Pre-Isolation

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NSF LIGO Annual Review, at MIT

23 October 2002

Issue

- Ground motion at LLO with the initial LIGO seismic isolation system makes it impossible to hold the interferometers locked reliably during the day
  - » Steady-state ambient noise is higher due to anthropogenic sources
  - » Transients, particularly from logging
- Wind induced seismic noise at LHO:
  - » exceeds locking threshold at ~25 mph, or 10% of the time
  - » Expect that up-conversion is a problem at significantly lower wind speeds & a large fraction of the time
- Upgrade is required to allow both reliable locking and to allow better noise performance while locked
  - » Need 90% duty cycle & lock durations > 40 hours
  - » Need to reduce noise in the control band (< 40 Hz) to permit a smaller suspension actuator authority & lower noise
  - » Suppression in the 1-3 Hz band is most important due to excitation of the lower stack modes (Q ~ 30)

Scope

- Retrofit design
  - » Original design included expansion capability for active control
  - » No commercially available systems with acceptable performance
  - » Accelerate the existing advanced LIGO R&D effort for an active pre-isolator
    - – An LSC effort scientifically led by Joe Giaime (LSU) and Brian Lantz (Stanford)
    - – Digital servo controls (flexibility & graceful degradation under failure)
    - – Two alternative actuator designs
  - » Install without disturbing in-situ optics alignment
  - » BSC & HAM chambers
  - » Prove performance with full scale prototypes at LASTI
- Active Isolation with the Fine Actuation Systems (FAS) on Test Mass chambers
  - » Use of the FAS actuator for active control is known as PEPI: Piezo-electric External Pre-Isolation
  - » PEPI is an interim solution for LLO; installed for S1
  - » PEPI is the planned solution for LHO
- Number of retrofit systems:
  - » All chambers with suspended optics at LLO (8 systems)
  - » Addition of PEPI systems to Test Mass and Mode Cleaner chambers at LHO (6 systems per interferometer)

External Pre-Isolator performance requirements

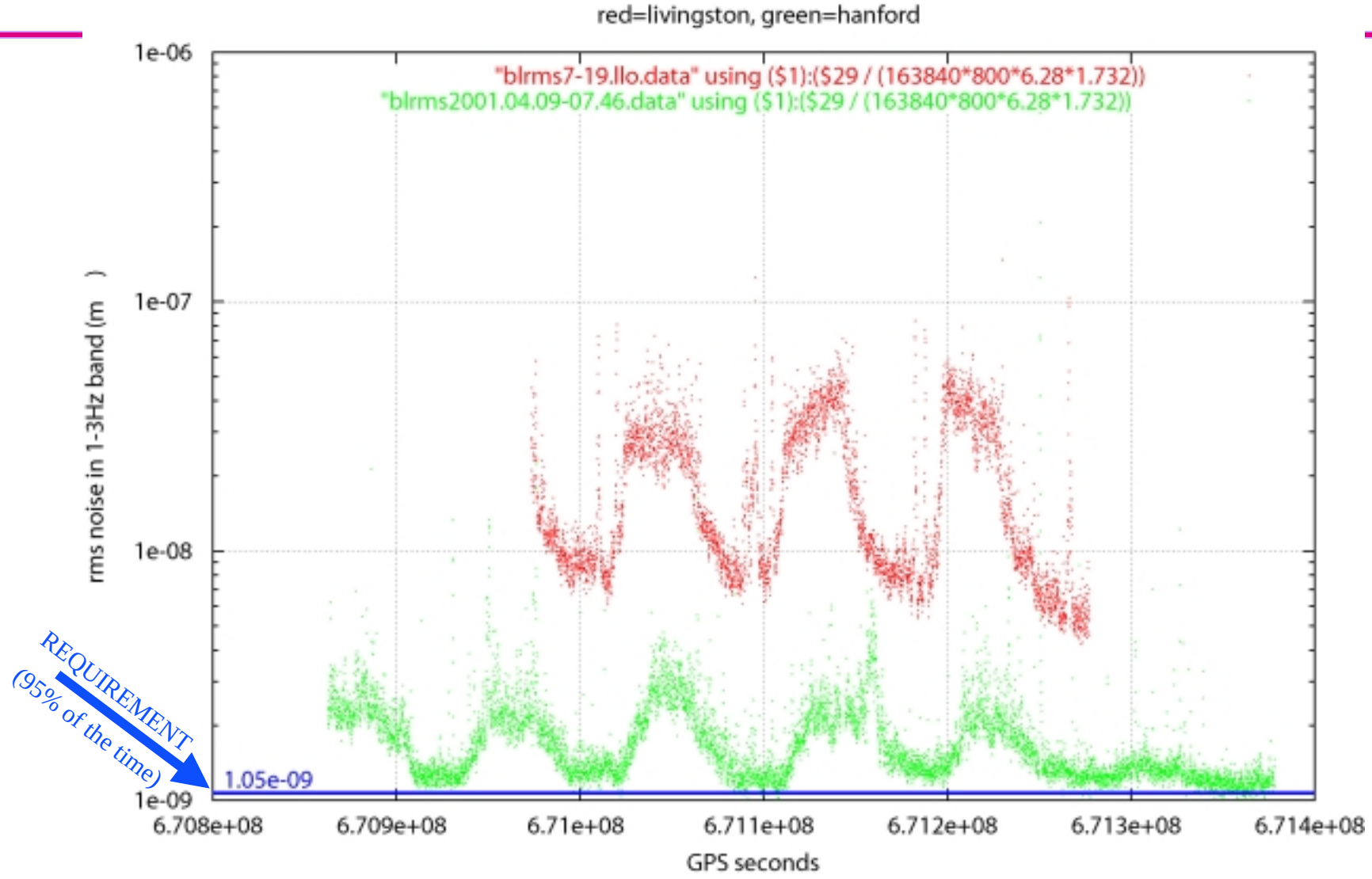
Basic tenets:

