Interferometric sensors for low frequency isolation and control

• Sam Cooper, Conor Mow-Lowry, Chris Collins, Leonid Prokhorov, Amit Ubhi, Denis Martynov, Chiara di Fronzo
Breaking the seismic wall

Want to detect low frequency gravitational waves: intermediate mass black holes + early warning of mergers.

Limited by technical noise sub ~ 30Hz. Caused in part by residual ISI motion.

SRCL Note: T1900107
We have developed a tool that can fix this in two ways

1) Local damping of suspensions

2) Reducing ISI motion with new sensors
HoQI: HOmodyne Quadrature Interferometer

Fibre-coupled laser input

PD1

PBS1

PD2

PBS3

NPBS

PD3

Polarisation Key
X-Arm ←→
Y-Arm ←→
Mixed ←→

\( \frac{\lambda}{4} \)

\( \frac{\lambda}{2} \)

Ly

Lx

\( + \frac{\lambda}{4} \)
As a reminder...

Displacement Sensor Sensitivity (In air, no isolation)

Cooper et al 2018 Class. Quantum Grav. 35 095007
Beamsplitter damping with interferometers

Use the beamsplitter model to compare with current damping.

Adding HoQI at M2 (2\textsuperscript{nd} stage) allows increased damping, reducing suspension resonances.

Plots by Leonid Prokhorov
Suspension Projection

- Top Mass
- Upper Intermediate Mass (UIM)
- Penultimate Mass
- Test Mass

Reaction Chain
Main (test) Chain

BOSEM damping
HoQI damping

G1400964
Damping UIM with HoQI

Plot from Brian Lantz
Breaking the seismic wall

We have developed a tool that can fix this in two ways

1) Local damping of suspensions

2) Reducing ISI motion with new sensors
Inertial Sensor Sensitivity (In air, no isolation)

~ 100x higher resolution @10mHz than coil L4C
Ham ISI Model

Need to be able to quantify how much improvement new sensors, like the one’s we’re developing can improve the ISI performance.

We need to be able to add new filters to take advantage of new sensors

Useful to have a useable model to test different filters + filter design techniques and new sensors.

See DCC: T1800092 for more details
As a reminder - Model Performance

H1:HAM5-Z RMS Model Vs Reality Current Sensors

Displacement m/s/Hz

Frequency (Hz)

Ground input
Estimated Motion
Estimated Signal
Measured
GS13 Noise
ST1 Motion RMS
ST1 Signal RMS
ST1 Measured RMS
Blending filters

To get best idea of ISI performance with new sensors, need to design some new filters.

High and low pass filters designed looping over a range of different binomial filters (~1000), minimising the velocity RMS of the sensor noises.
HAM ISI: CPS + Optical Inertial

H1: HAM5-Z RMS Model Vs Reality Opt IS + CPS

- Estimated Motion (Optical Inertial+CPS)
- GS13 Noise
- ST1 Motion RMS (Optical Inertial + CPS)
- Estimated Motion (Current Sensors)
- ST1 Motion RMS (Current Sensors)

Looks good in Z but harder in translation…
6D Isolator Concept

If replacing the current sensors is not enough, need to change the dynamics.

Developing a 6D isolator at Birmingham with low stiffness in all 6 DOFs.

Current Progress: Ordered vacuum chamber, design of ISI and control scheme is underway.

C.M. Mow-Lowry and D. Martynov
arXiv:1801.01468
6D Sensitivity

Plot by Amit Ubhi

Plot by Amit Ubhi
6D Performance

Plot by Conor Mow-Lowry
Extra slides
Optical inertial sensor noise budget

Displacement m/√(Hz) vs Frequency (Hz)

- IFO Readout Noise
- Structural Thermal Noise
- Frequency Noise
- Total Noise
- L4C Noise

Graph showing the noise budget at different frequencies.
Loop structure

Model Features:

- 6 Degree of Freedom
- Custom sensor noises
- Custom filter support
- Support for LHO and LLO*
- Can now calculate suspension point motion for use in suspension models

Available on SEI SVN at:

seiSVN/HAM-ISI/Common/hamISIModel2018/
Model Performance: SEI Coordinates

Caused by tilt from RY.

H1:HAM5-X Model vs Reality

- Ground input
- Estimated Motion
- Estimated Signal
- Measured Signal
- GS13 Noise

Displacement m/√(Hz)

Caused by tilt from RY.

Frequency (Hz)
Model Performance: SUS Coordinates

Longitudinal, Transverse, Pitch, Roll work ‘well – similar agreement to above’

Yaw: some disagreement between 0.1 and 1Hz caused by RZ error

Vertical: Bad (Z, RX, RY contribute here – needs further investigation)