Mechanical design of the UF Torsion Pendulum for testing the LISA Gravitational Reference Sensor

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Abstract

The Laser Interferometer Space Antenna (LISA) requires free falling test masses, whose acceleration must be below 3 fm/s²/√Hz in the lower part of LISA's frequency band ranging from 0.1 to 100 mHz. Gravitational reference sensors (GRS) house the test masses, shield them from external disturbances, control their orientation, and sense their position at the nm/√Hz level. The UF Torsion Pendulum is a laboratory test bed for GRS technology. By decoupling the system of test masses from the gravity of the Earth, it is possible to identify and quantify many sources of noise in the sensor. The mechanical design of the pendulum is critical to the study of the noise sources and the development of new technologies that can improve performance and reduce cost. The suspended test mass is a hollow, gold-coated, aluminum cube which rests inside a gold-coated, aluminum housing with electrodes for sensing and actuating all six degrees of freedom. This poster describes the design, analysis, and results to date of the mechanical subsystems of the UF Torsion Pendulum.

Introduction

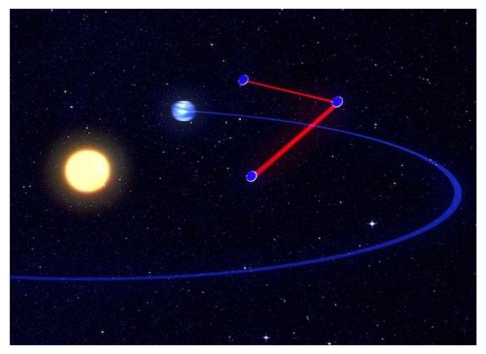
LISA is the most mature concept for detecting gravitational waves from space [2, 3, 4]. The LISA design consists of three Sun-orbiting spacecraft that form an equilateral triangle, with each side measuring 1-5 million kilometers in length. Each spacecraft houses two free-floating test masses (TM), which are protected from all disturbing forces so that they follow pure geodesics in spacetime. Laser interferometry is used to measure the minute variations in the distance, or light travel time, between these purely free-falling TMs, caused by gravitational waves.

As a testbed for a LISA-like GRS, the UF Torsion Pendulum will build on the work from University of Trento to quantify known noise sources and help to identify unknown noise sources. Also, the torsion pendulum can be used to evaluate new technologies, such as different sensor configurations.

Key Features:

- Long (22 cm) arm length to accommodate optical bench
- More thermally and seismically isolated underground pit
- Ultraviolet LED-based charge control
- Optical interferometric readout

LISA Spacecraft Formation



[Bild: AEI/Milde Marketing/Exozet]

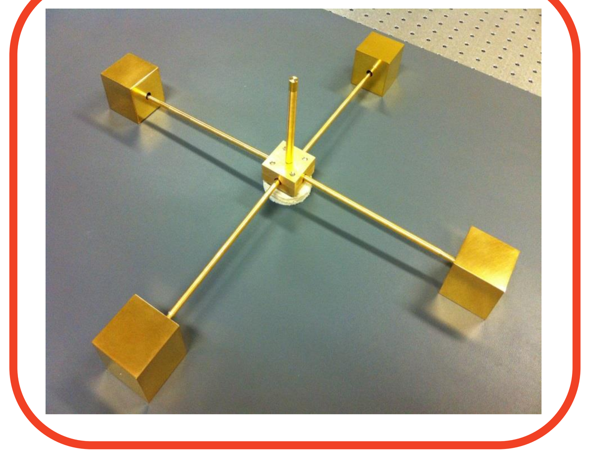
Expected Noise Sources

Noise Source	Relevant Parameters
Differential Outgassing	Temperature Gradients
Differential Radiation Pressure	Temperature Gradients
DC Biases	Charge
In-band TM Voltage Fluctuations	Charge
Voltage Thermal Noise	Finite Conductivities
Residual Gas Damping	Vacuum Chamber Pressure

