Hydraulic Actuators for Advanced LIGO and LIGO I

Stanford, Caltech, LSU, MIT, LLO

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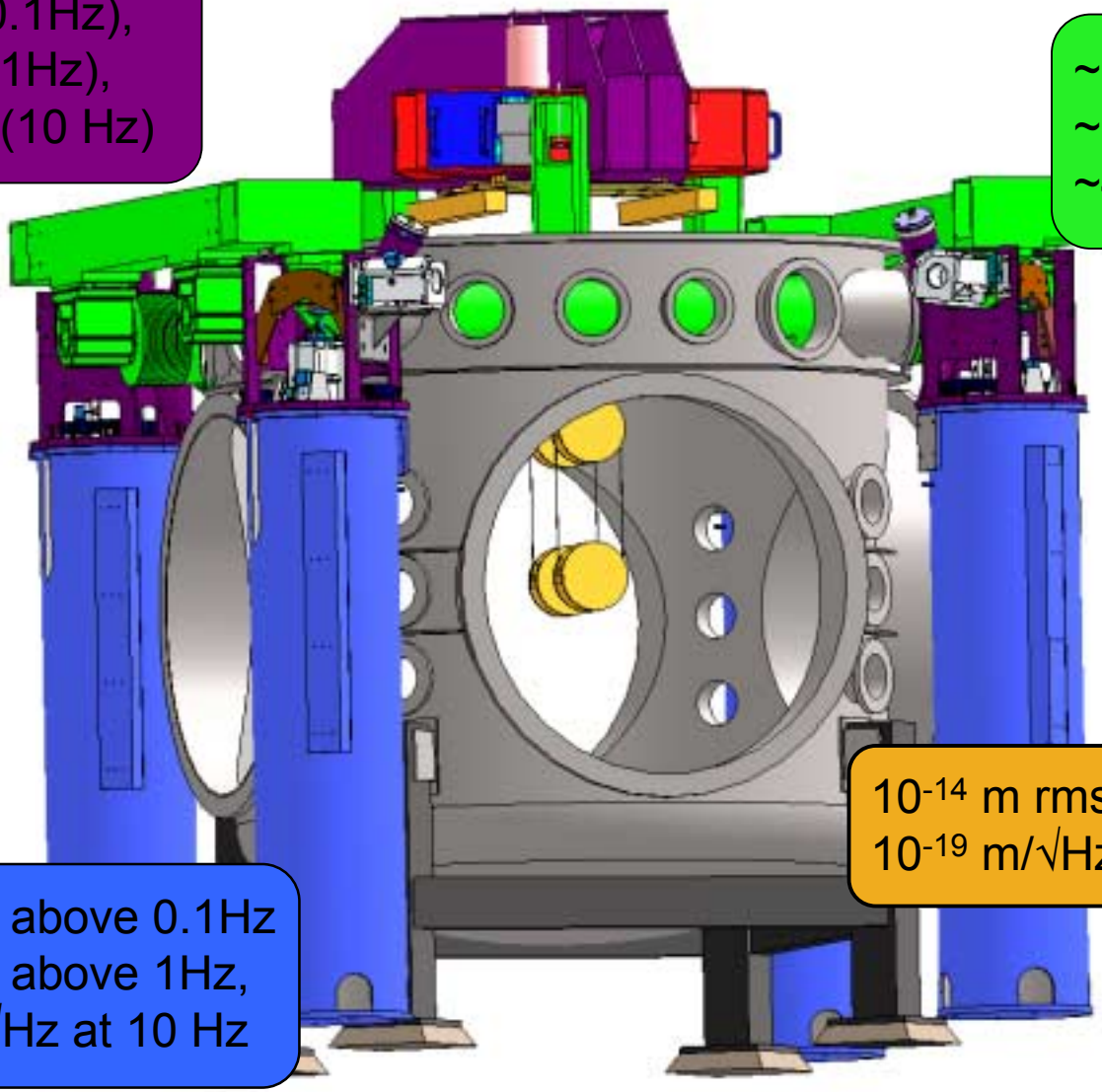
LIGO-G030206-00-Z

Advanced LIGO Suspensions

~10^{-7} m rms (0.1Hz),
~10^{-11} m rms (1Hz),
2 10^{-13} m/√Hz (10 Hz)

~10^{-7} m rms (0.1Hz),
~10^{-8} m rms (1Hz),
~4 10^{-10} m/√Hz



10^{-14} m rms differential,
10^{-19} m/√Hz (10 Hz)

~10^{-6} m rms above 0.1Hz
~10^{-8} m rms above 1Hz,
~4 10^{-10} m/√Hz at 10 Hz

Motivation for Pre-Isolator

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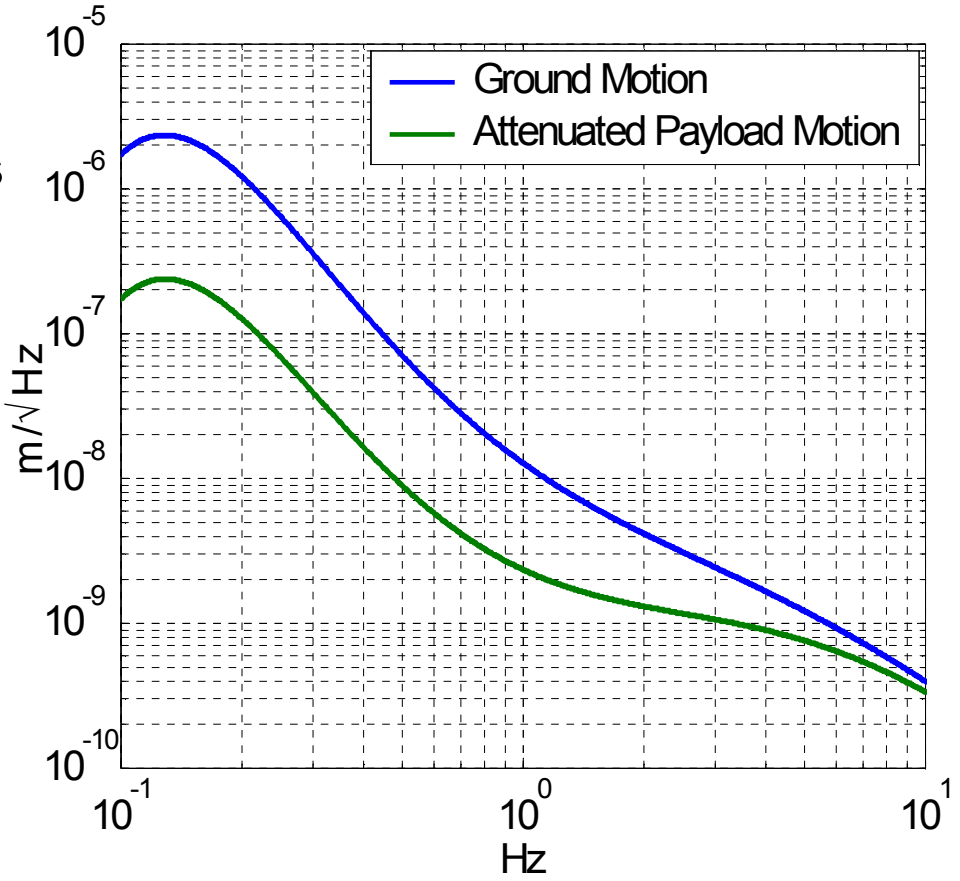
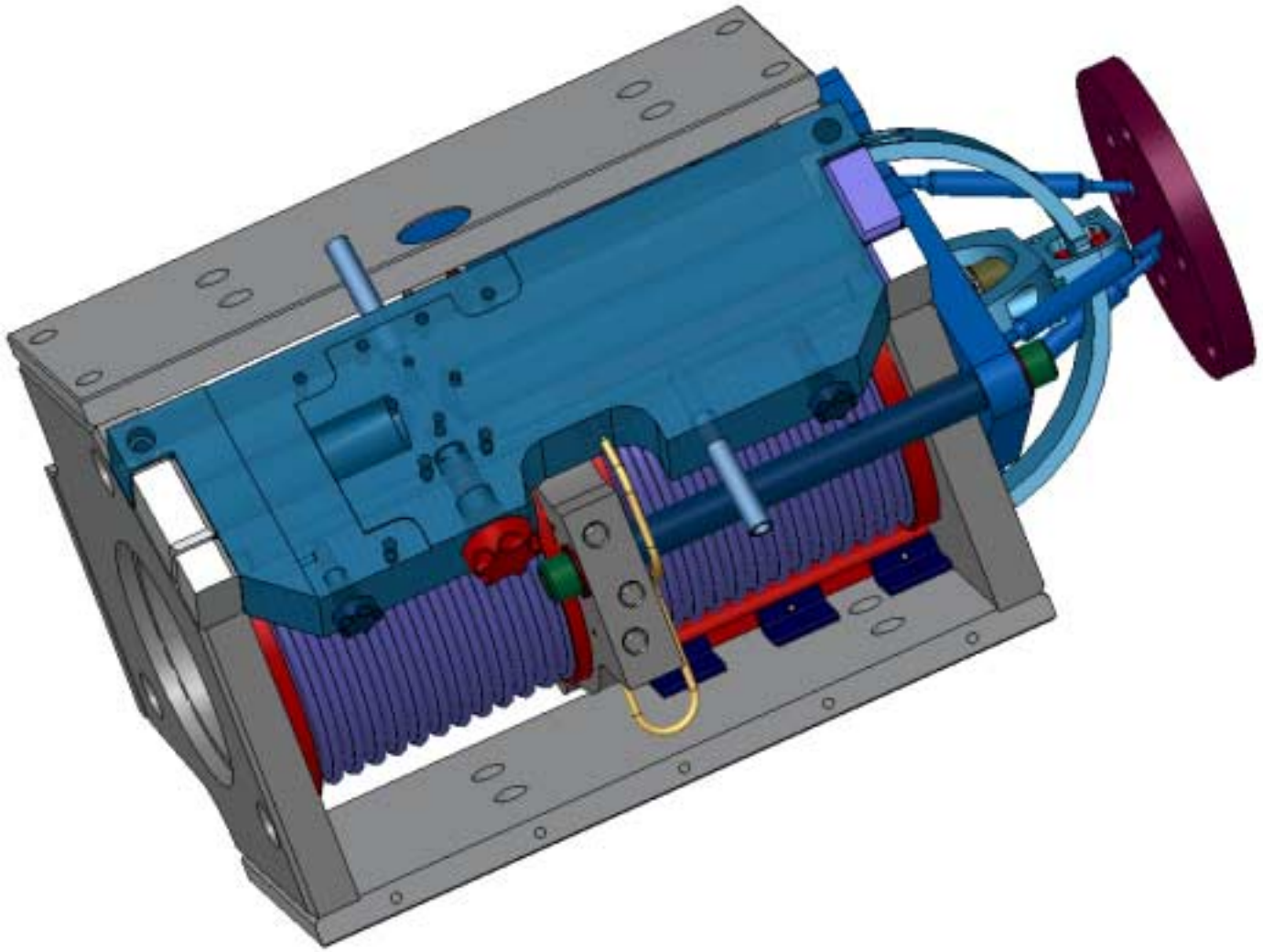
- Alignment
  - Seasonal Temperature Changes
- Isolation
  - The micro-seismic peak
- Control Reallocation
  - Reduce control effort / noise from inner stages



