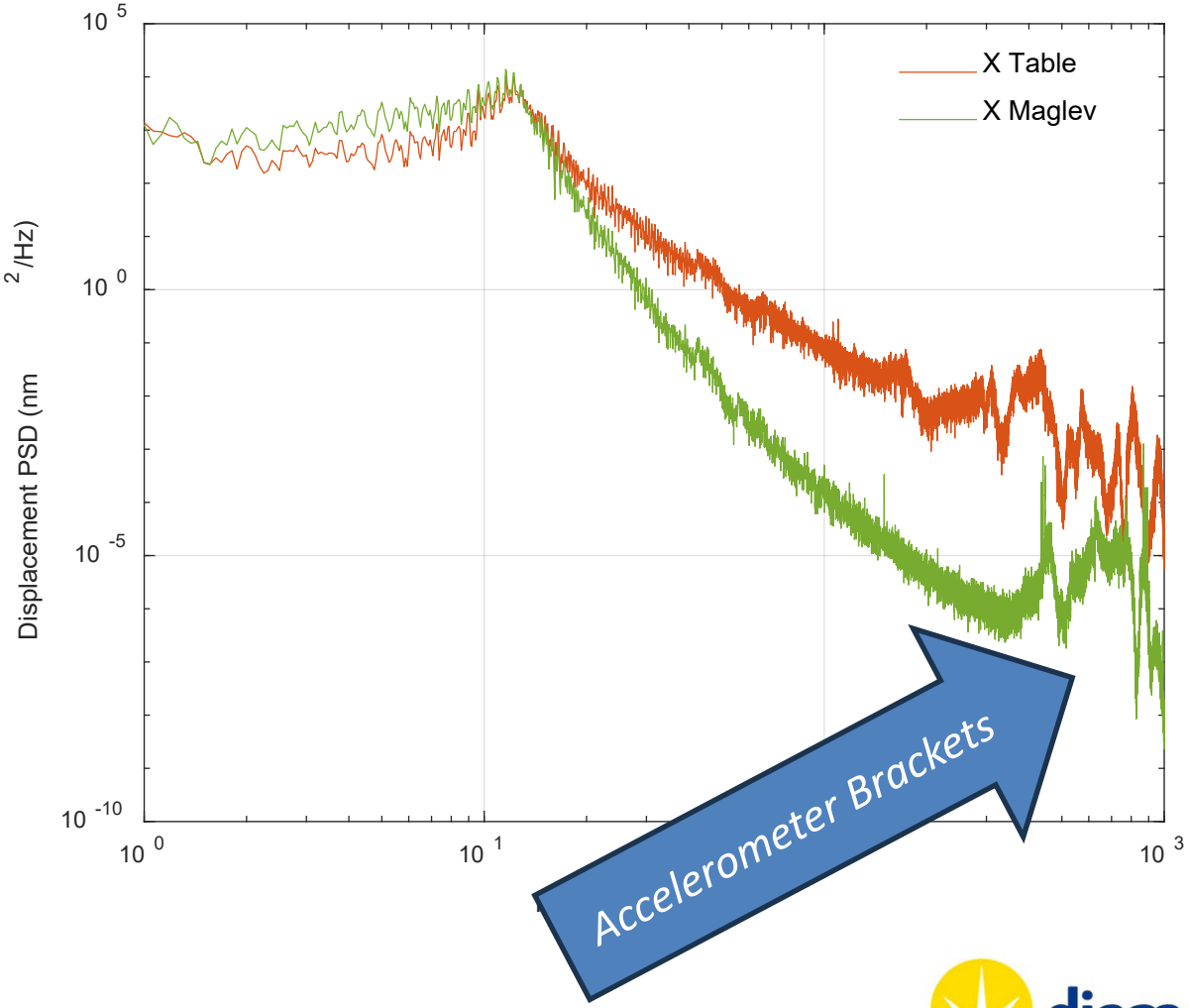
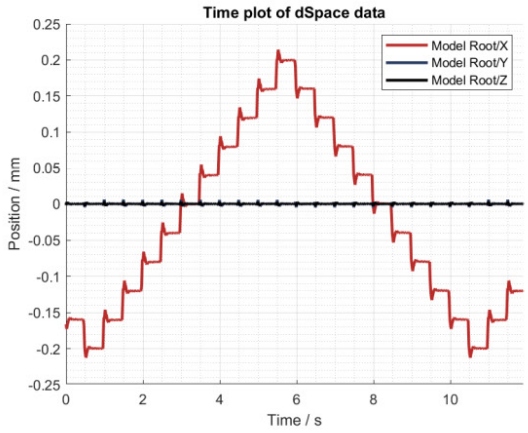
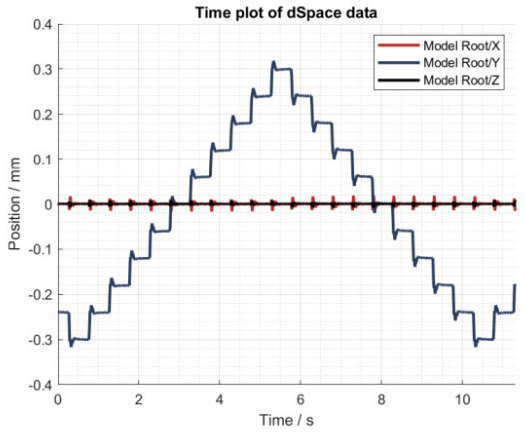
Vibration Transmission: Impact Table

