CCAUV/17-40

National Physical Laboratory

Charlie Jarvis

A 6DOF micro-vibration measurement and generation test facility

Workshop of the Consultative Committee for Acoustics, Ultrasound and Vibration
September 2017

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Microvibration on spacecraft

- Vibration generated on-board spacecraft limits the performance of the payload.
- Scientific and EO require increasingly stringent microvibration environments.
- Ground-based microvibration test facilities are needed to reduce mission risk and cost.


New Scientist

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Hubble picking up bad vibrations

WHILE the world's press waits for the Hubble Space Telescope to take its first photographs next week, NASA's engineers are battling to sort out technical problems afflicting the device. Although the telescope would still work despite these problems, its accuracy would be severely limited.

The snags are created by unwanted vibrations which blur measurements. Robin Laurence, programme manager for Hubble at the European Space Agency, says that one vibration, with a frequency of 0.1 hertz, occurs as the spacecraft passes in its orbit from day to night, and at certain times when it is bathed in sunlight.

He tracks this problem to the solar arrays, which bend slightly when the spacecraft is in sunlight and straighten out at night. The change takes about 60 seconds. 'My guess,' says Laurence, 'is that this process causes the vibration, and that the control system is not damping down the vibration sufficiently.'

Other unexplained vibrations on the spacecraft each last between one

Isolation stage
Passive isolation

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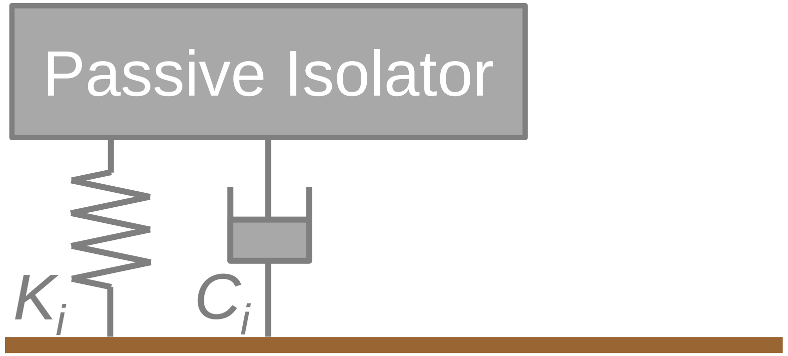
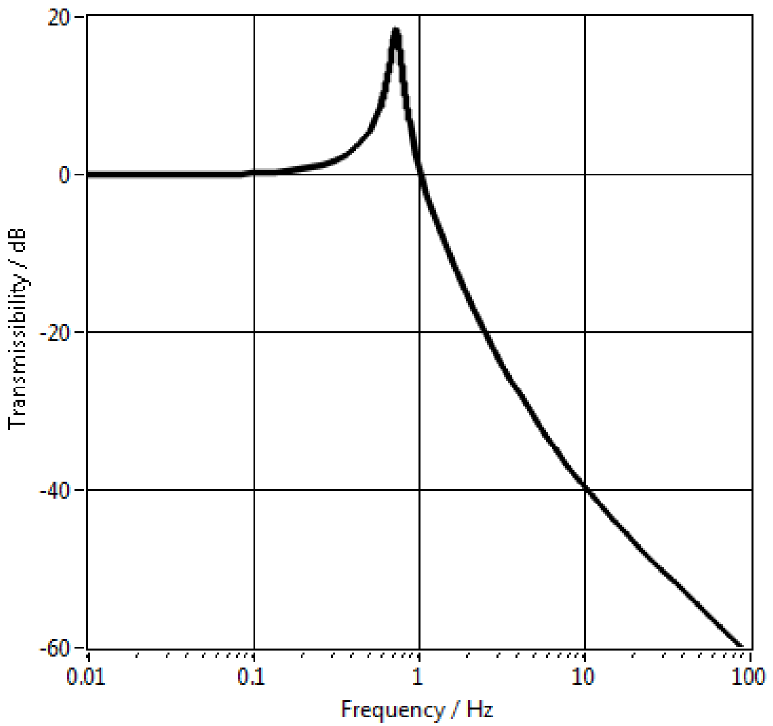
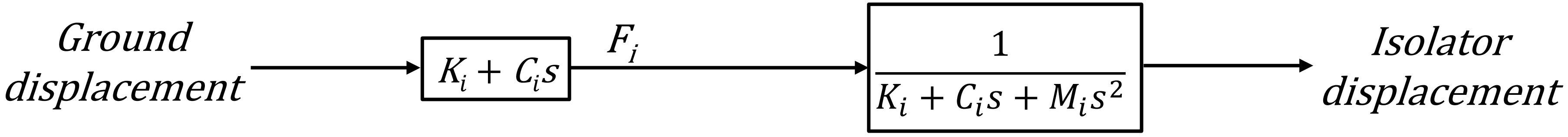
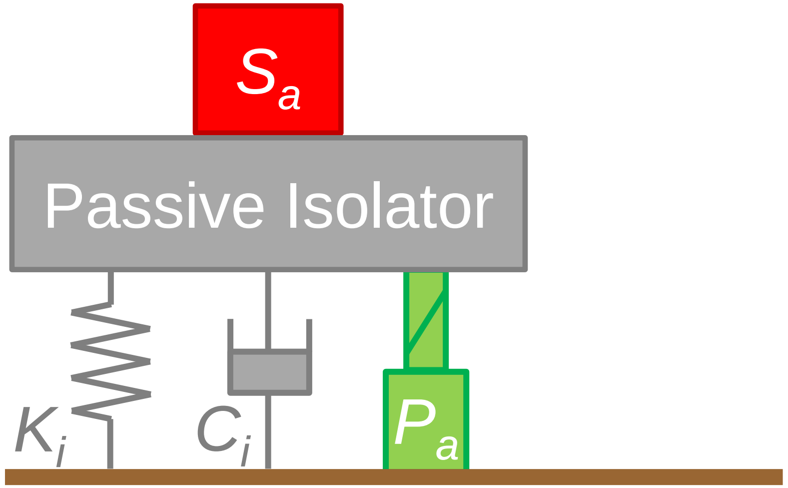
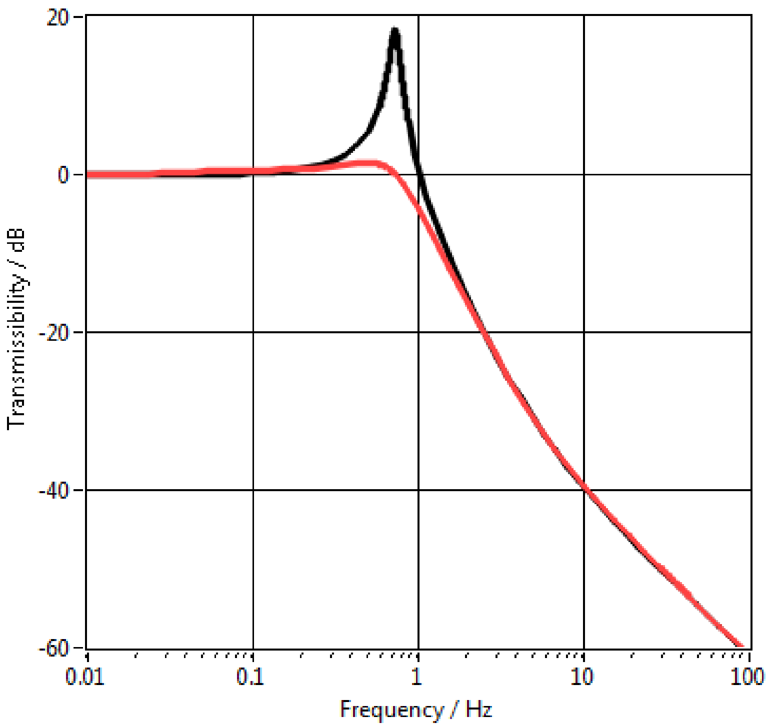