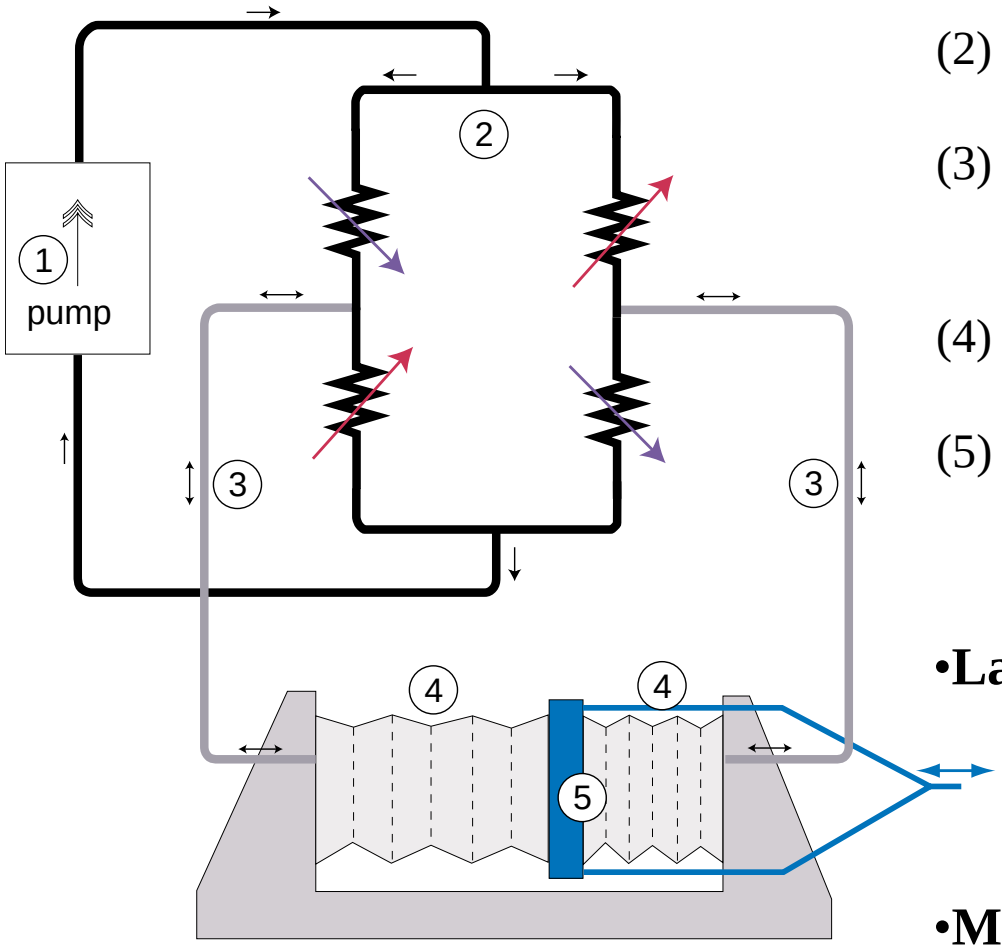
Performance Requirements

- Range of Motion
  - Mechanical Adjustment: 5 mm.
  - Active Control: +/- 1 mm.
- Response
  - Initial Response: 1 mm. in 10 sec.
  - Bandwidth: .1 - 10 Hz.
- Resolution and Noise
  - 10 nm. rms (10-2 to 3 Hz)

Quiet Hydraulic Actuator



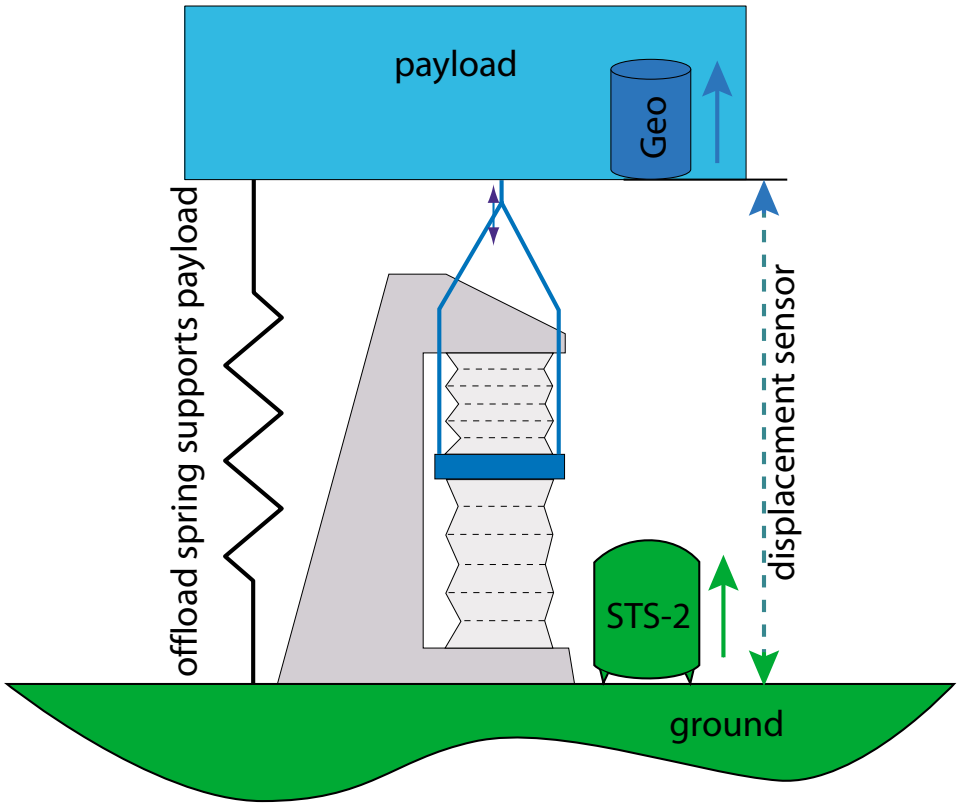
Quiet Hydraulic Actuator Basics



(1) Pump supplies a constant flow of fluid to the actuator.
(2) Fluid flows continuously through a hydraulic Wheatstone bridge.
(3) By controlling the resistance, one generates differential pressure across the bridge, which are connected to
(4) Differential bellows which act as a stiction-free piston.
(5) The actuator plate is between the bellows, and is connected to the payload with a flexure stiff in 1 DOF

- **Laminar flow**
  high viscosity (100 x water),
  low velocity (80 microns/ sec.),
  fluid path geometry.
- **Motion with flexures**
- **Offload springs to keep bridge balanced**
  common mode rejection of pump noise

How to get Isolation from the Ground



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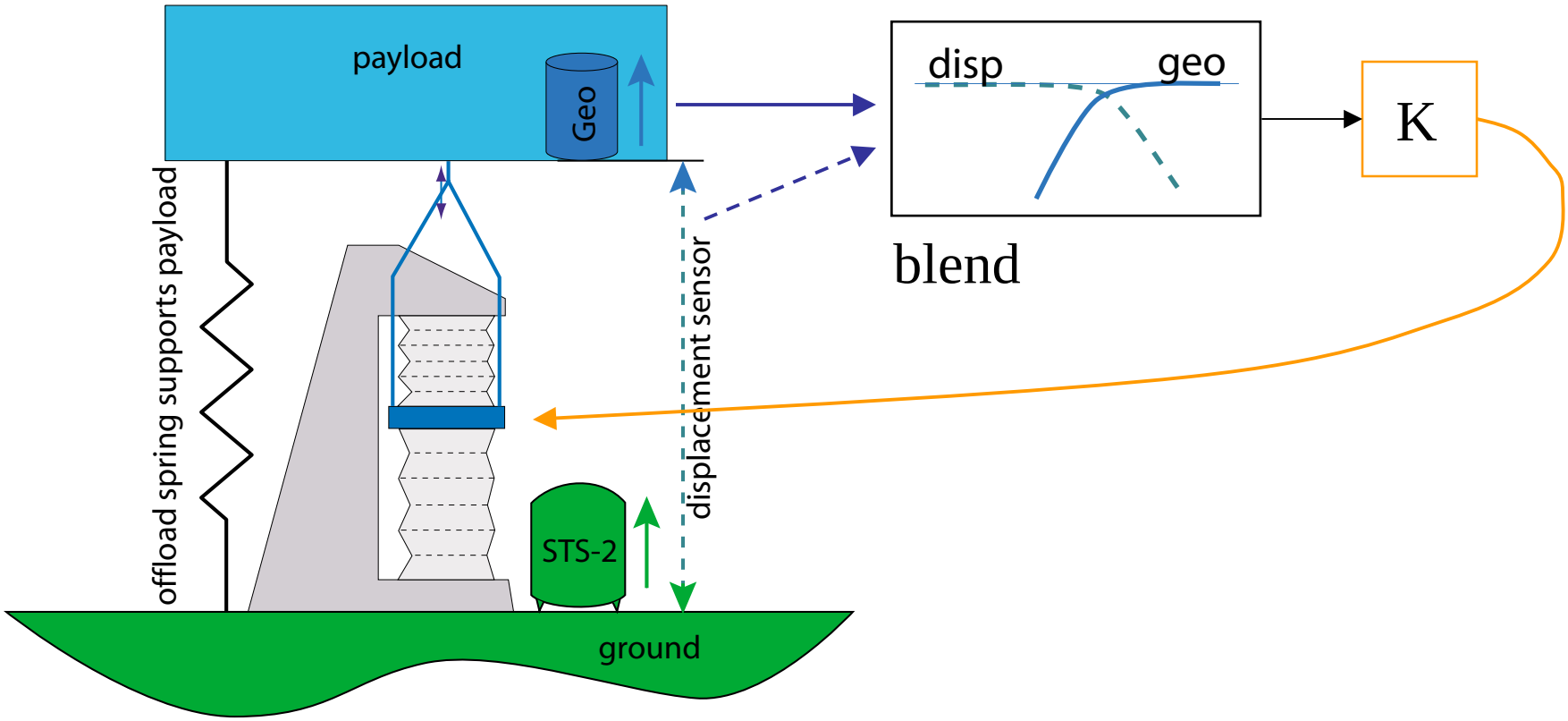