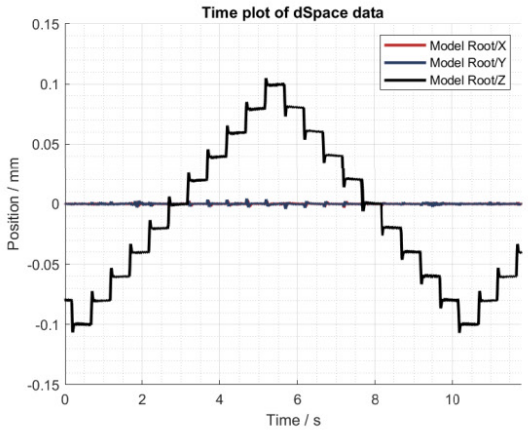
A hammer impact to the table increases the vibration magnitude reducing the sensor noise effect
Transmission 1 @ 10Hz
0.1 @ 30Hz
0.0001 @ 250Hz

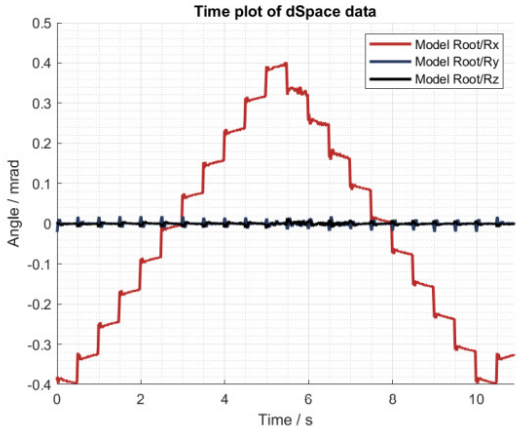


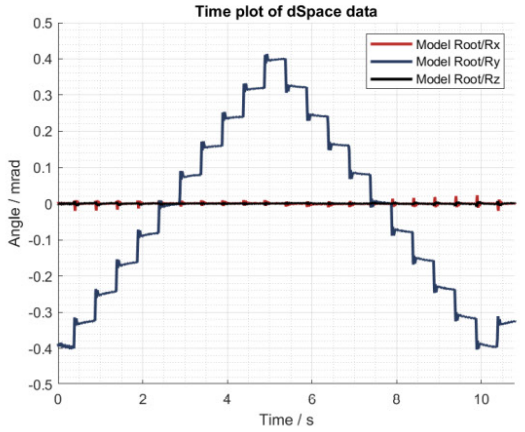
Pyramid Step Scans In All 6 DOF

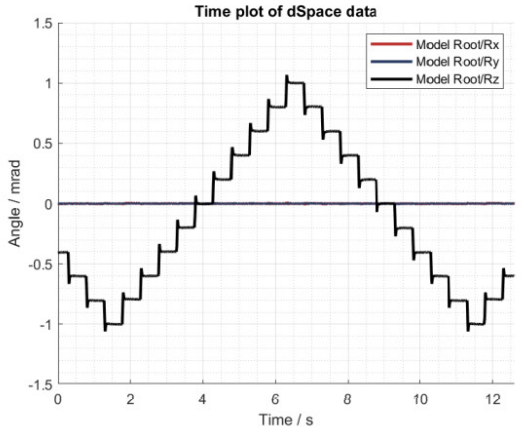






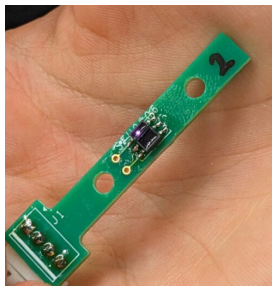


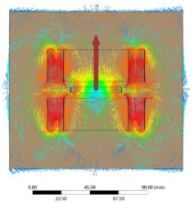


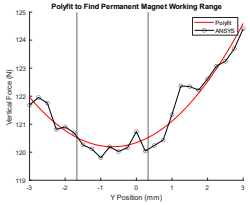


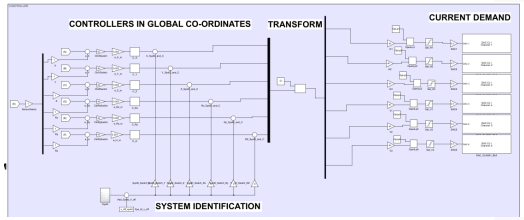
Summary

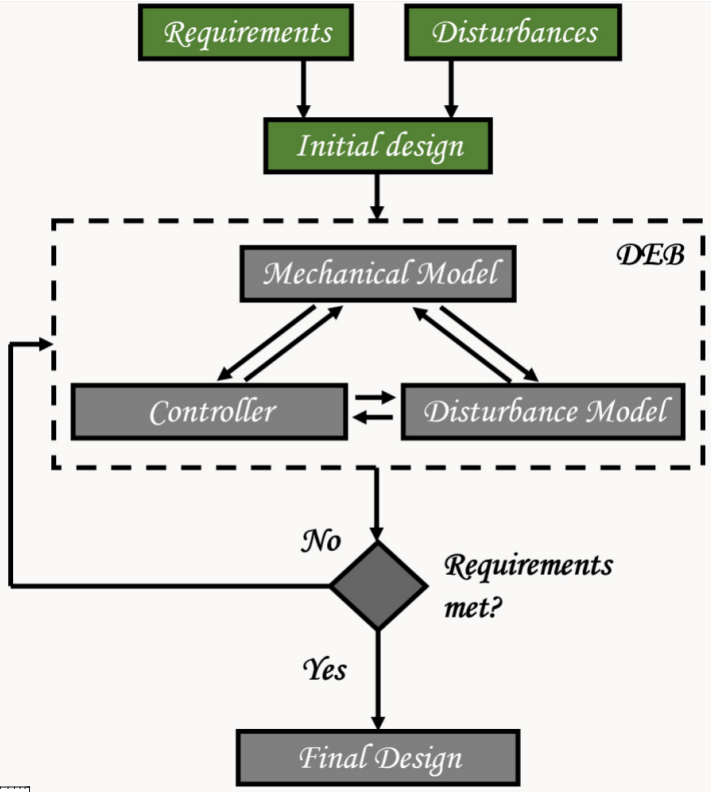
Vibration transmission < 10%
from 10 – 500 Hz