The pre-isolator must not increase the present noise in the GW-band, and

Must bring the day LLO environment to the level of the LHO night environment.

1 month 100 seconds	10 microns pk-pk 1 micron pk-pk	Presently observed stability of system
0.16 Hz	4e-7 m/√Hz	To original seismic model
1 Hz	1e-9 m/√Hz	Hanford night-time
10 Hz	4e-10 m/√Hz	spectrum in 1-3 Hz band 95% of the time
15 Hz 30 Hz 50 Hz and higher	2e-10 m/√Hz 6e-11 m/√Hz 2e-11 m/√Hz	Not to exceed presently observed spectrum

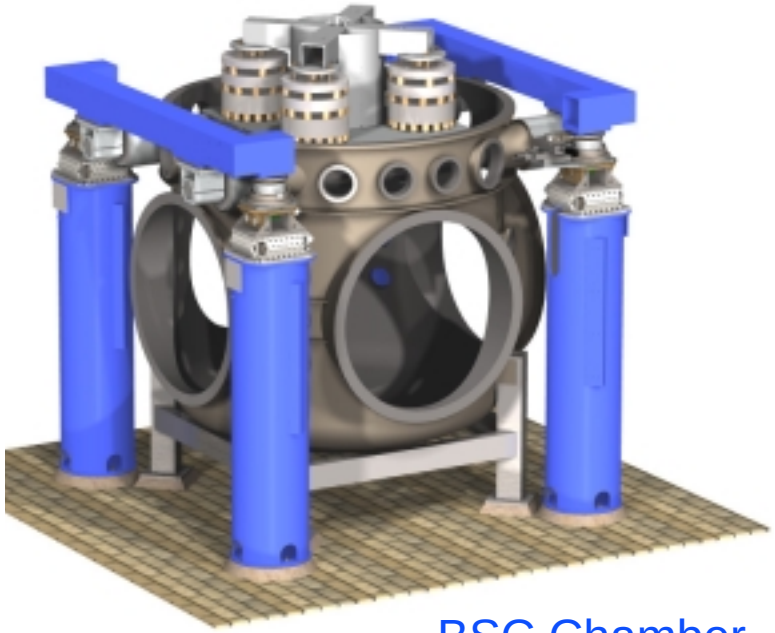
Daily variability – and requirement



Initial Vibration Isolation Systems

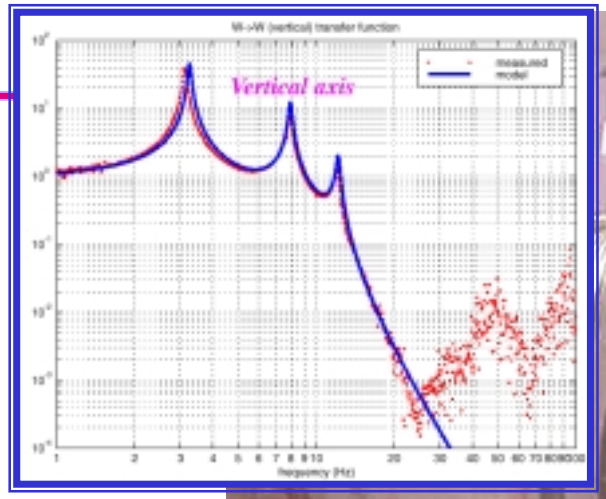
- Reduce in-band seismic motion by 4 - 6 orders of magnitude
- Little or no attenuation below 10Hz; amplification at stack mode resonances
- Large range actuation for initial alignment and drift compensation
- Quiet actuation to correct for Earth tides and microseism at 0.15 Hz during observation