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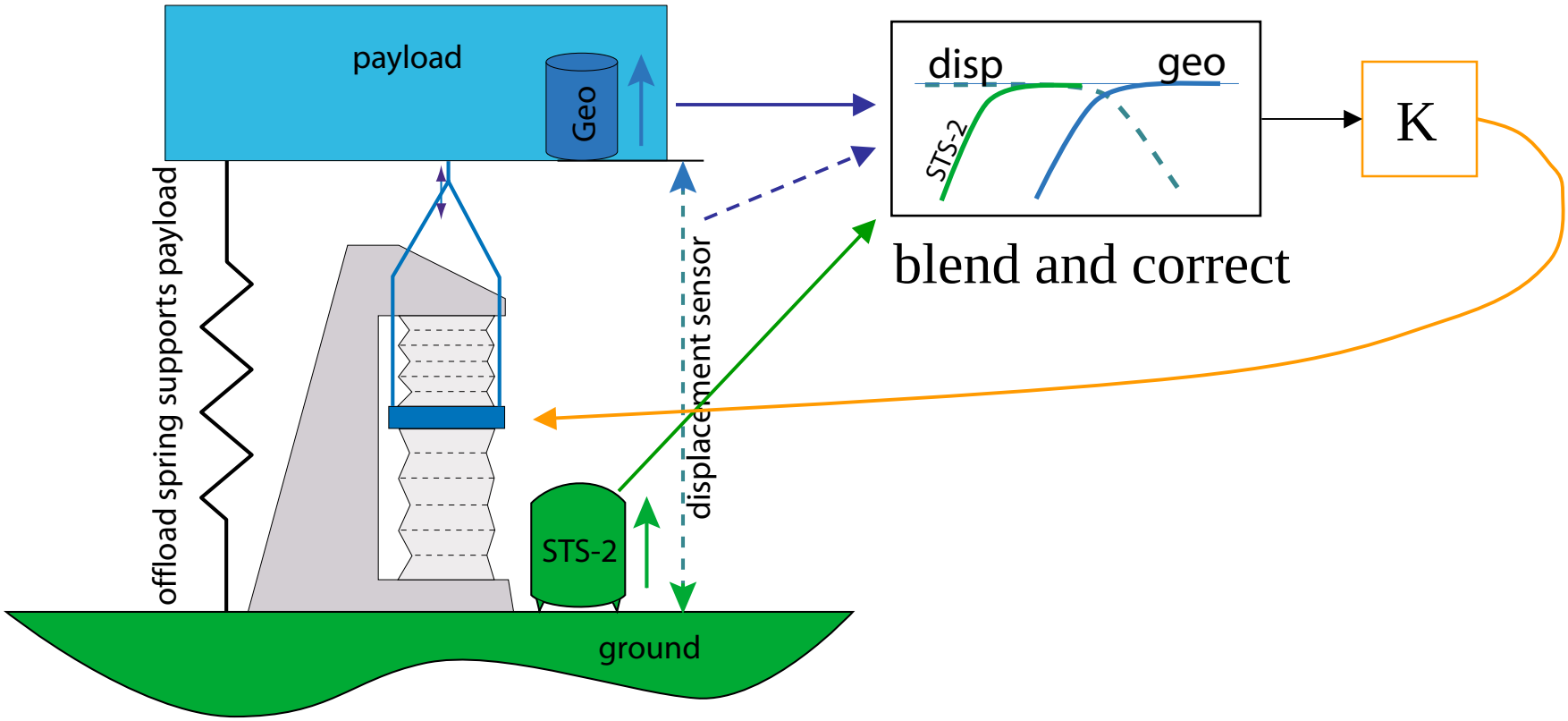
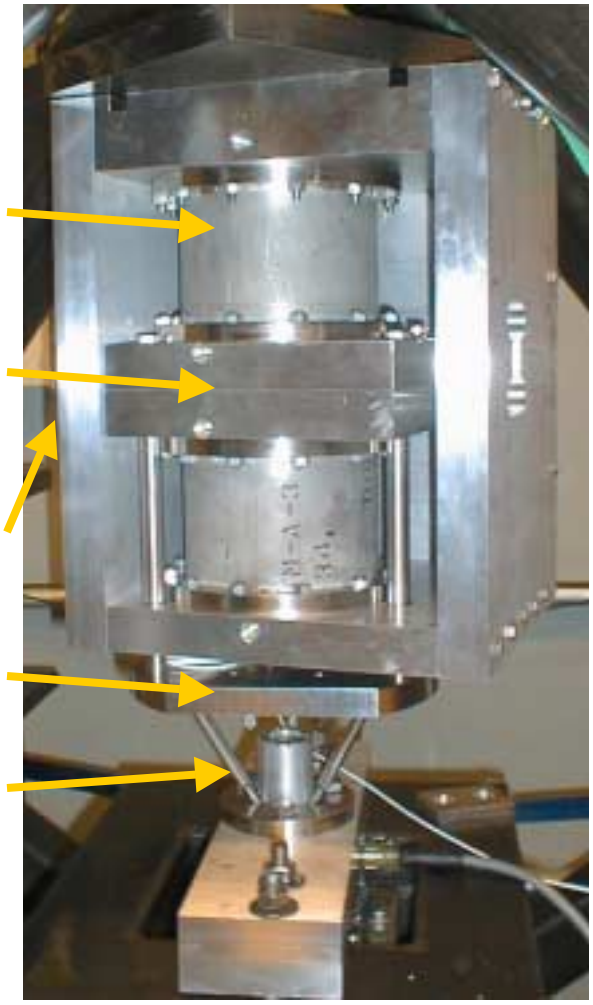
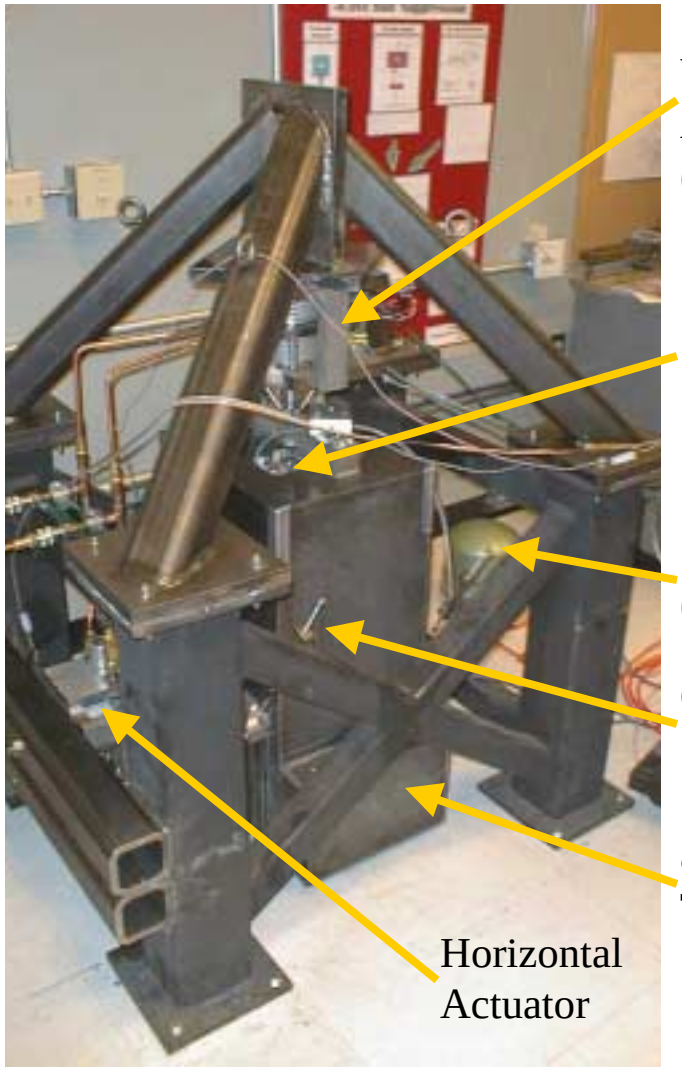