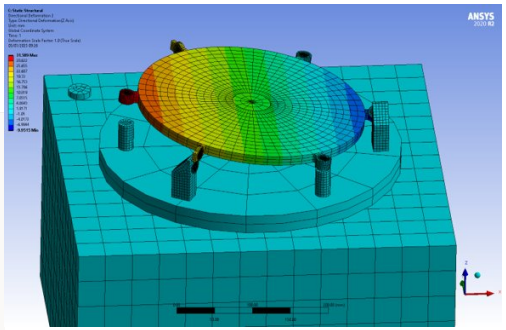


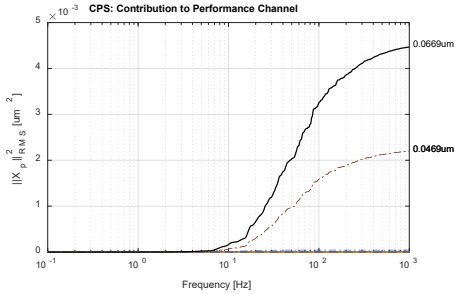


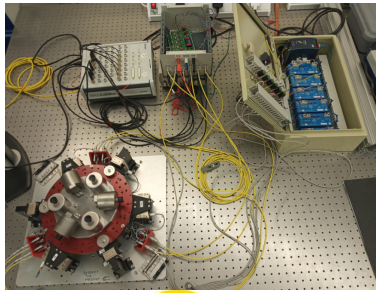


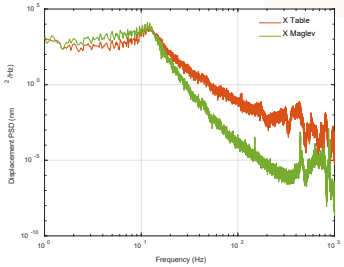


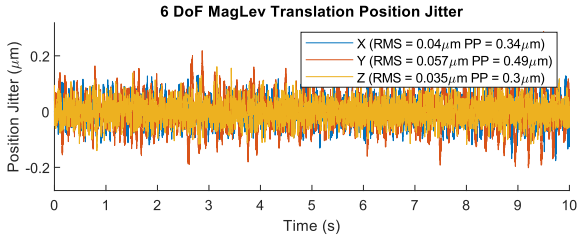












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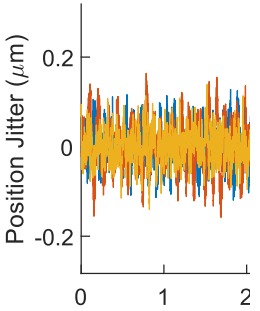
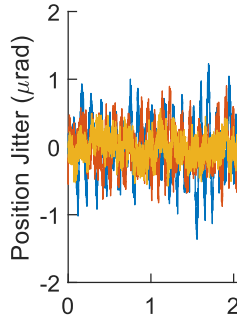
CONCLUSIONS

The top-level requirements defined for the project were:

- Load capacity >10 kg ✓
- Low profile ~ 0.5 x 0.5 x 0.2 m maximum envelope ✓
- Vibration transmission < 10% from 10 – 500 Hz ✓
- Provide 6 DOF motorised alignment ✓
- Position Stability ± 500 nm, 1-1000 Hz Peak-Peak ✓