HAM Chamber



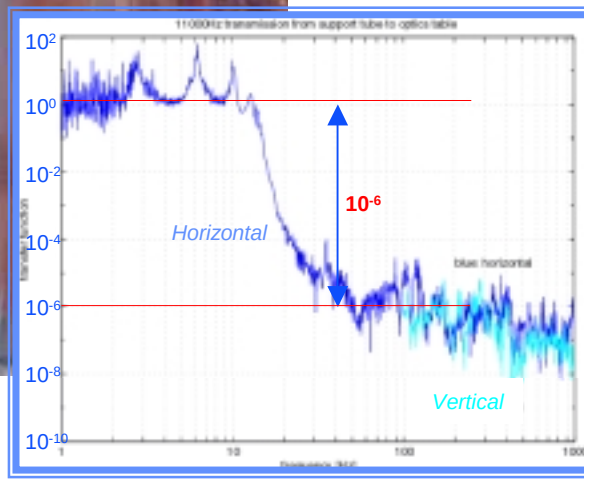
BSC Chamber

Seismic System Performance

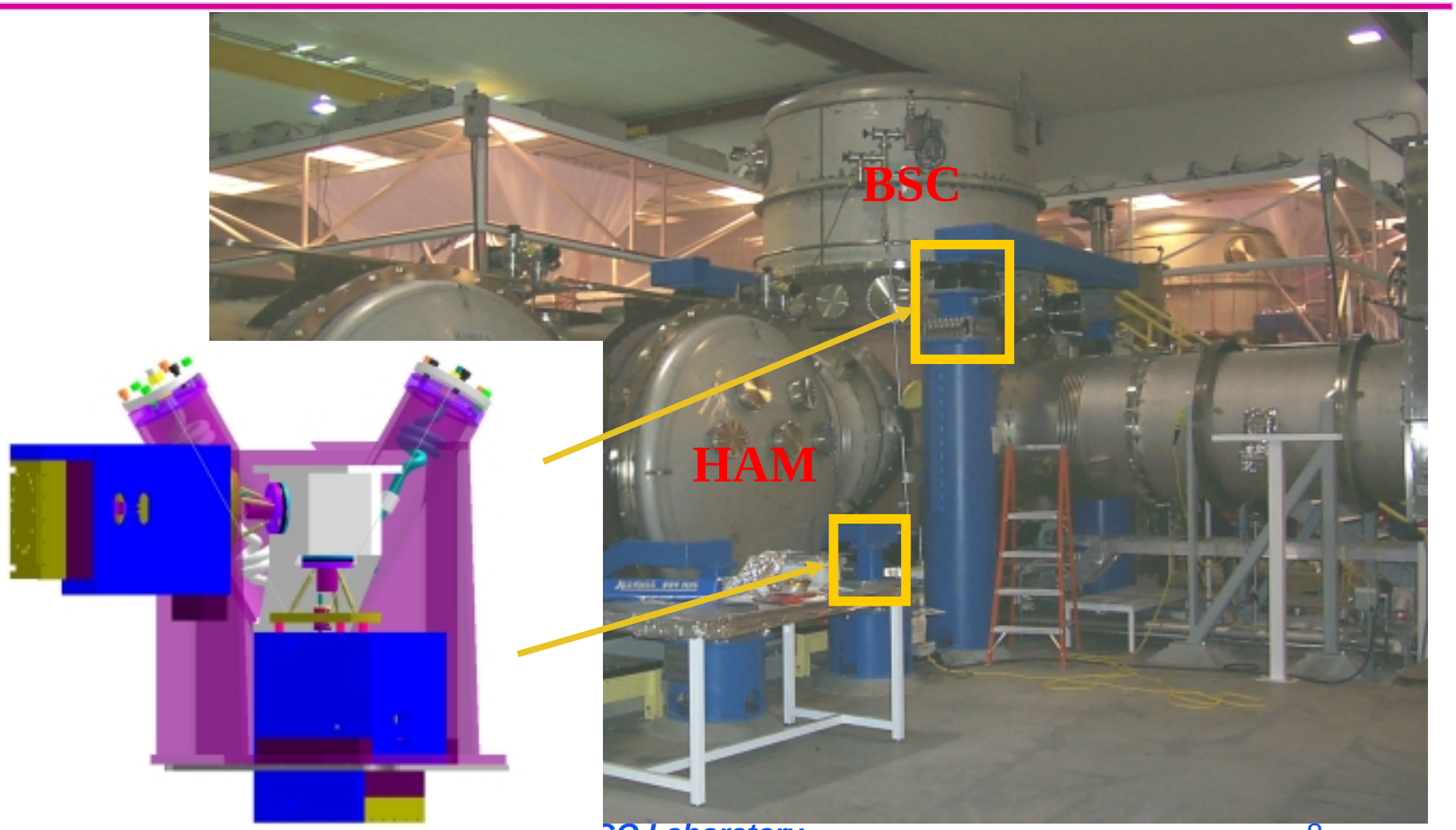


HAM stack
in air

BSC stack
in vacuum

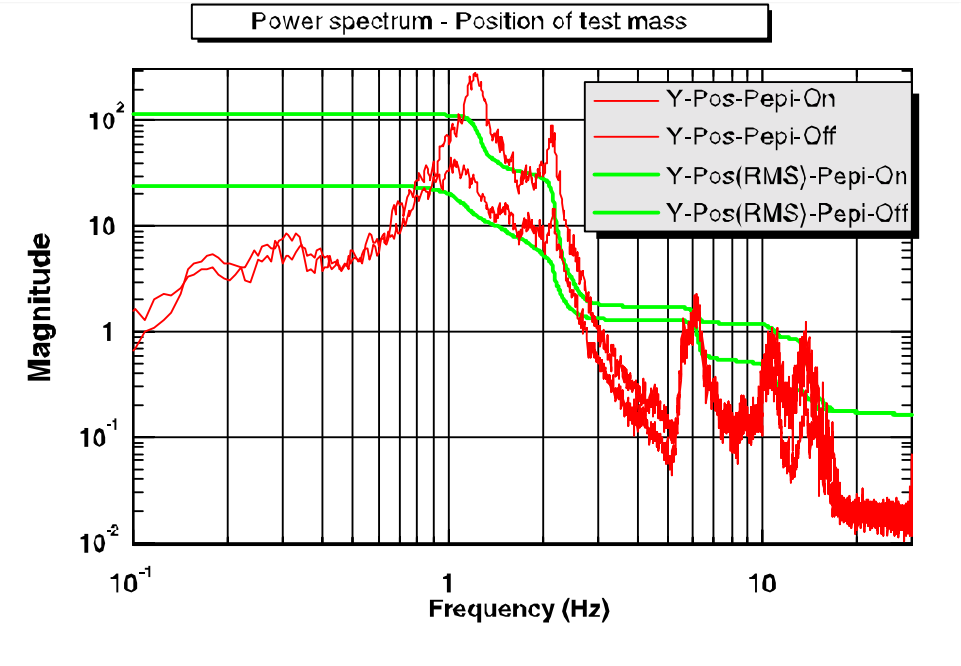


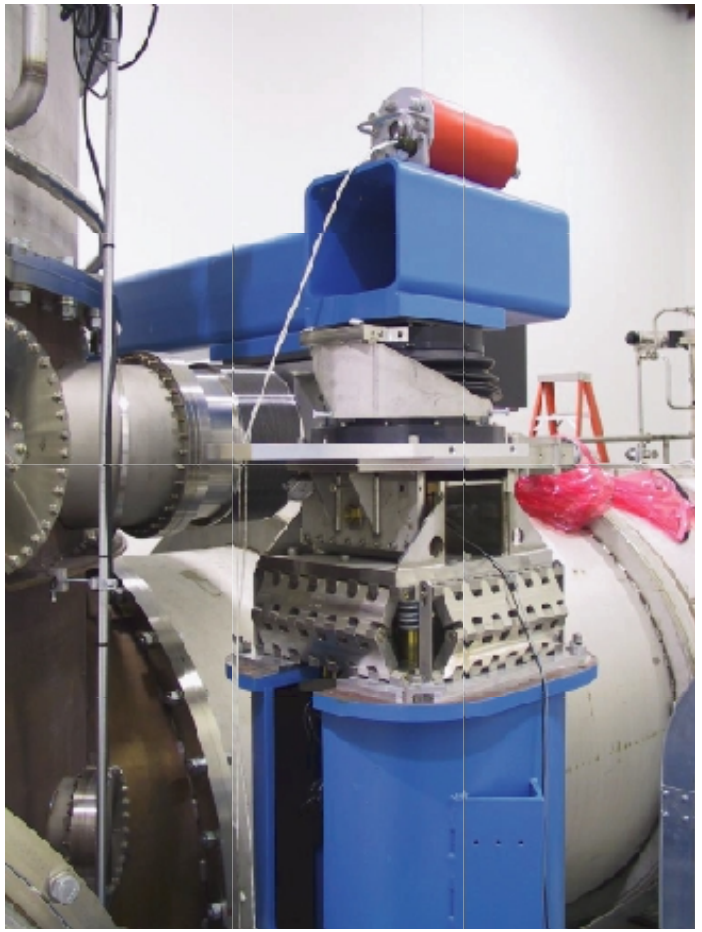
Planned Initial Detector Modifications



Piezo-electric External Pre-Isolator (PEPI)

- Single (longitudinal) degree of freedom isolation
- Employs Fine Actuation System on End Test Mass Chambers (also used for Tidal and Microseismic control)
- Added to Input Test Masses at LLO for the S1 Run
- Baseline approach for LHO for S3