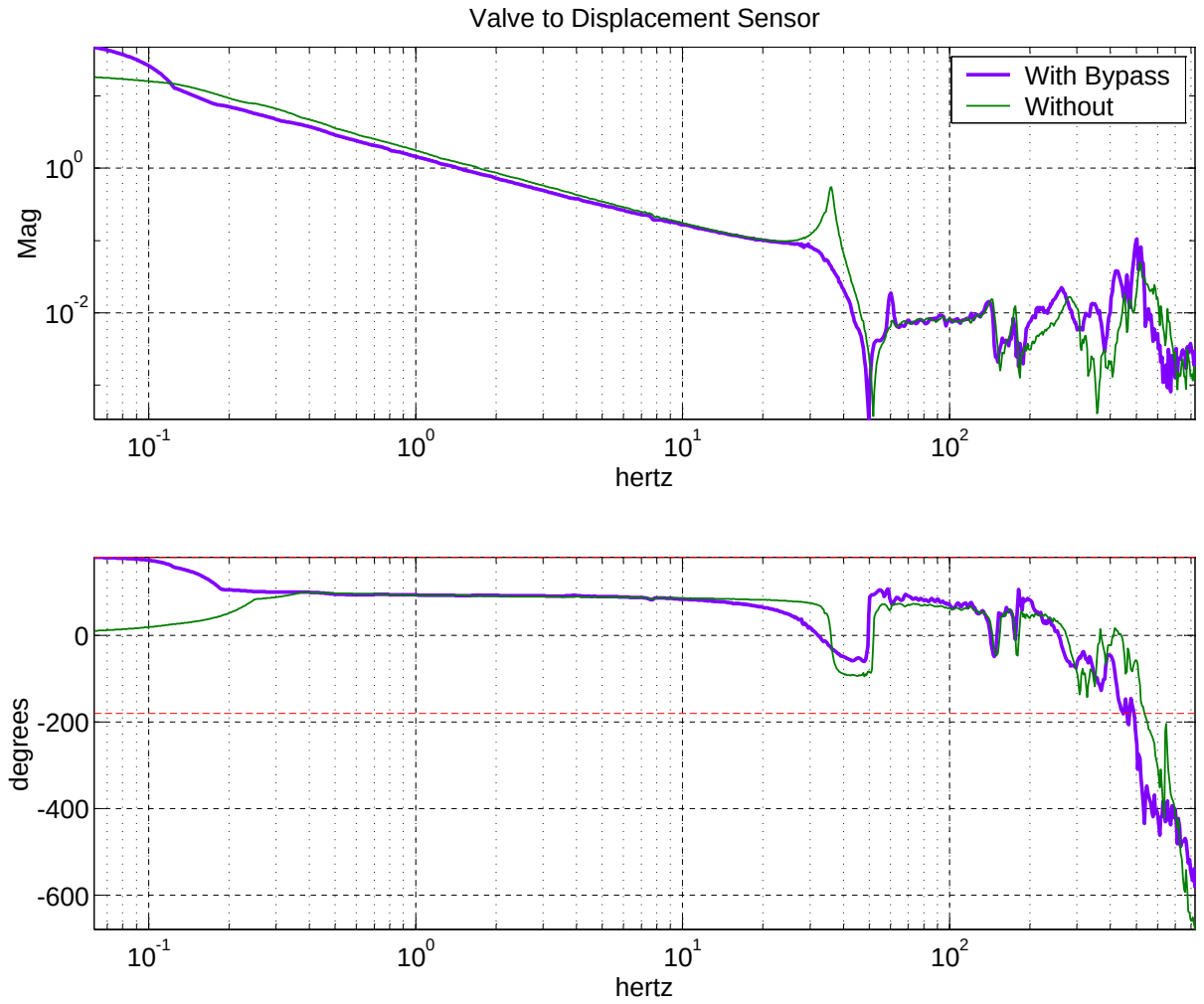
Development at Stanford



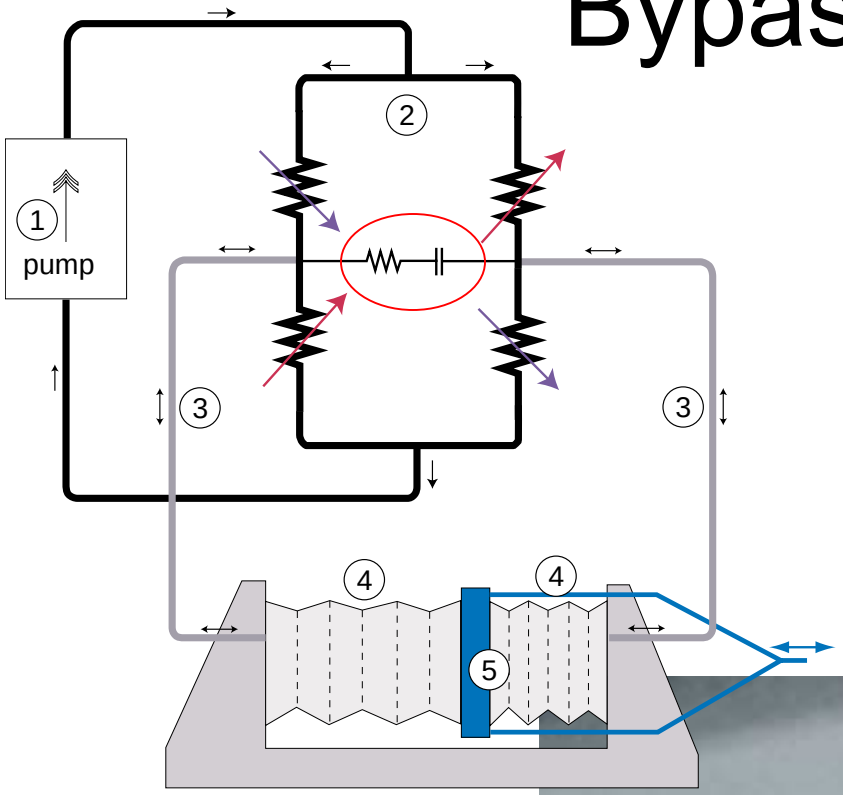
Vertical Actuator –version 2

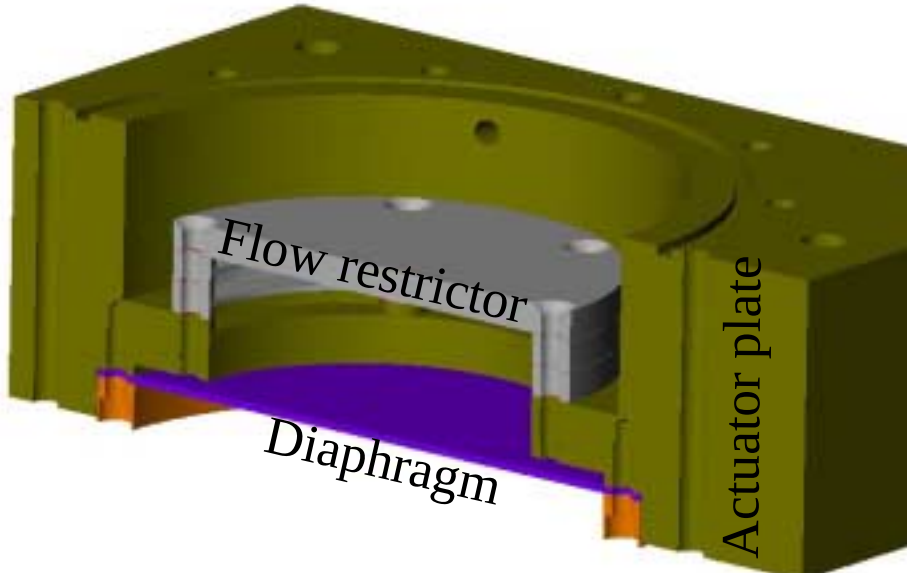


Actuator Development

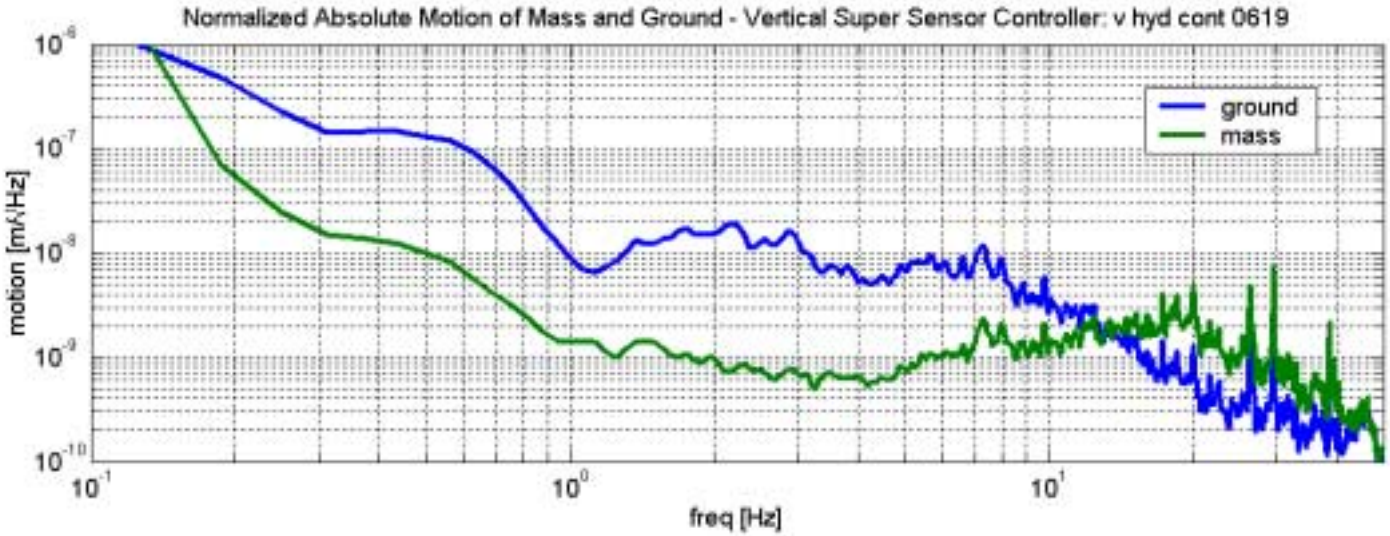


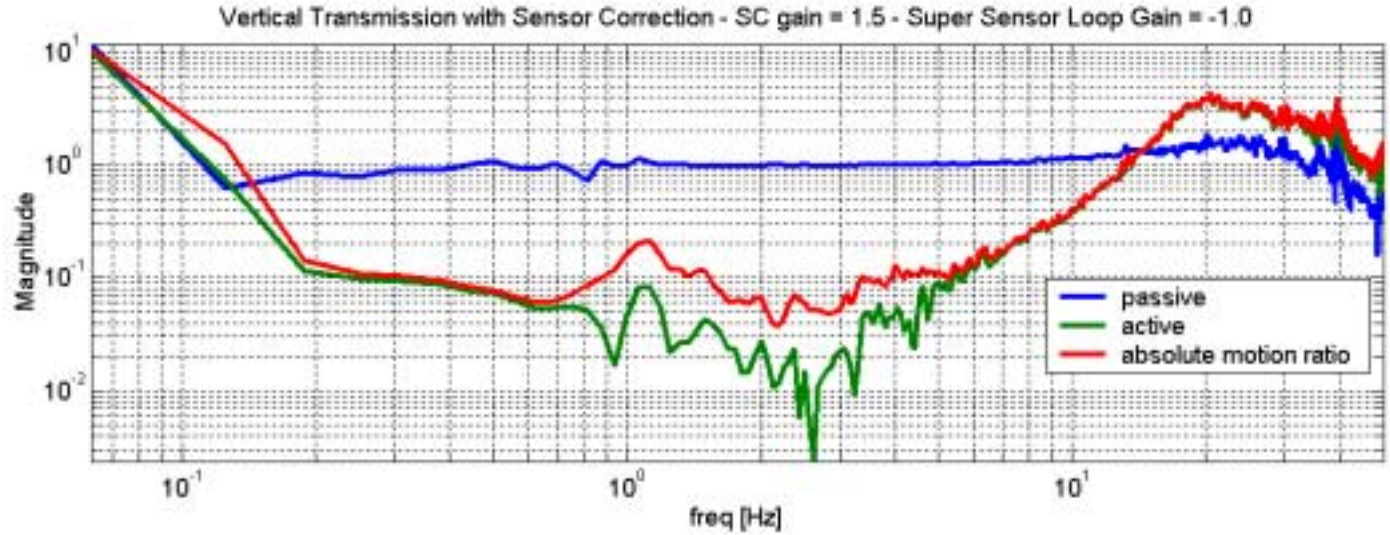
Bypass Network





Test Platform Performance

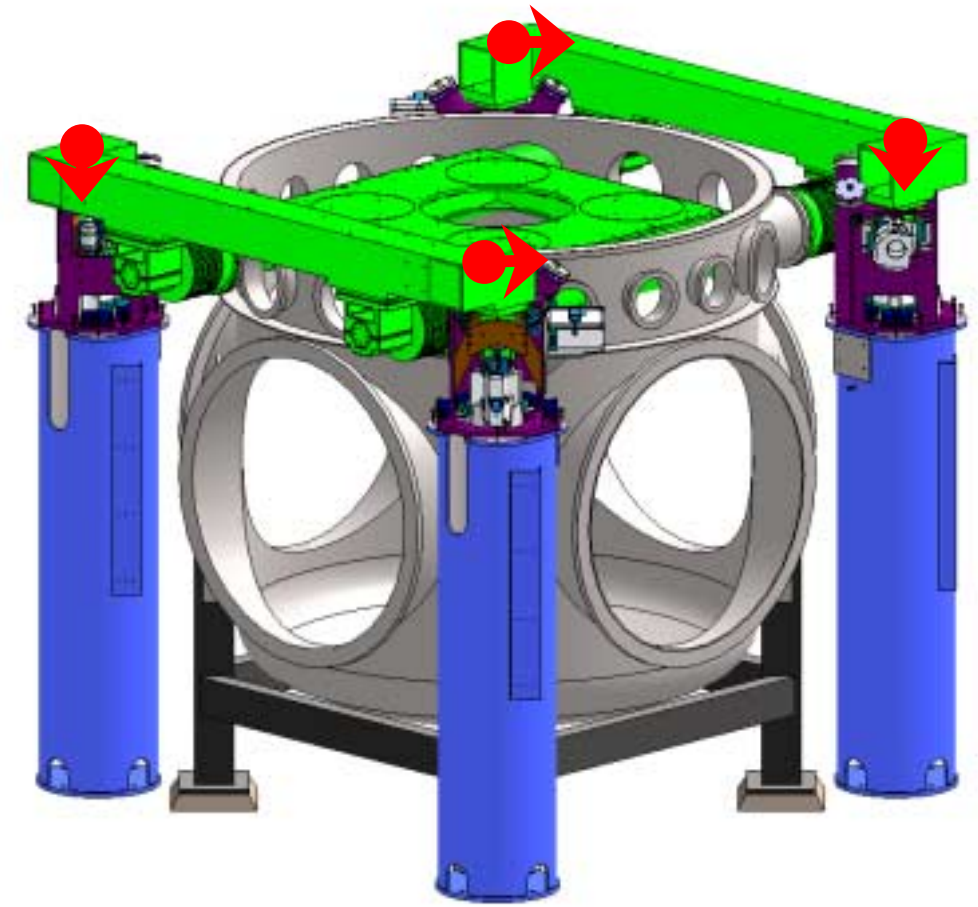




GO TO LASTI