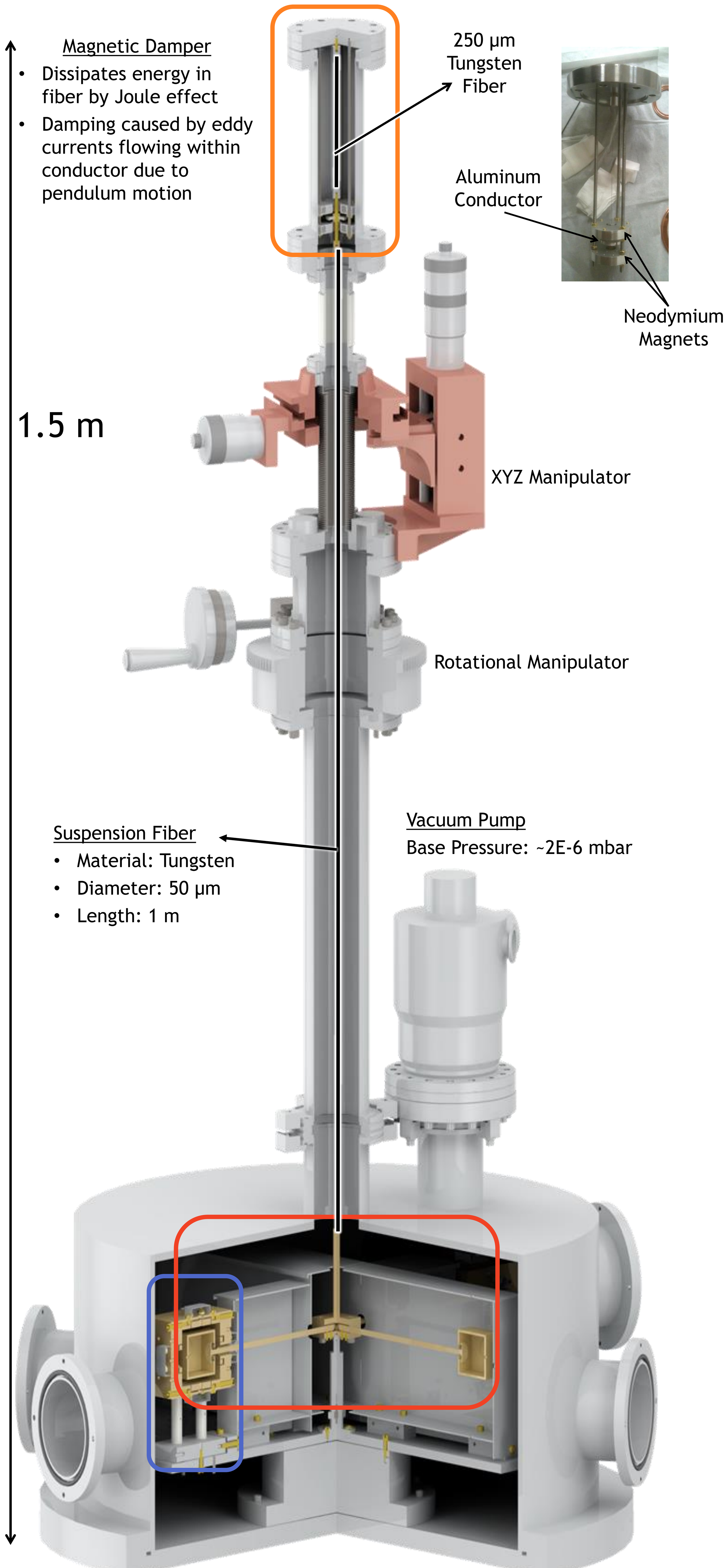
Natural Frequencies	Rotational Mode	Swinging Mode
Parameters	$\Gamma = \frac{\pi r^2}{2L}\left(E + \frac{mg}{\pi r^2}\right)$ [1] $r = 25\ \mu m$ $E = 161\ GPa$ $I = 0.0163\ kg\ m^2$ $m = 473\ g$	$L = 1\ m$ $g = 9.81\ m/s^2$
Equation	$f_r = \frac{1}{2\pi}\sqrt{\frac{\Gamma}{I}}$	$f_s = \frac{1}{2\pi}\sqrt{\frac{g}{L}}$
Predicted Value	$f_r = 0.394\ mHz$	$f_s = 0.498\ Hz$

Inertial Member

- Mass: 473 g
- Material: Gold-coated aluminum (minimizes heterogeneous surface charges and mass)
- Arm length: 22 cm
- Electrically isolated test masses via quartz rings