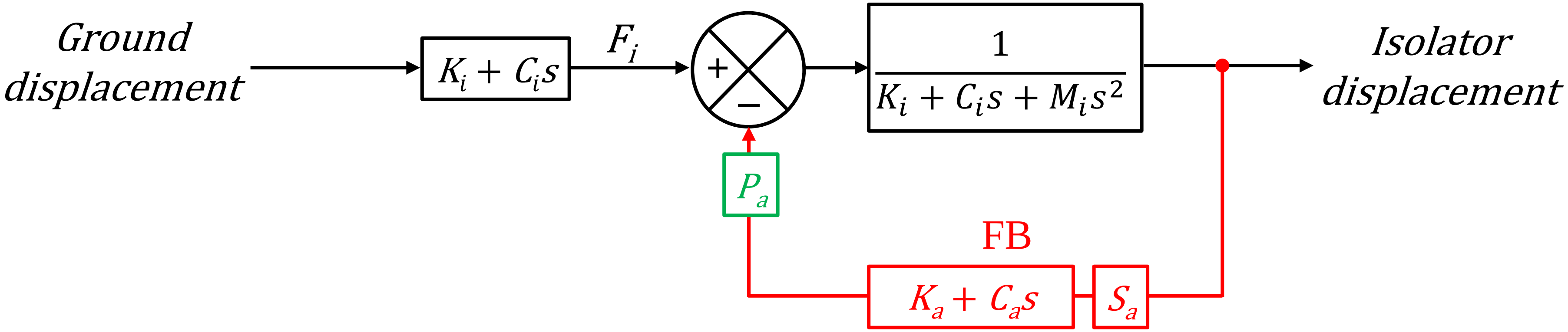




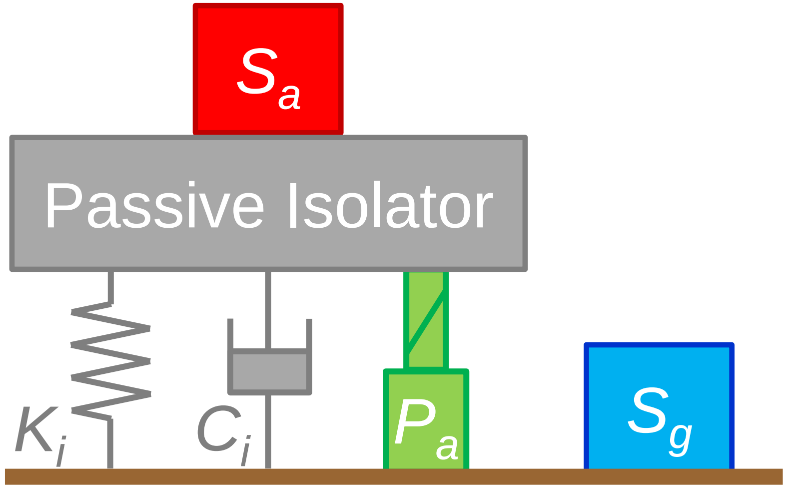
Isolation stage
Feedback isolation

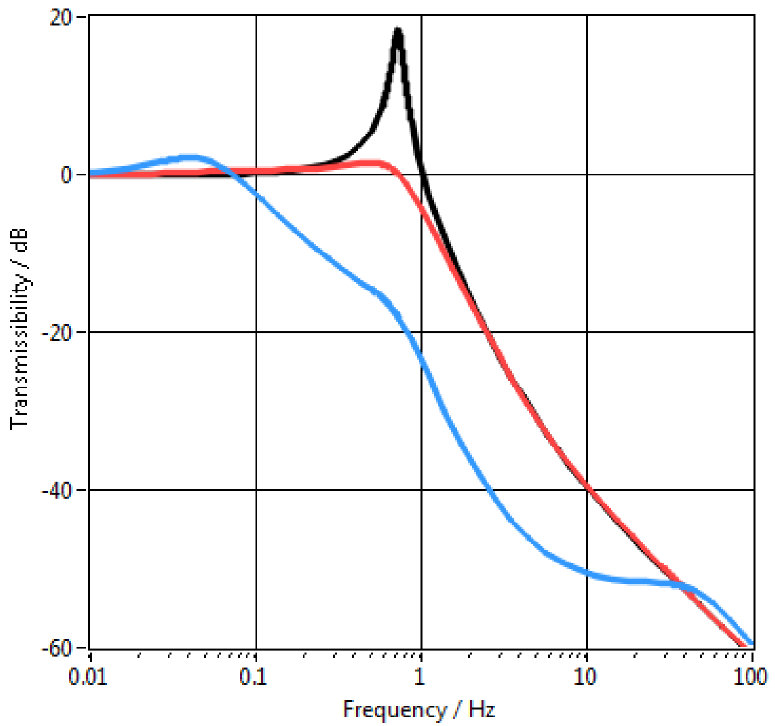


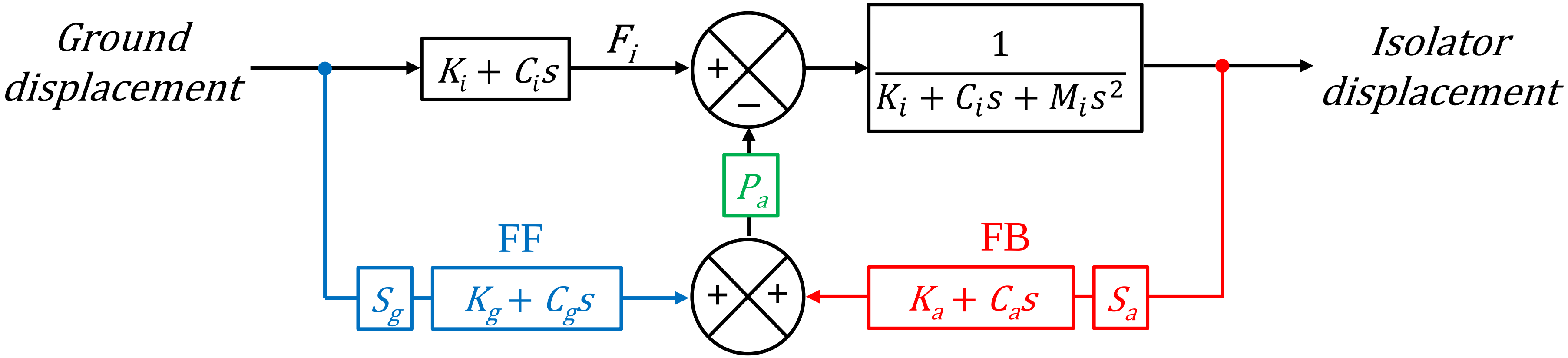




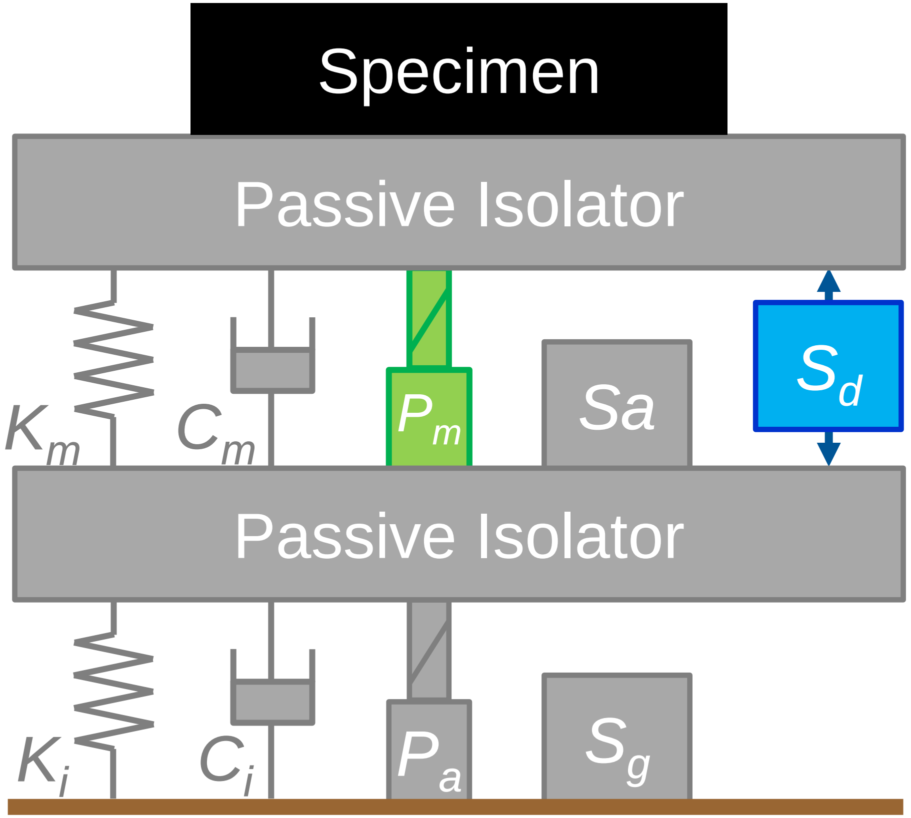
Isolation stage
Feedforward isolation