Control Strategy

- Translation X
- Translation Y
- Translation Z
- Pitch
- Roll
- Yaw
- O.C. Vert
- O.C. Horz



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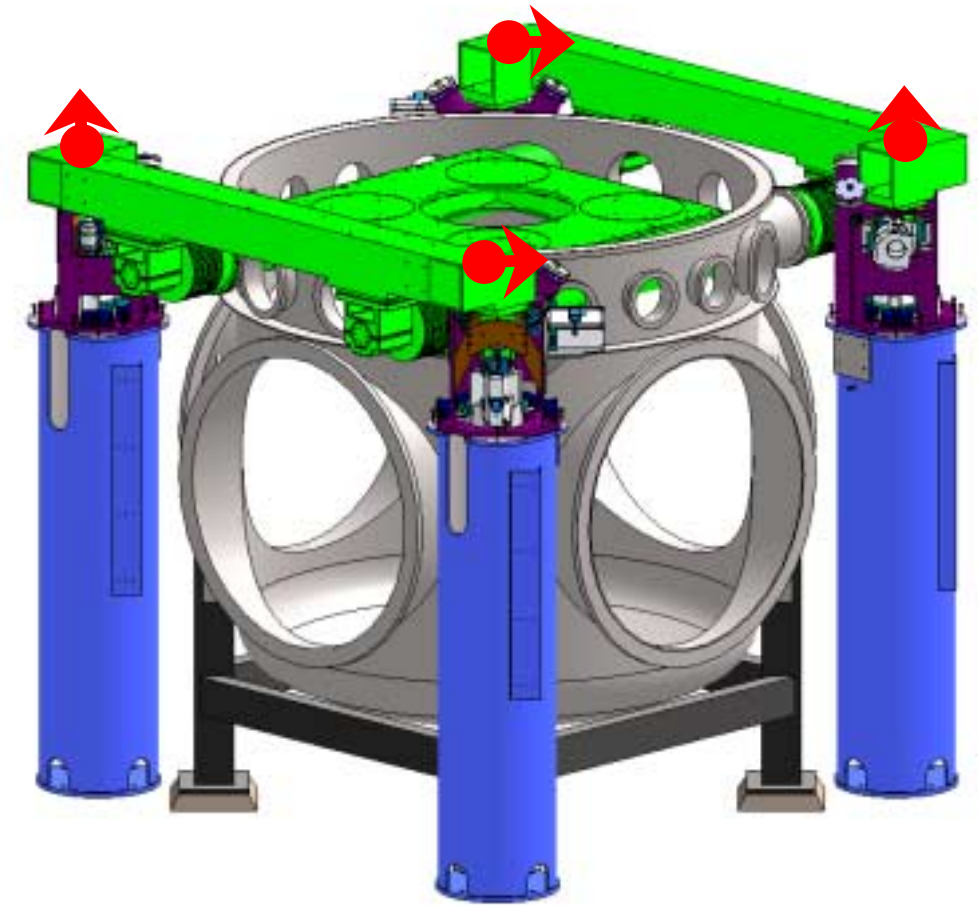

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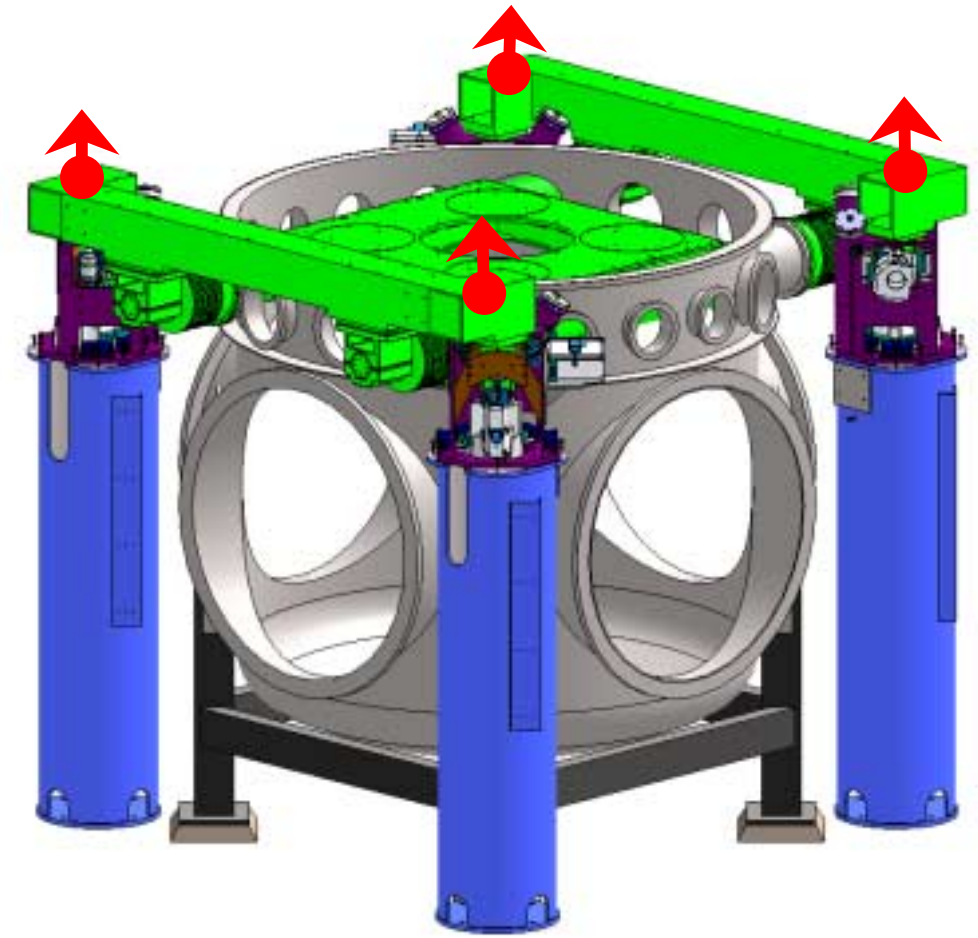

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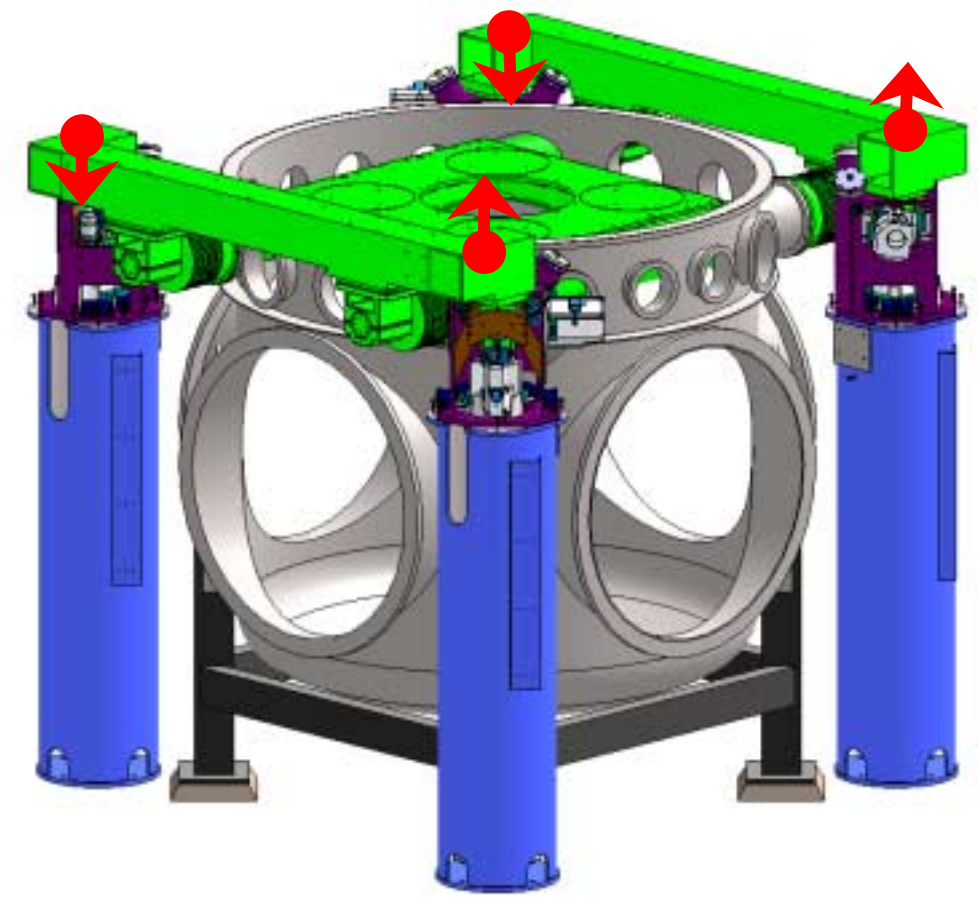