Subsystems

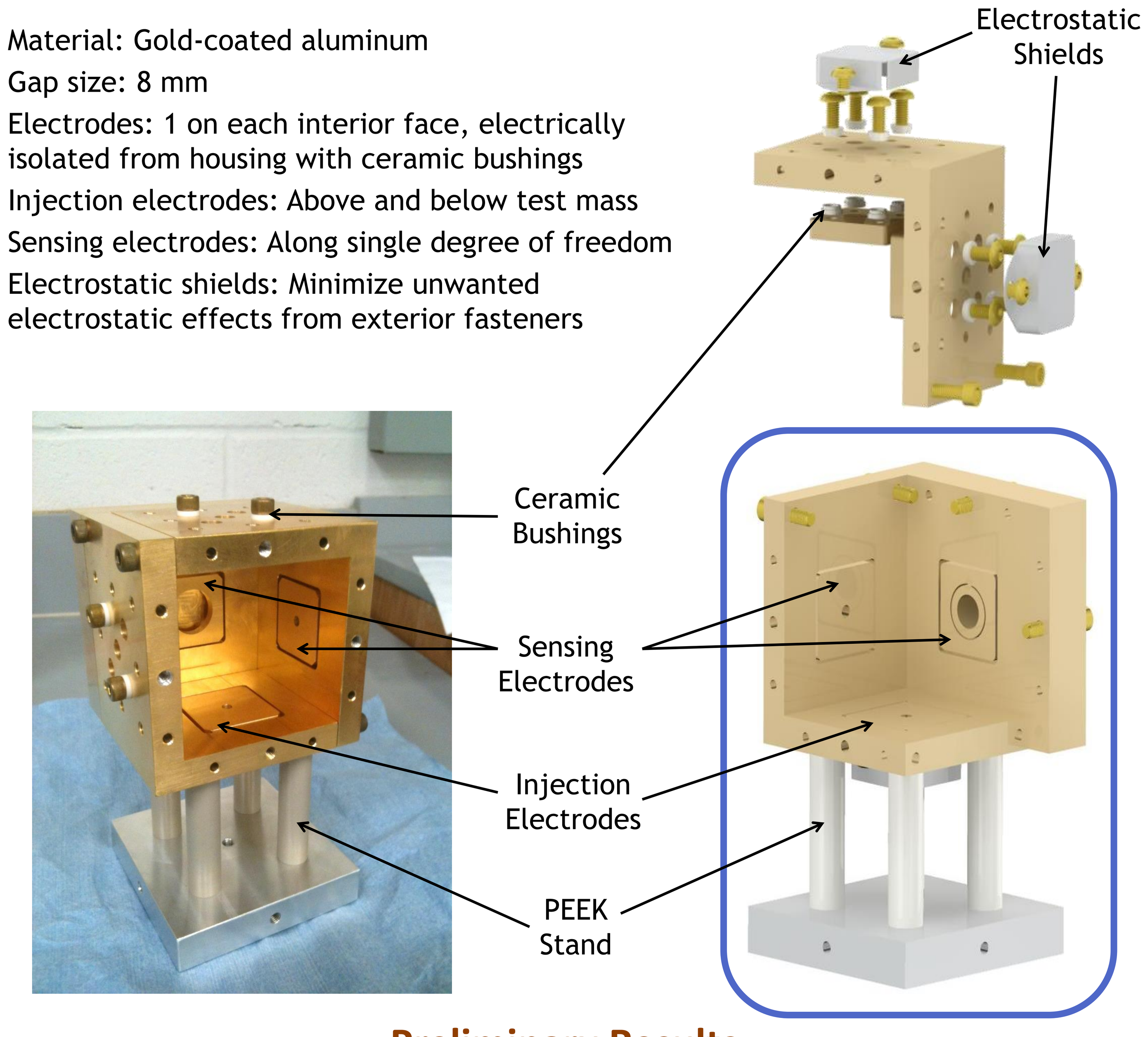


References

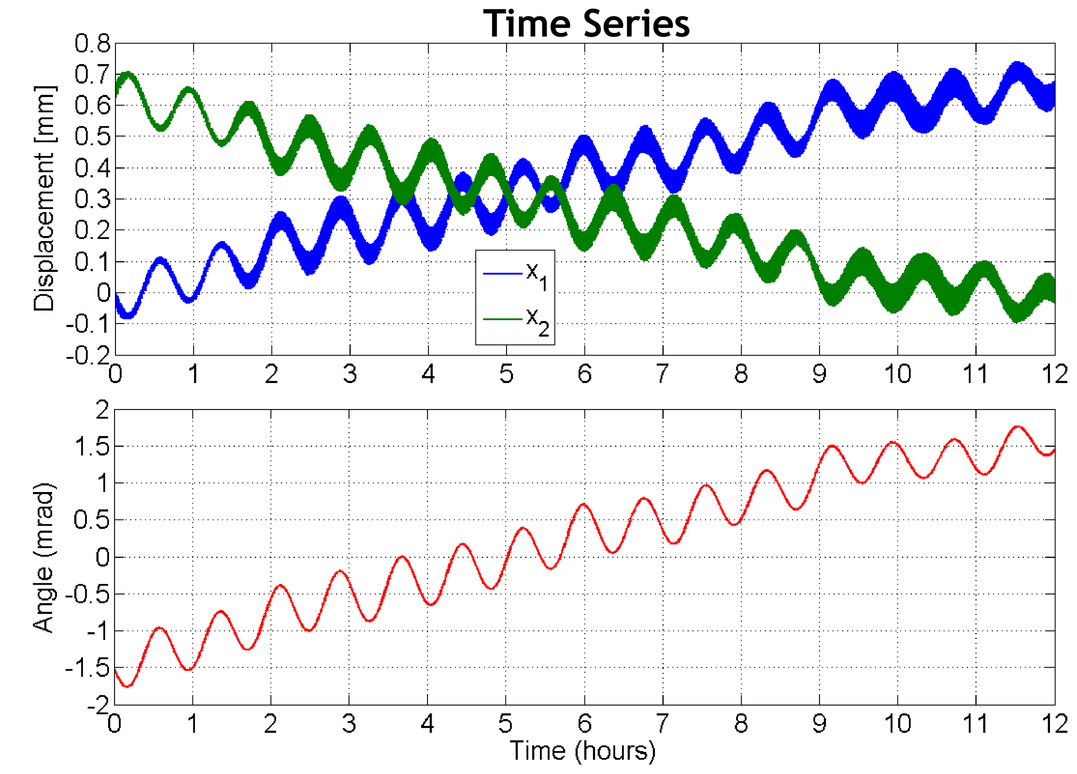
1. A Cavalleri *et al*, "A new torsion pendulum for testing the limits of free-fall for LISA proof masses", *Classical and Quantum Gravity*, **26**(9), 094017 (2009).
2. K. Danzmann and A Rudiger, "LISA technology—concept, status, prospects", *Classical and Quantum Gravity*, **20**(10) S1-S9, (2003).
3. LISA study team, "LISA Pre Phase A Report," 2nd Edition, ESA (1998).
4. LISA Science Team, "System and technology report", ESA (2000).