- Angular Stability ± 500 nrad, 1-1000 Hz Peak-Peak Almost
- Travel Range XYZ ± 1 mm Almost
- Pitch/Roll/Yaw ± 1 mrad Almost
- Low budget & Delivered within 1 year ✓





Low Budget = Stage + Amplifiers < £15k

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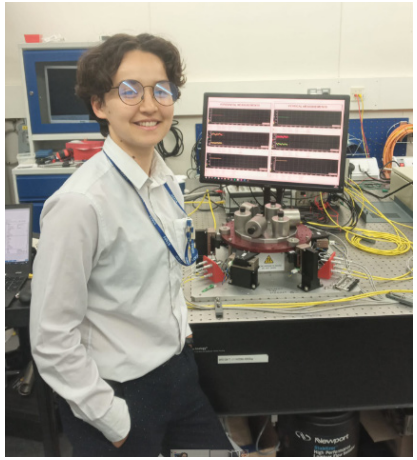
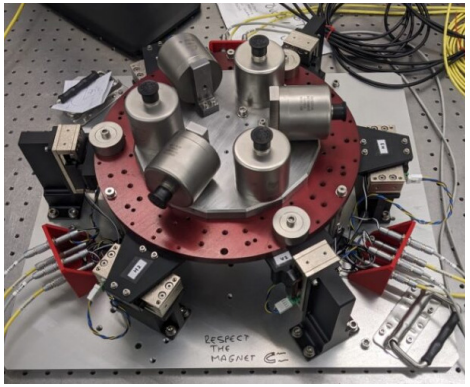
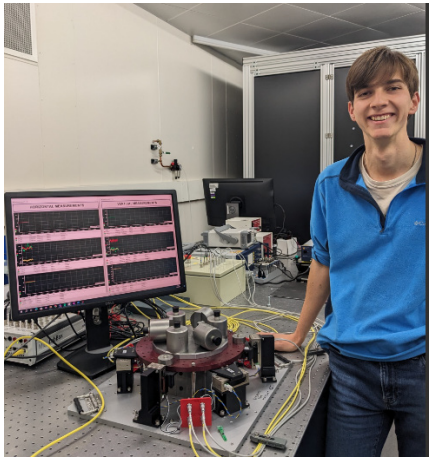
Mechatronics Rock Stars



Serena: s.farrelly.2020@bristol.ac.uk, [Serena Farrelly | LinkedIn]





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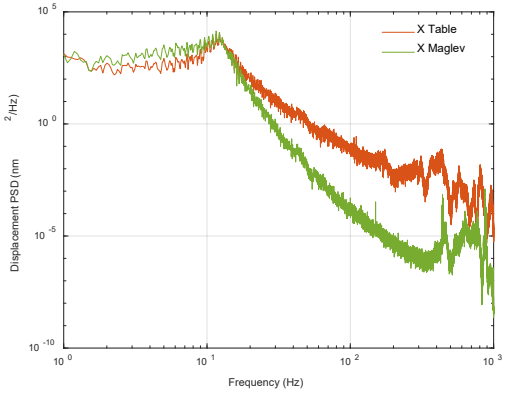

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Jon Kelly: Maglev on a budget

Thank your for your attention