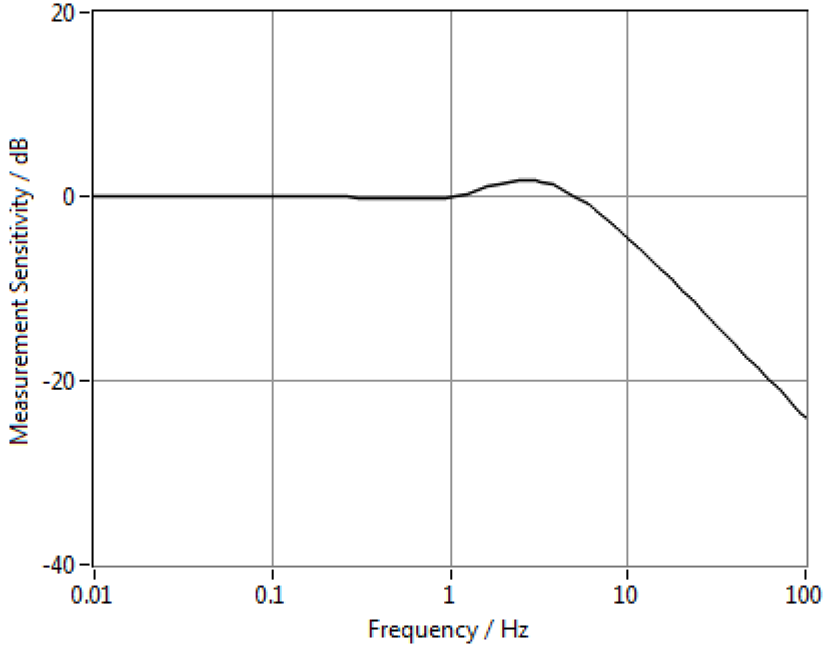


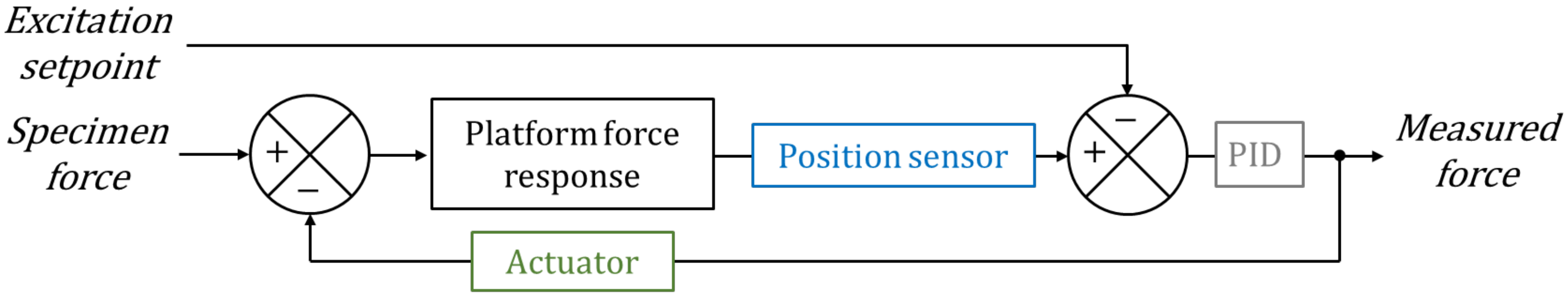




Measurement stage







Mechanical design & instrumentation

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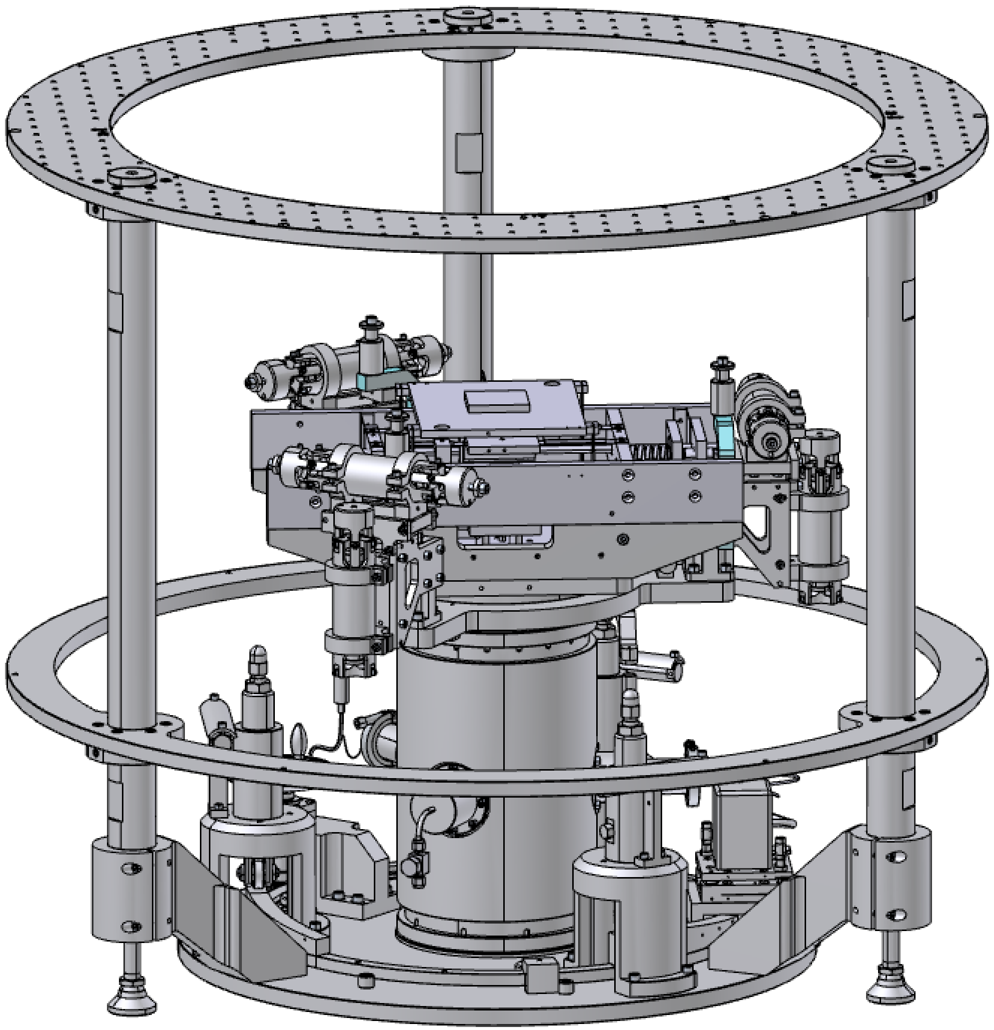
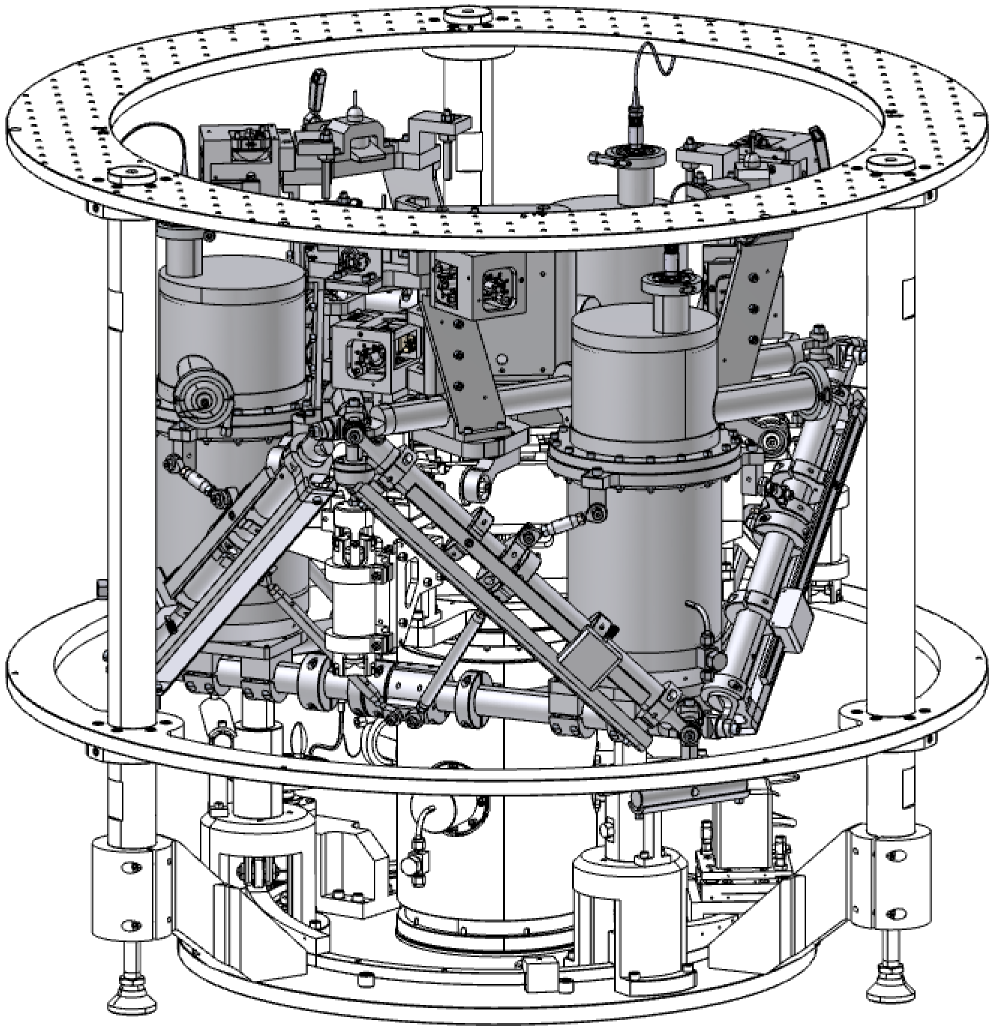