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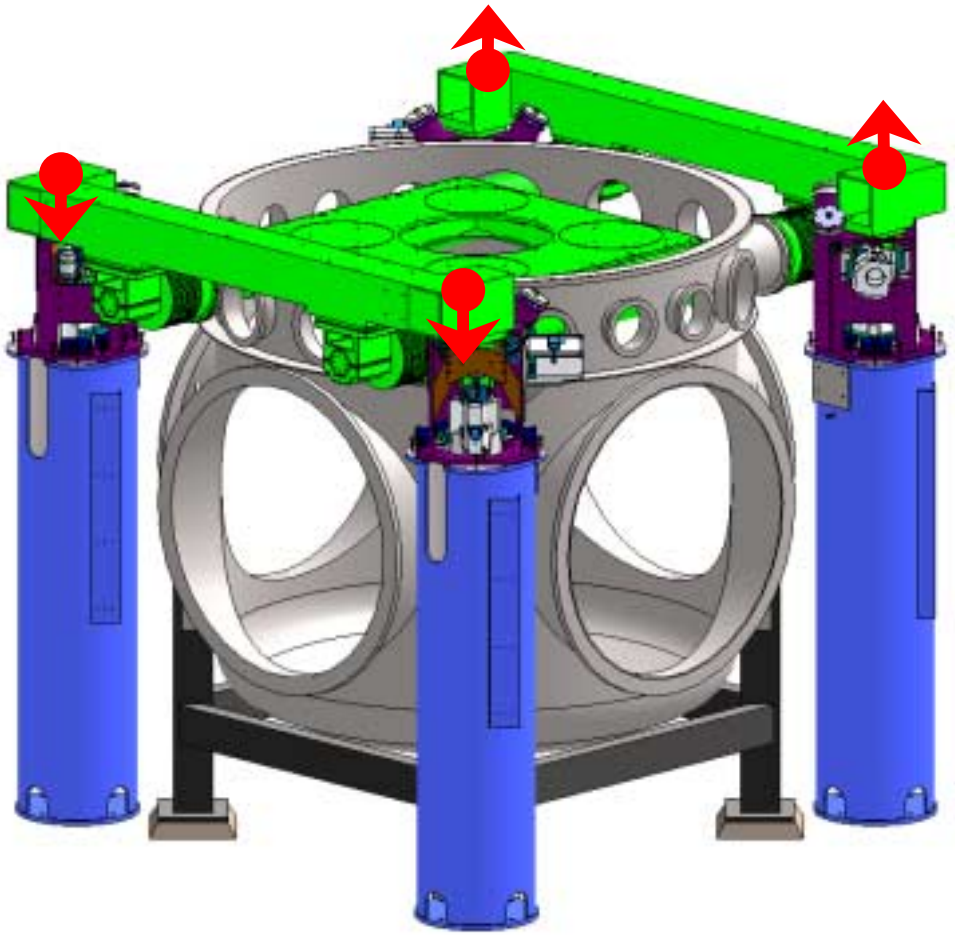

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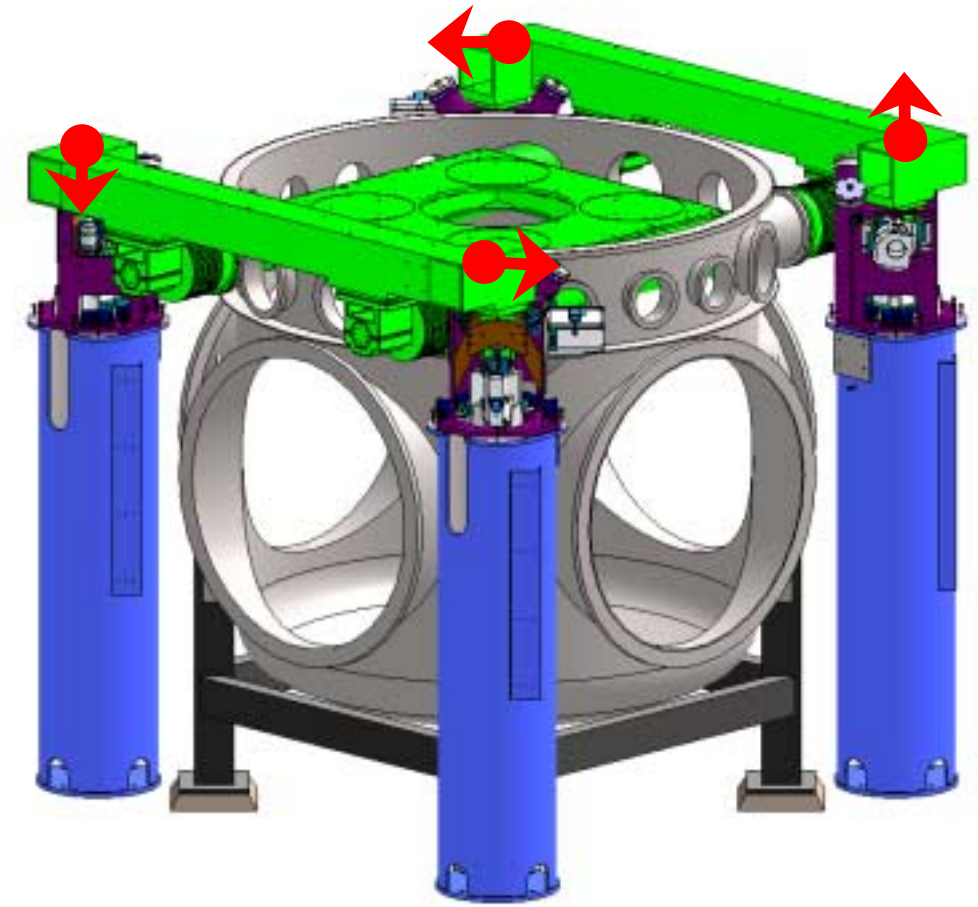

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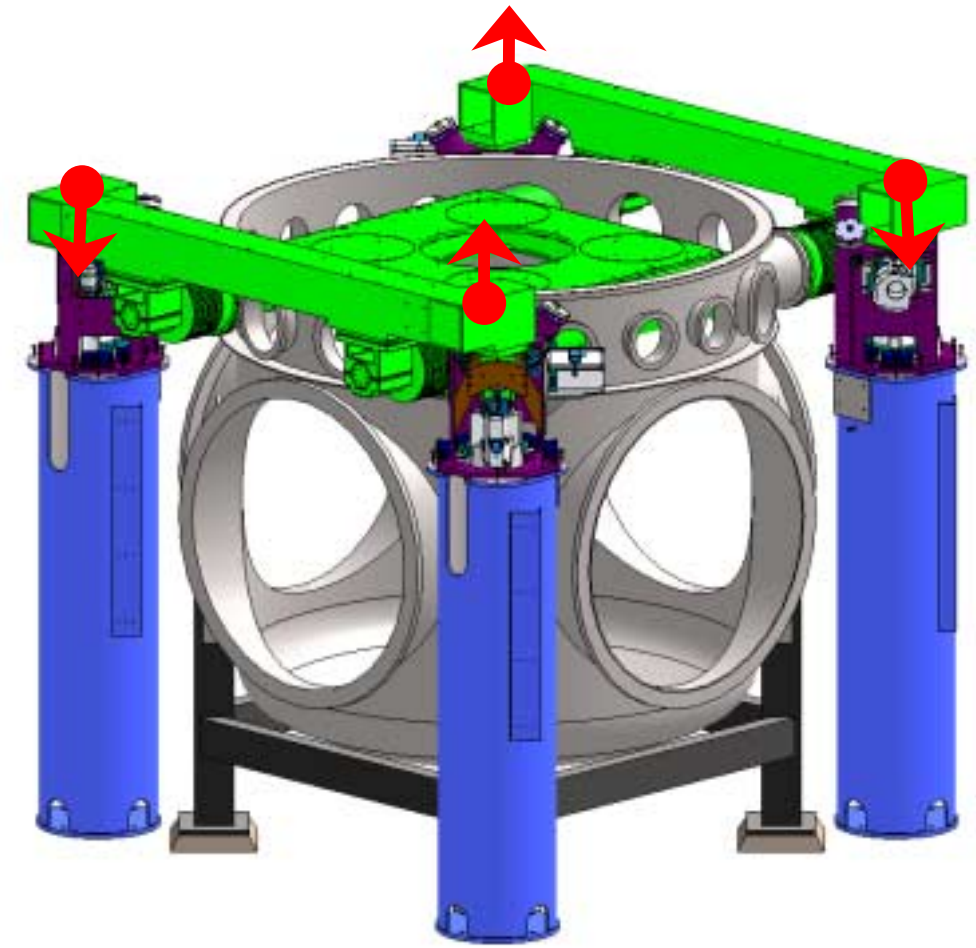