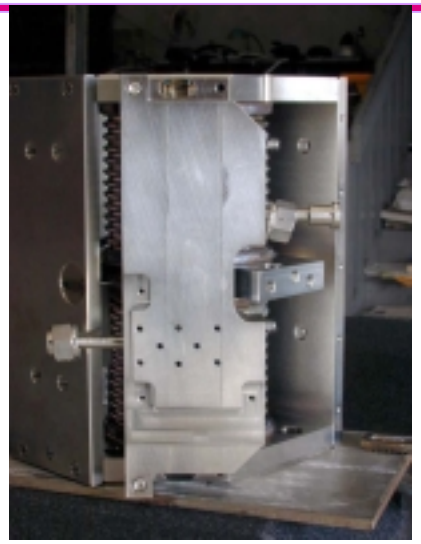


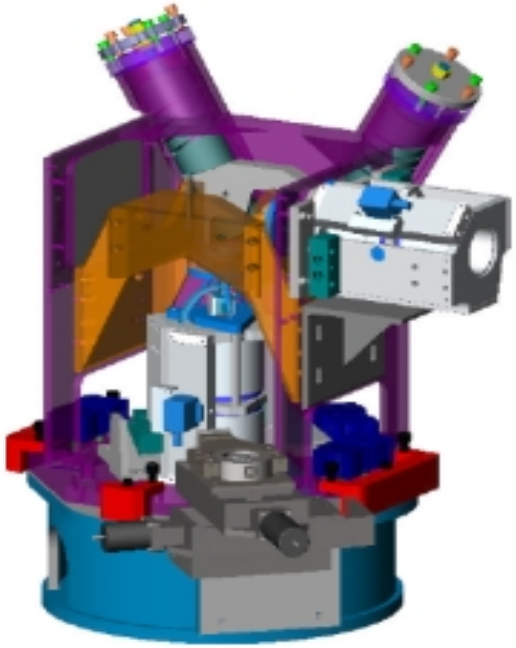


Actuators for an External Pre-Isolation (EPI) System

- Large range (300 microns p-p) required for tidal & microseismic correction
  - » Goal of 1 mm for coarse positioning/alignment
  - » Piezo-electric actuation may not be suitable
- Quiet Hydraulic Actuators
  - » Hydraulic Wheatstone bridge
  - » Used for precision diamond turning vibration isolation
  - » High range, high stiffness, high bandwidth, high velocity
  - » Developmental system (not commercially available)
- Electro-magnetic actuators
  - » Different actuator (force instead of displacement)
  - » Increased robustness of EPI solution – a second path
  - » Familiar technology (in contrast to quiet hydraulics)
  - » Reduced risk of contamination
  - » Less complexity in power supply
  - » Same performance requirements, mechanical superstructure, sensors
  - » Concern regarding EM coupling to the magnets on the suspended optics

Hydraulic External Pre-Isolators (HEPI)

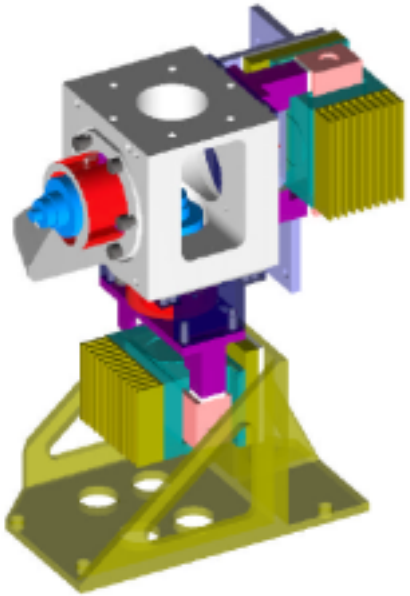


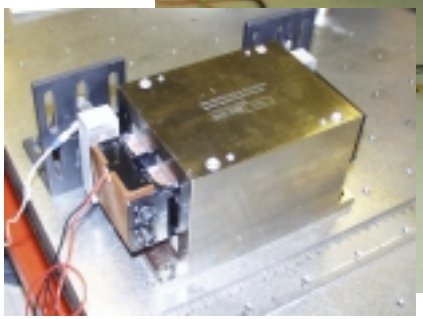


- Working fluid is high-viscosity fluid (glycerin/ethanol or mineral oil)
- Bellows hydraulic pistons apply force without sliding friction, moving seals
- Laminar-flow differential valves control forces
- Stabilized “power supply” is remote hydraulic pump with fluid-equivalent “RC” pressure filtering
- Technology adapted from precision machine tool applications

MEPI Installed on HAM at LASTI

- Alternative to the developmental hydraulic actuator
- Uses commercially available voice-coil actuator
- ‘Pin-compatible’ mechanically
- Simpler electronics
- ‘Soft’ mechanical back impedance





Status & Decision Points

- MEPI
  - » Installed at LASTI & under Test
  - » Interaction of HAM structural support modes with the control system may limit performance, add control complexity or cause us to consider structural modifications/additions
  - » Initial MEPI/HAM Chamber results are promising; Hope to demonstrate control to required performance in the next 2 months
- HEPI
  - » 3rd generation hydraulic actuator in test on the Stanford test stand
  - » Pump station tests at CIT have demonstrated pressure noise performance requirements
  - » Installation at LASTI to start in 2 weeks
  - » Compliance of the BSC pier may likewise limit gain-bandwidth and performance
  - » Initial test results are expected by early December
- Design Review & Long-Lead Procurement Review, Jan, 2003
  - » After prototype installation & some preliminary experience will decide whether to go forward with the hydraulic actuator or the electro-magnetic actuator
  - » Commissioning will continue to improve performance and transition from dSpace to VME based controllers
- Installation start at LLO, April, 2003
  - » Following the S2 run