Base

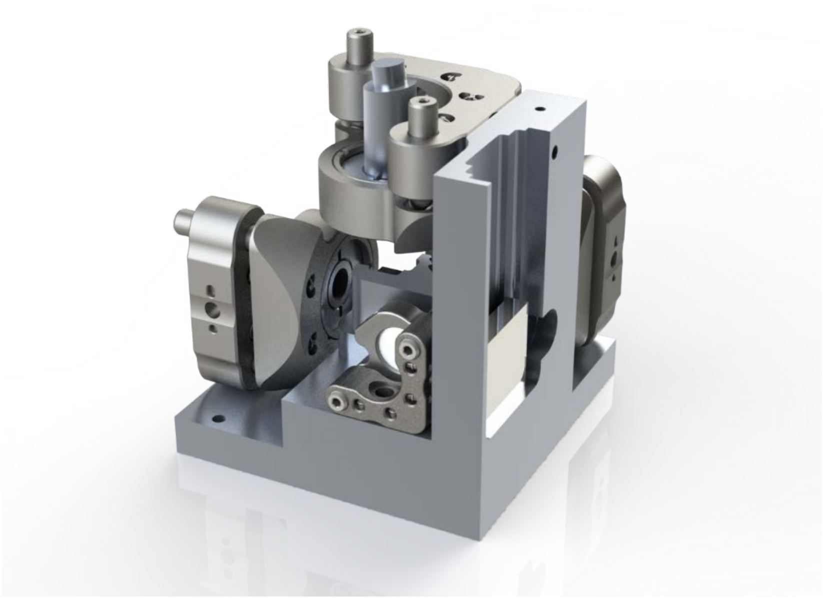
- Passive isolator
- Feedforward seismometer
- 6 actuators