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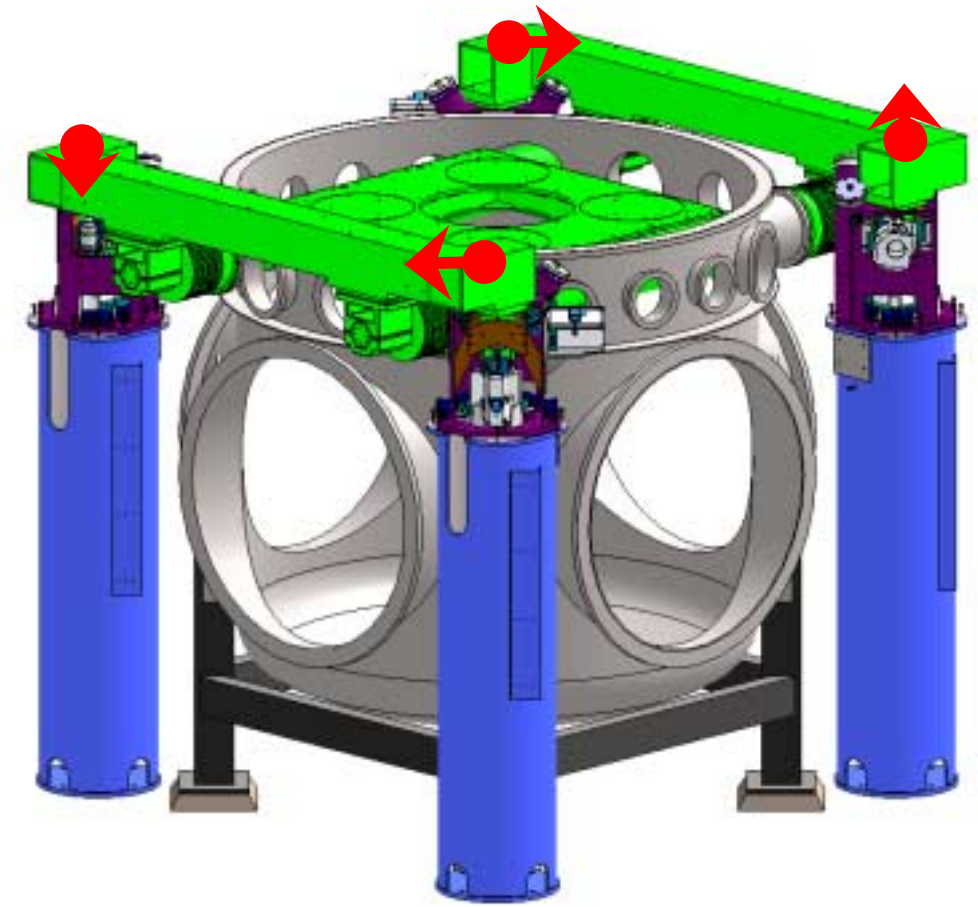
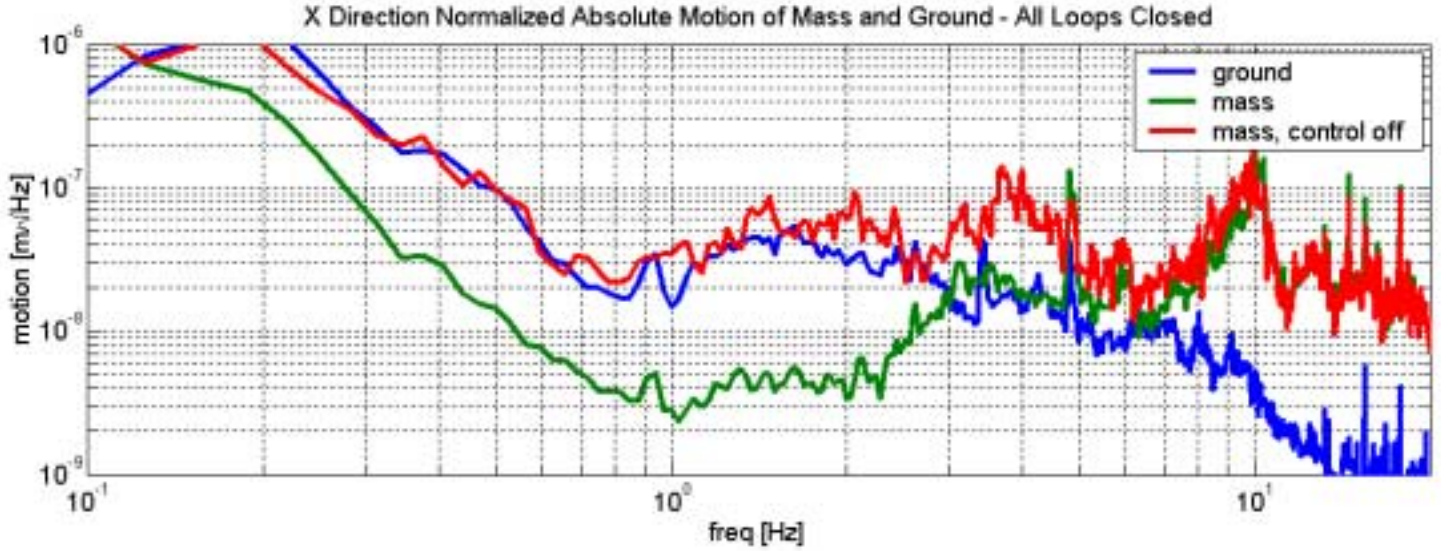
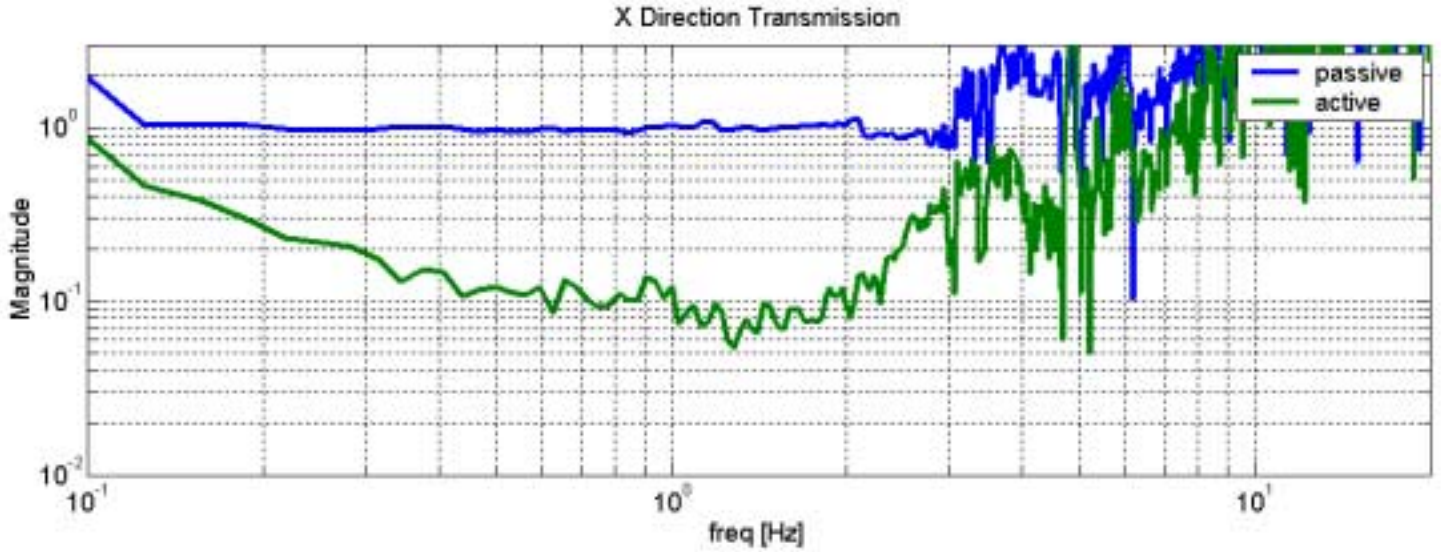
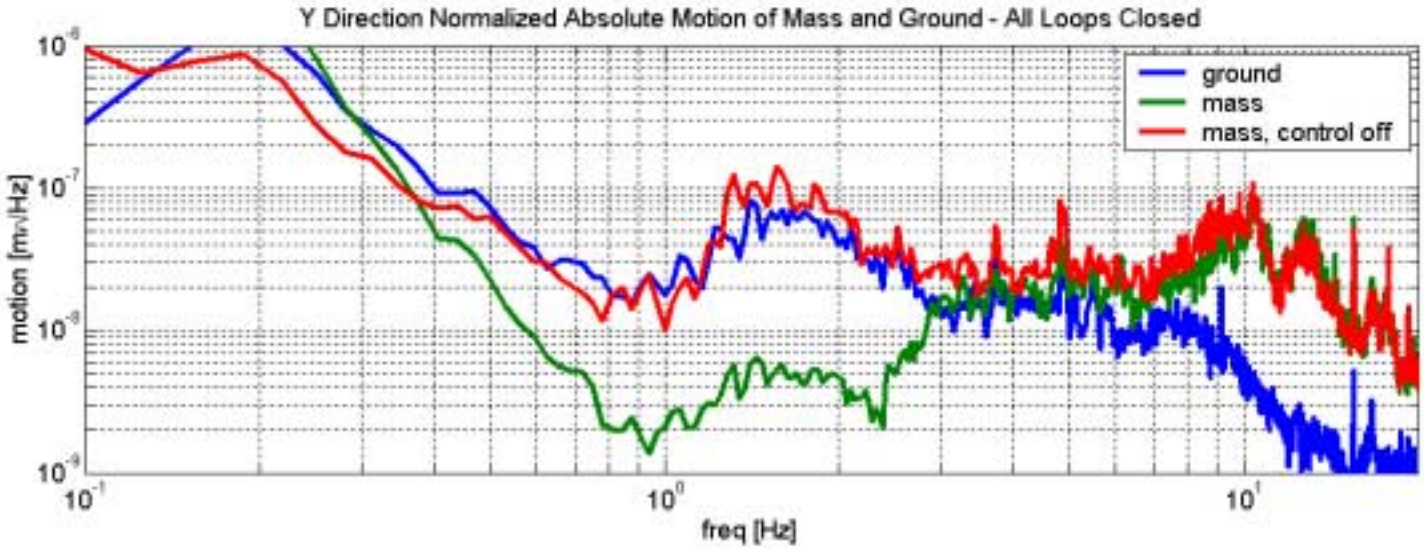