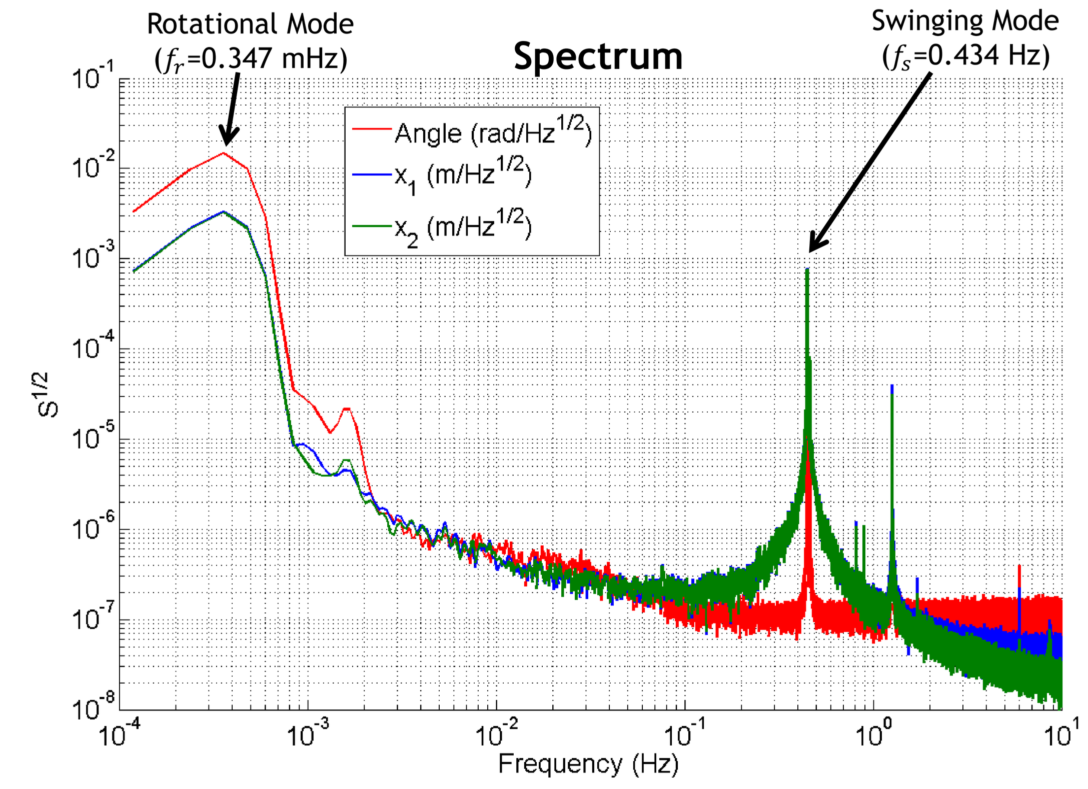
Simplified GRS

- Material: Gold-coated aluminum
- Gap size: 8 mm
- Electrodes: 1 on each interior face, electrically isolated from housing with ceramic bushings
- Injection electrodes: Above and below test mass
- Sensing electrodes: Along single degree of freedom
- Electrostatic shields: Minimize unwanted electrostatic effects from exterior fasteners



Preliminary Results





Forward Work

Debugging and Reducing Noise Floor → Designing Flight-Like GRS → Charge Control Demonstration → Interferometric Readout Integration → Relocate pendulum to pit