Mechanical design & instrumentation

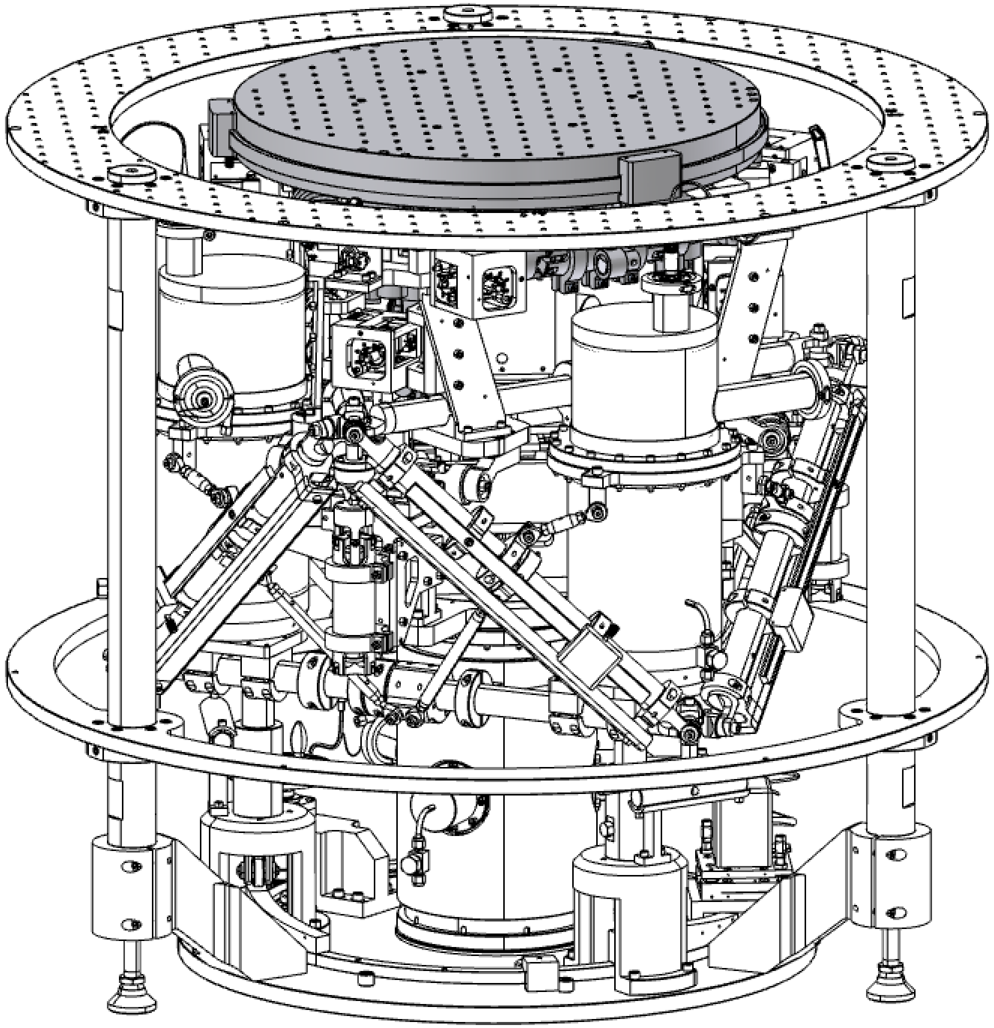


Isolation stage

- Passive isolator
- 3 feedback seismometers
- 6 actuators
- 6 interferometers

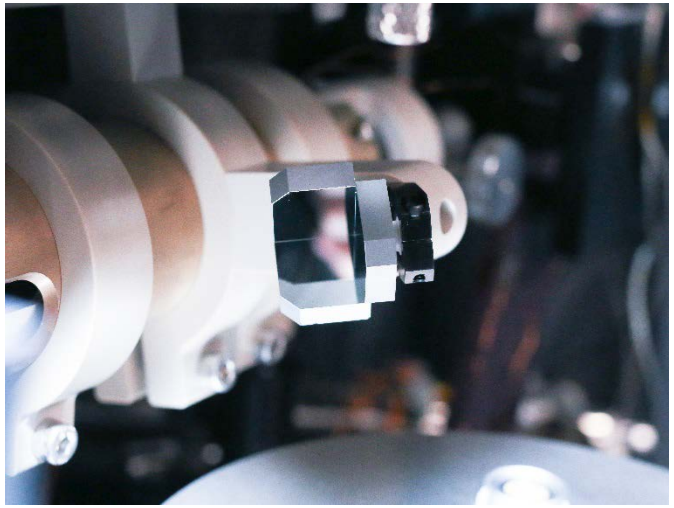


Mechanical design & instrumentation

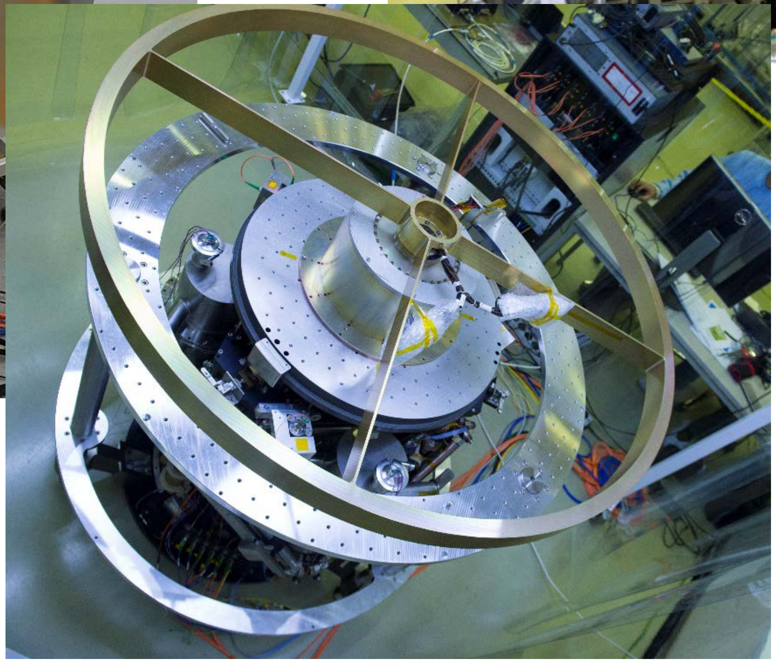


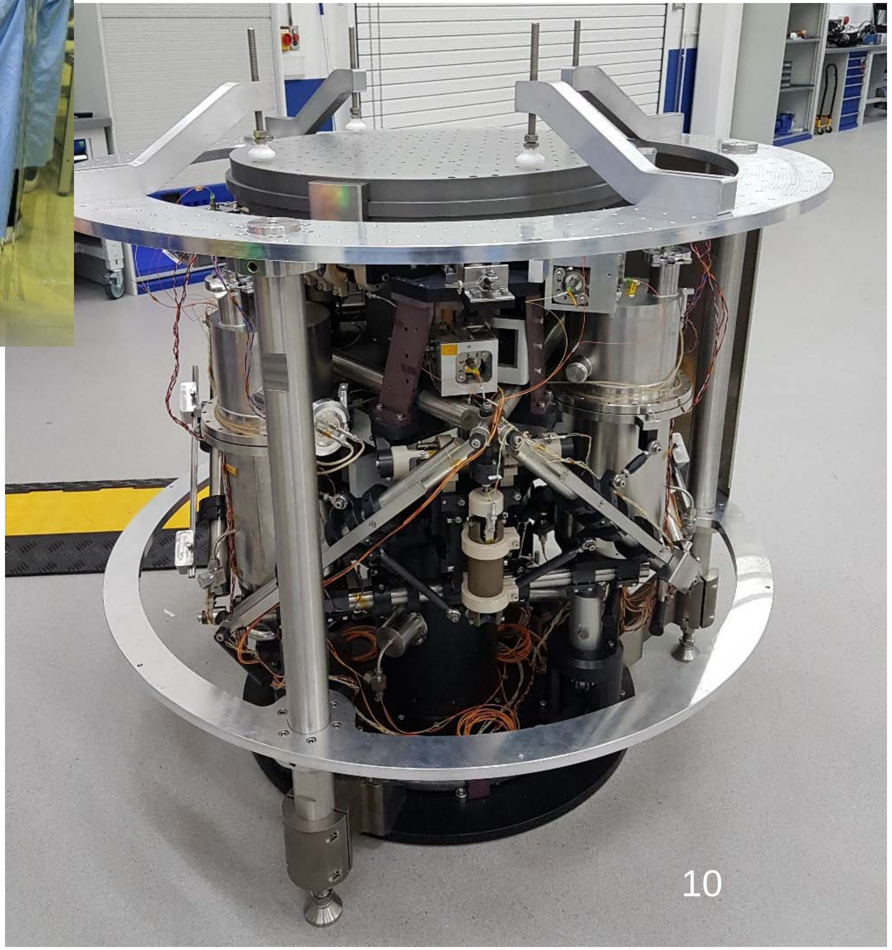
Measurement platform

- Interface plate
- 6 retroreflectors
- 6 accelerometers



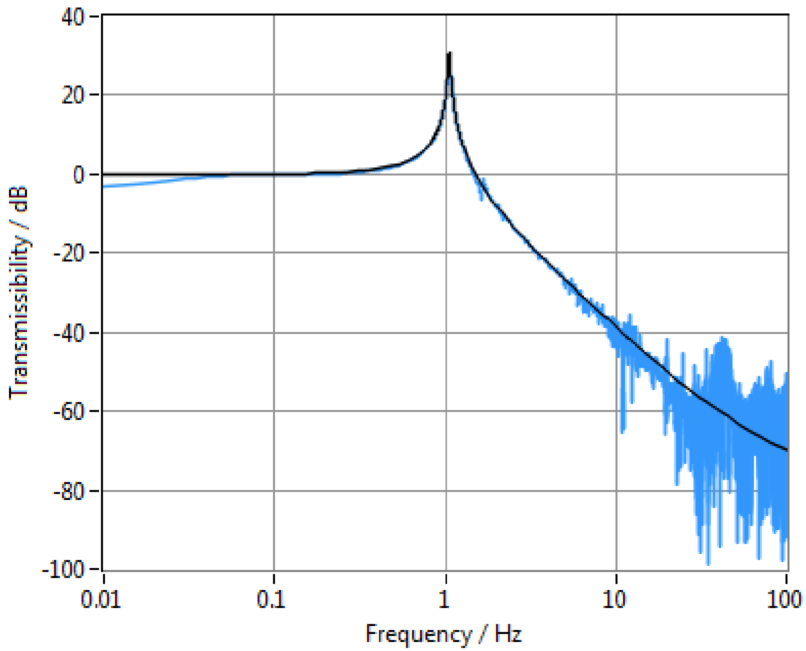
Mechanical design & instrumentation

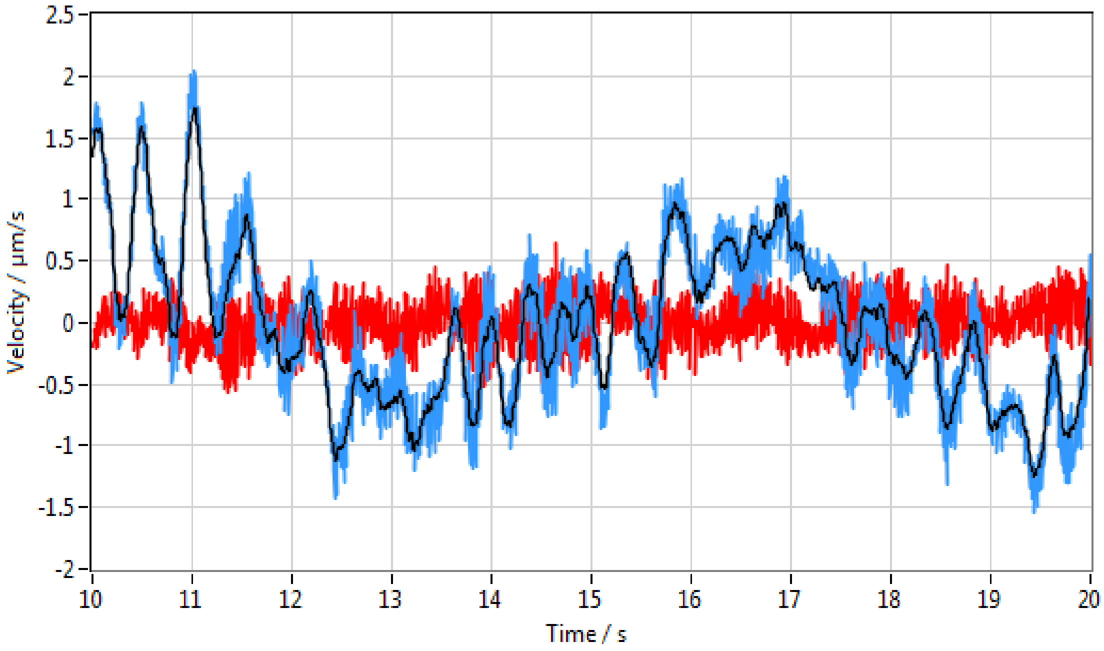




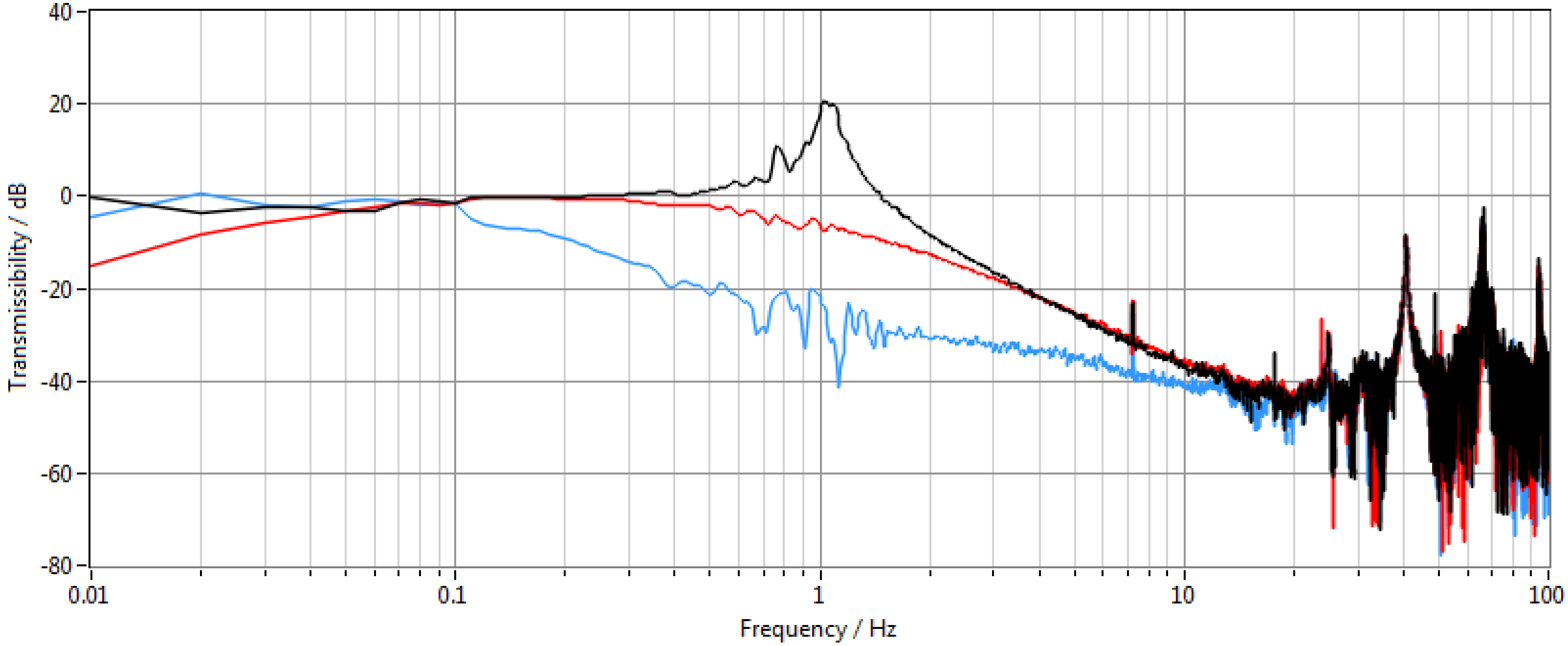
System identification