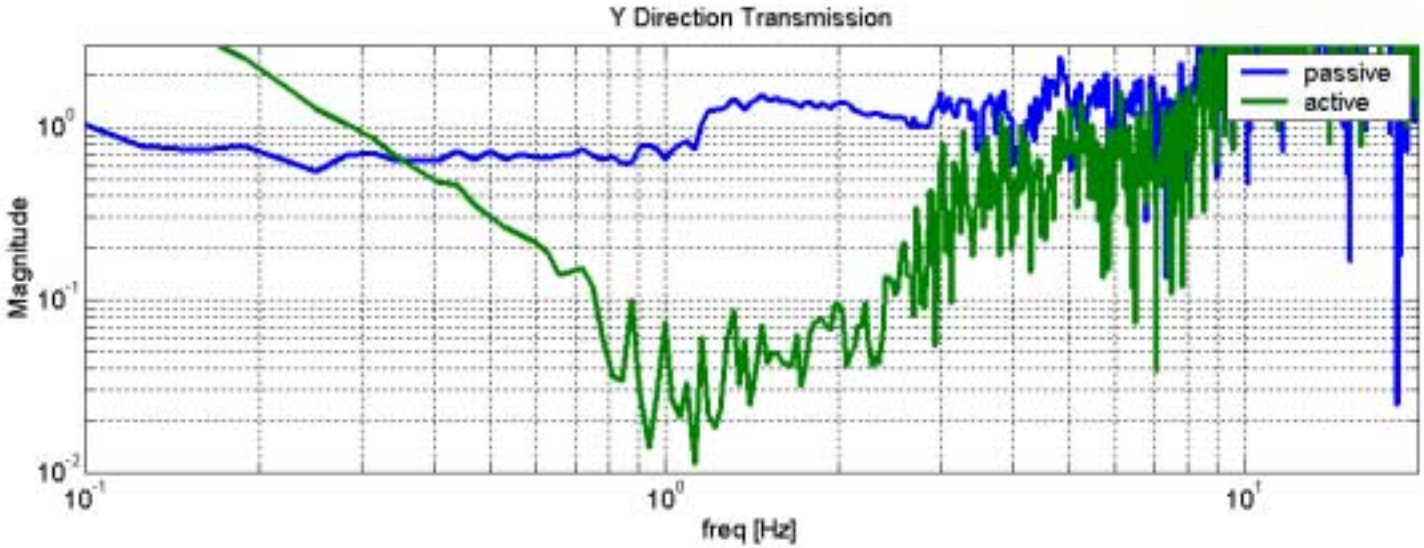
Results from LASTI: X



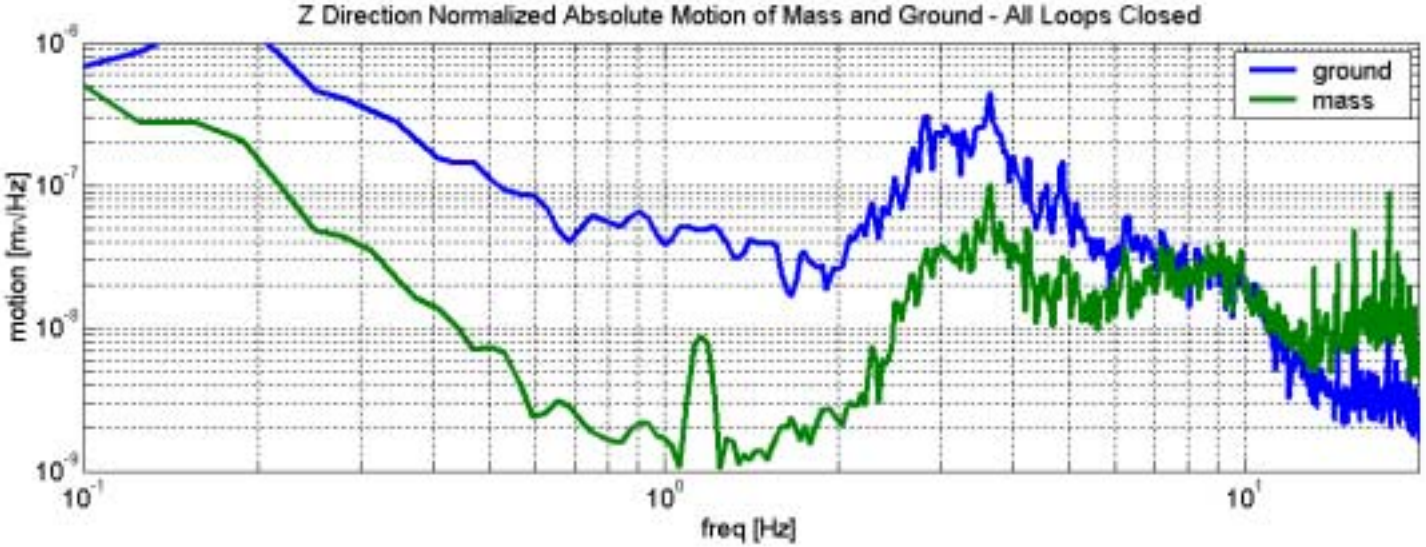


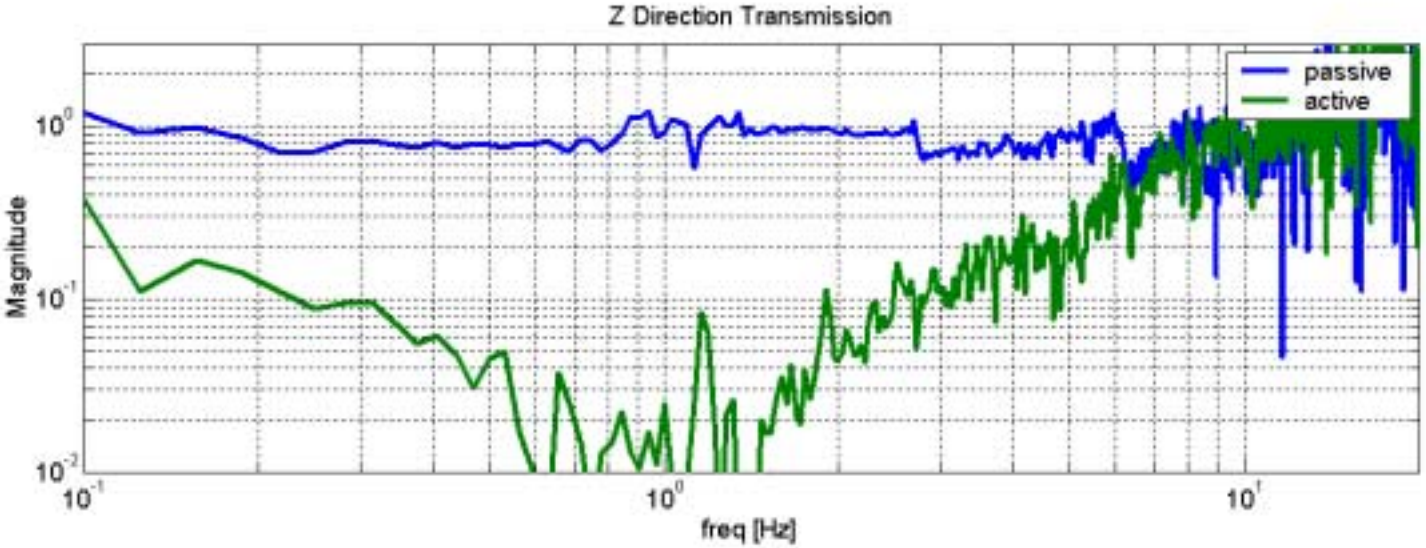
Results from LASTI: Y





Results from LASTI: Z





Summary

- Hydraulics Installed at LASTI
- 6 DOF Controlled
- Demonstrated Performance

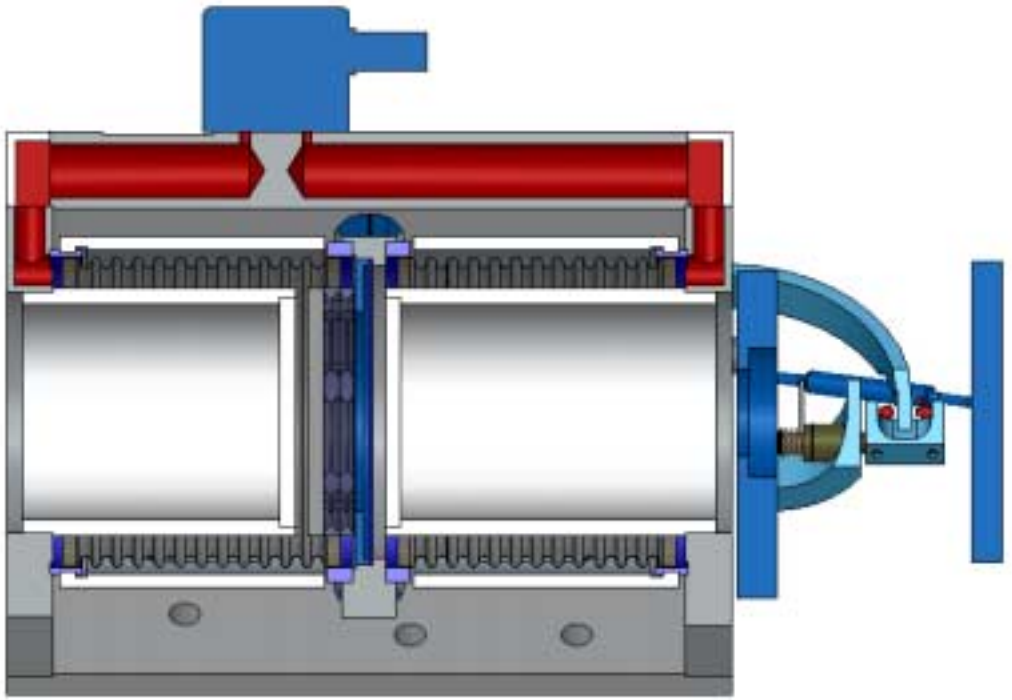
Future Work at LASTI

- Incorporate feedback seismometers
- Possible plant modifications
- More complicated control

Design Trades

Performance \ Parameter	Specification		Design					Related Parameter	
	δ=1mm	Δt=10 sec	Ps=5 bar	β=2e3 bar	R = 5e10 Pa-sec/m^3	A=.01 m^2	V=3e-4 m^3	m=1e3 kg	k=4e6 N/m
1) Hydraulic Resonance $\omega_n^2 = \frac{2A^2\beta}{mV}$ ↑			↑	↑		↑	↓	↓	
2) Damping $\zeta = \frac{1}{RA}\sqrt{\frac{m\beta}{2V}}$ ↑			↑	↑	↓	↓	↓	↑	
3) Bridge Power Dissipation $P_b = \frac{P_s^2}{R}$ ↓			↓		↑				
4) Acquisition Power $P_{acq} = \frac{k\delta^2}{\Delta t}$ ↓	↓	↑							↓
5) Microseism Power $P_\mu = k\delta\delta_s w_s$ ↓	↓								↓
6) Microseism vs. Bridge $\frac{P_{acq}}{P_b} = \frac{k\delta\delta_s\omega_s R}{P_s^2}$ ↓	↓		↑		↓				↓
7) Microseism vs. Acquisition $\frac{P_\mu}{P_{acq}} = \frac{\delta_s\omega_s\Delta t}{\delta}$ ↓	↑	↓							

Quiet Hydraulics



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