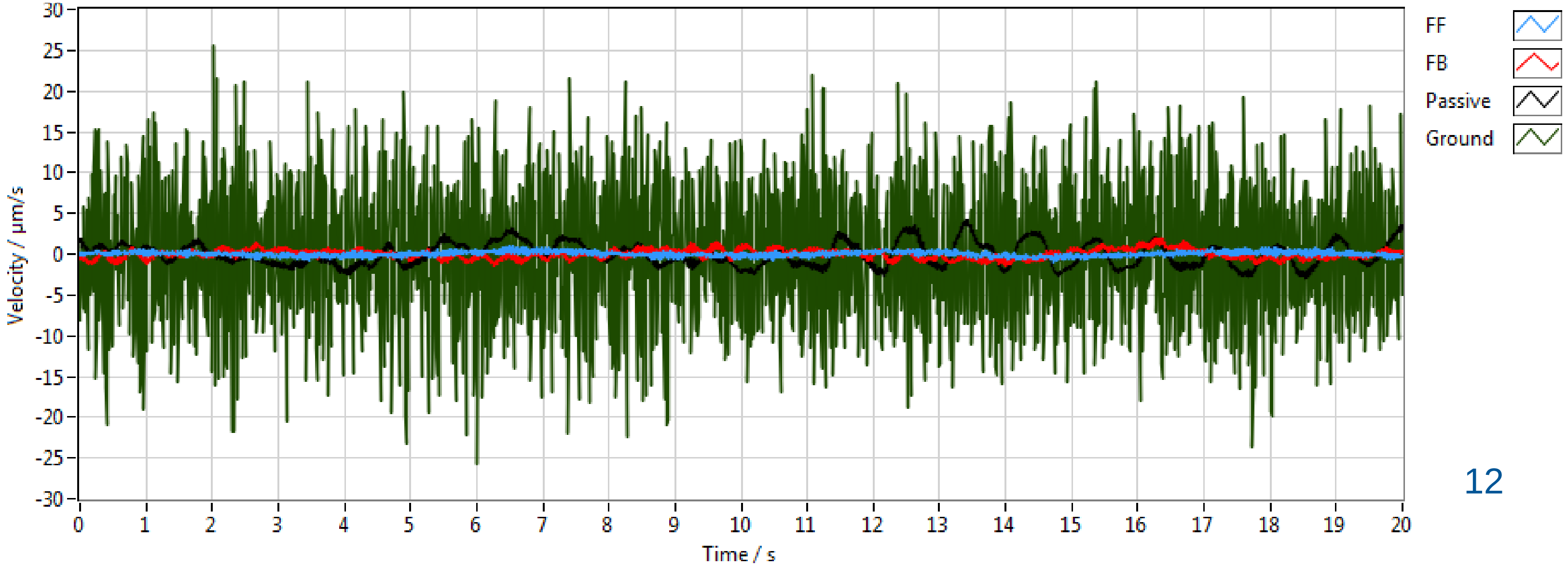
- Exert force steps in each DOF.
- Measure the platform response.
- Find the system parameters which best model the platform response to the exerted force and the ground vibration.





Example results – isolation





Example results – excitation

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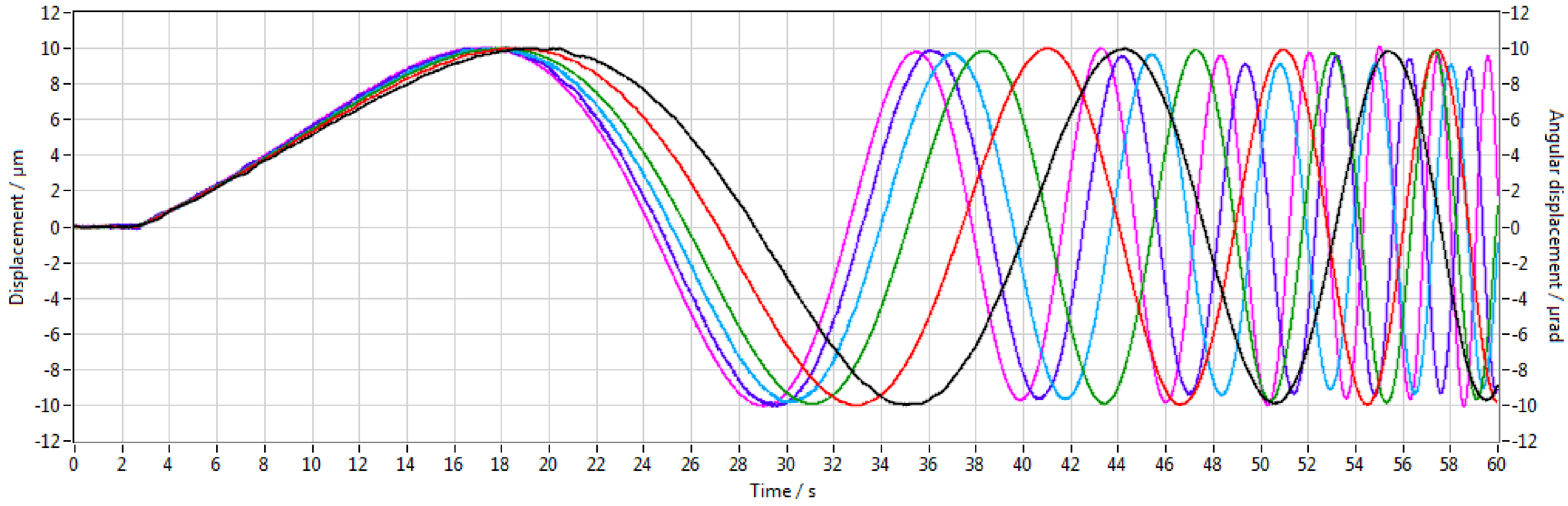


Measured platform displacement whilst being driven to a different swept sinusoid setpoint in each of the six degrees of freedom.

Measurement uncertainty
Actuator calibration

- Solenoid actuators can be calibrated *in-situ* using the Kibble Balance principle

Laplace force

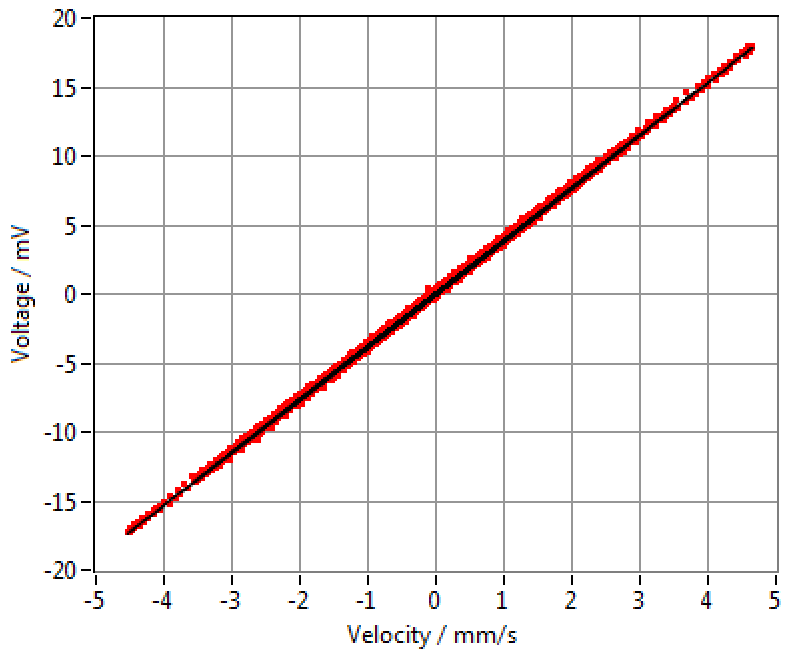
$$F = BLi$$

Faraday's law of induction

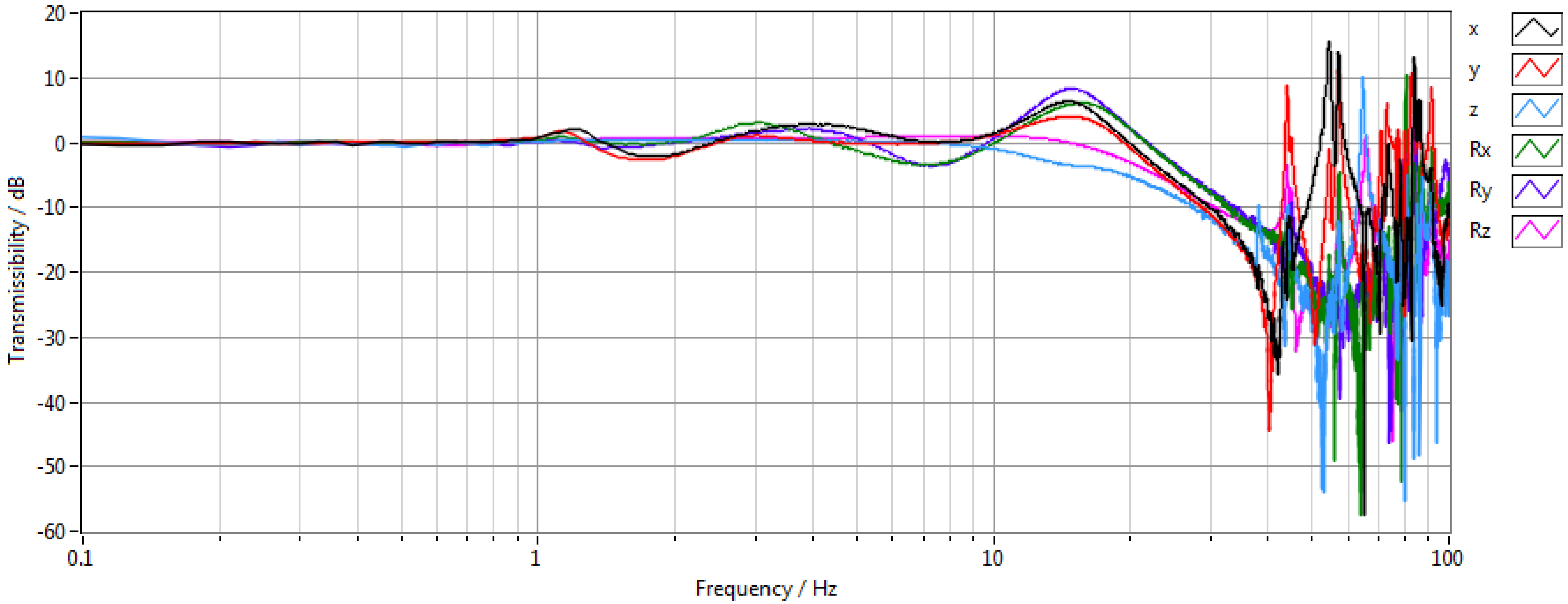
$$U = BLv$$

$$\frac{F}{i} = \frac{U}{v}$$

F – force
B - magnetic field strength
L – length of wire
i – current
U – voltage induced
v – velocity



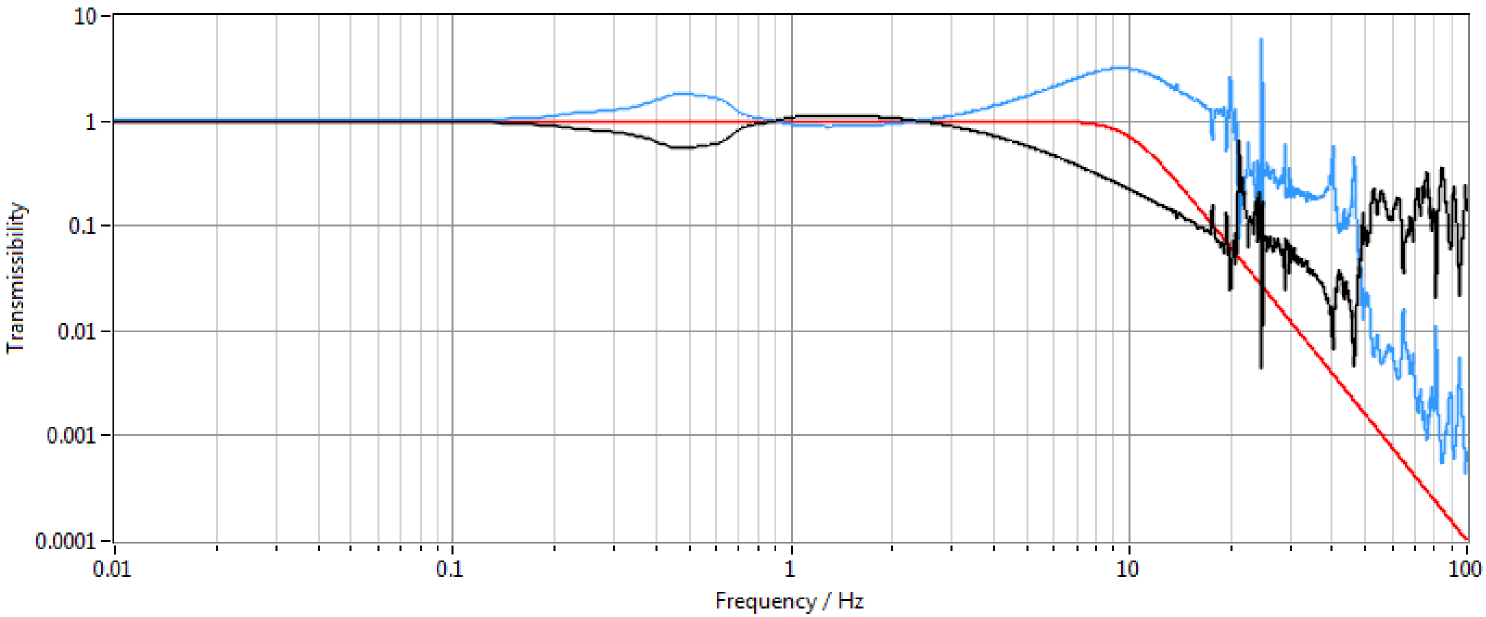
Measurement uncertainty
Measurement sensitivity



- Measurement sensitivity can be estimated using the system actuators as an input.
- Sensitivity deviates from unity at higher frequencies.
- Deviation is dependent on specimen dynamics.

Measurement uncertainty
Deconvolution

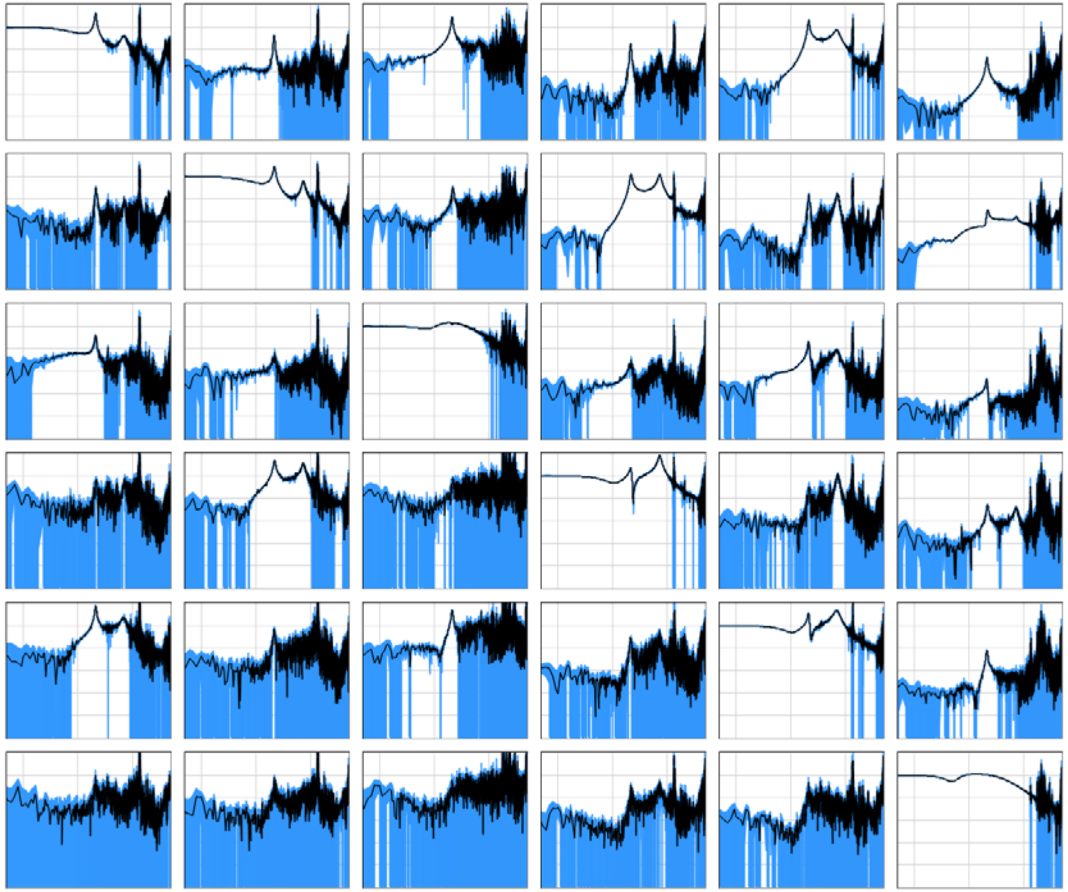
- Can use calibrated actuators to measure measurement sensitivity.
- Measurement response may be flattened using deconvolution filter.



Measurement uncertainty
Response uncertainty and cross-talk

- Must take into account cross-talk and uncertainty of measured sensitivity.
- Need to invert 6×6 measurement frequency response matrix.

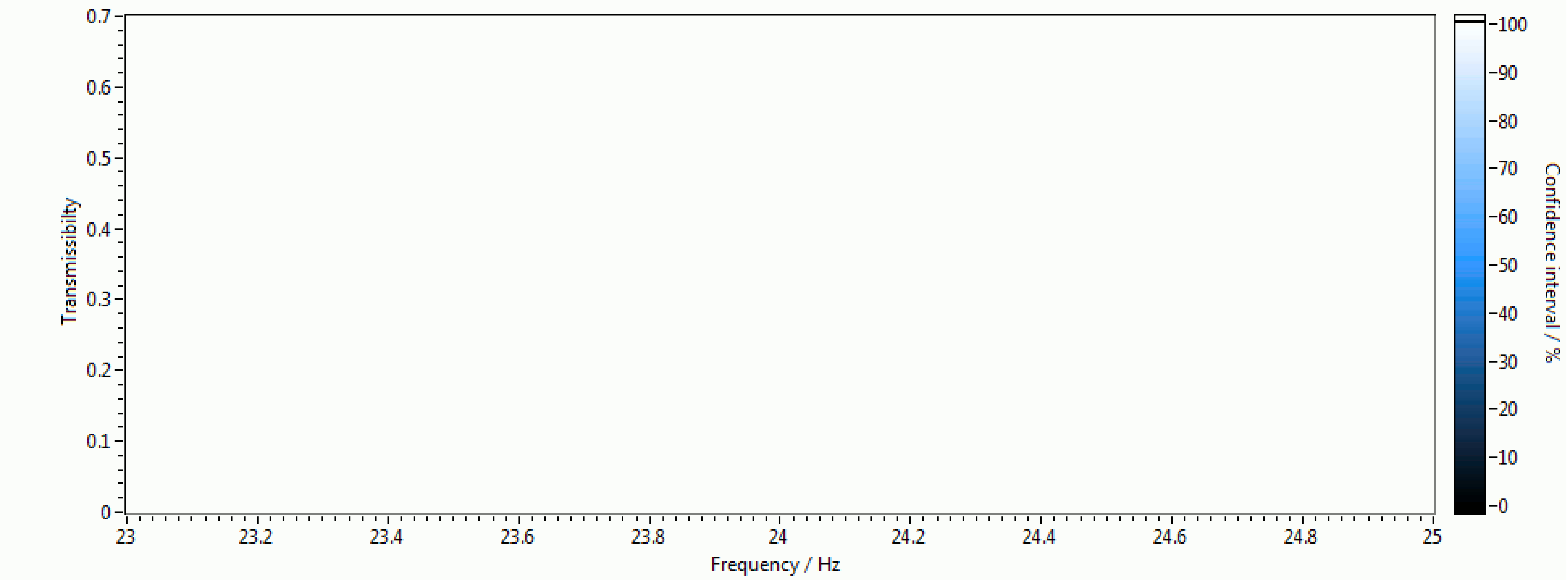
$\boldsymbol{measured\ force} =$



$\cdot\ \boldsymbol{calibration\ force}$

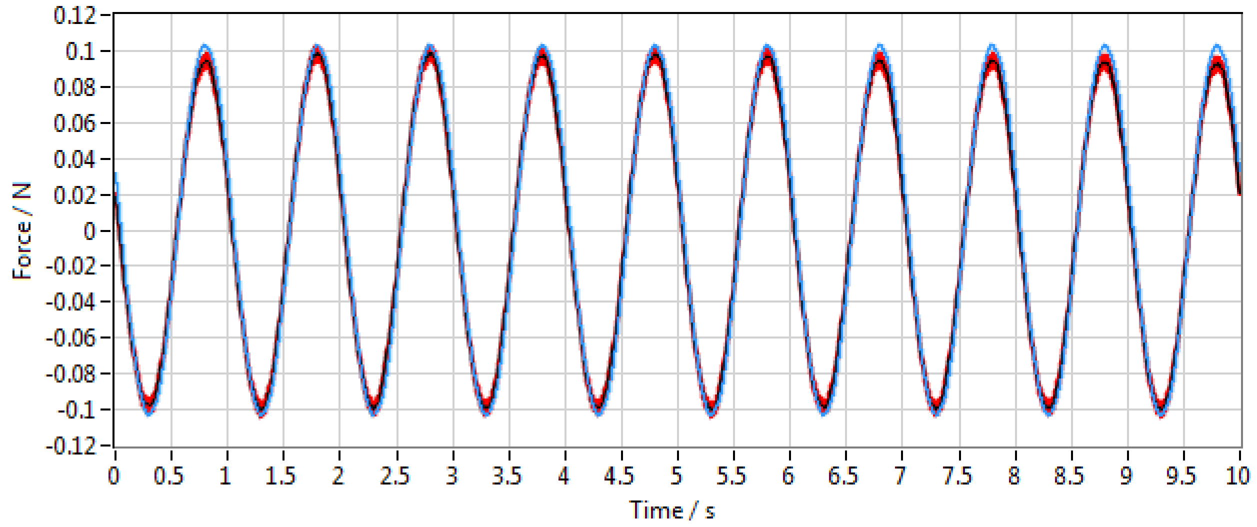
Measurement uncertainty
Monte-Carlo

- Deconvolution filter drawn as part of Monte-Carlo uncertainty estimate.

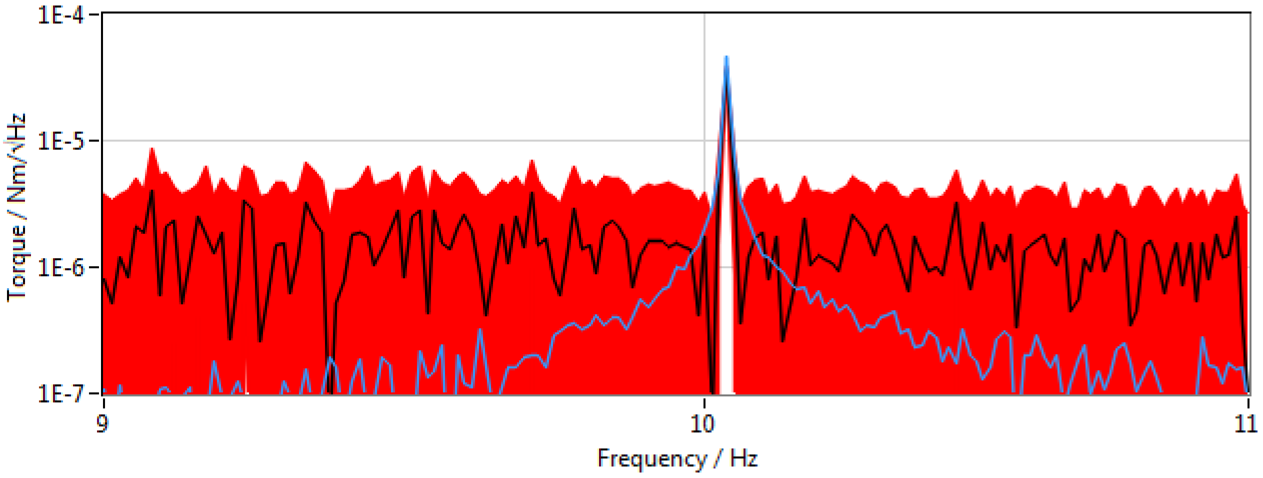


Example results - measurement

A time domain plot of a 1 Hz, 100 mN sinusoidal force exerted in the vertical direction.



A frequency domain plot of a 10 Hz, 7 μNm sinusoidal torque exerted about the vertical.



The exerted force is plotted in blue, the measured force in black and its *k* = 1 uncertainty in red.

Thank you,
any questions?