Update on Advanced LIGO Suspensions, Including the Quad Controls Prototype

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for the Advanced LIGO suspensions (SUS) team

LSC meeting, LHO, Aug 17th 2005

G050369-00-R

SUS Team

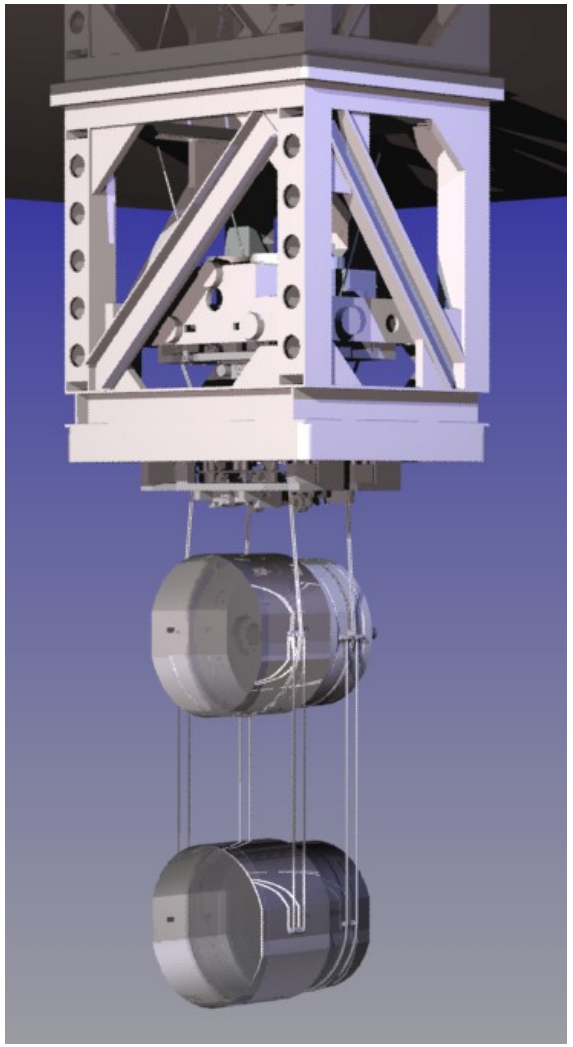
- **LIGO LAB:** CIT: H. Armandula, M. Barton, D. Coyne, J. Heefner, M. Mageswaran, K. Mailand, J. Romie, B Taylor, C. Torrie MIT: P. Fritschel, K. Mason, R. Mittleman, L. Ruet, D. Shoemaker LHO: B. Bland, D. Cook LLO: O. Spjeld, G. Traylor
- **GEO600**: GLASGOW: G. Cagnoli, C. Cantley, D. Crooks, A. Cumming, E. Elliffe, A Grant, A. Heptonstall, J. Hough, R. Jones, I. Martin, M. Perreur-Lloyd, M. Plissi, D. Robertson, S. Rowan, K. Strain, P. Sneddon, H. Ward
  UNIVERSITAT HANNOVER: H. Lueck
- **STANFORD UNIVERSITY**: N. Robertson (also GEO/Glasgow)
- **RUTHERFORD APPLETON LABORATORY**: J. Greenhalgh, T. Hayler, J O'Dell, I. Wilmut
- **THE UNIVERSITY OF BIRMINGHAM**: S. Aston, D. Hoyland, C. Speake, A. Vecchio
- **STRATHCLYDE UNIVERSITY**: N. Lockerbie

Outline of Presentation

- Quad controls prototype update
  - Structure fab and assembly
  - Overall assembly and suspension: top wire issues
  - Installation issues
- Quad noise prototype update
  - Ribbons, ears, welding and bonding
  - Sensor development
  - Mechanical design
- Modecleaner triple suspension update

Quadruple Suspension for ETM/ITM

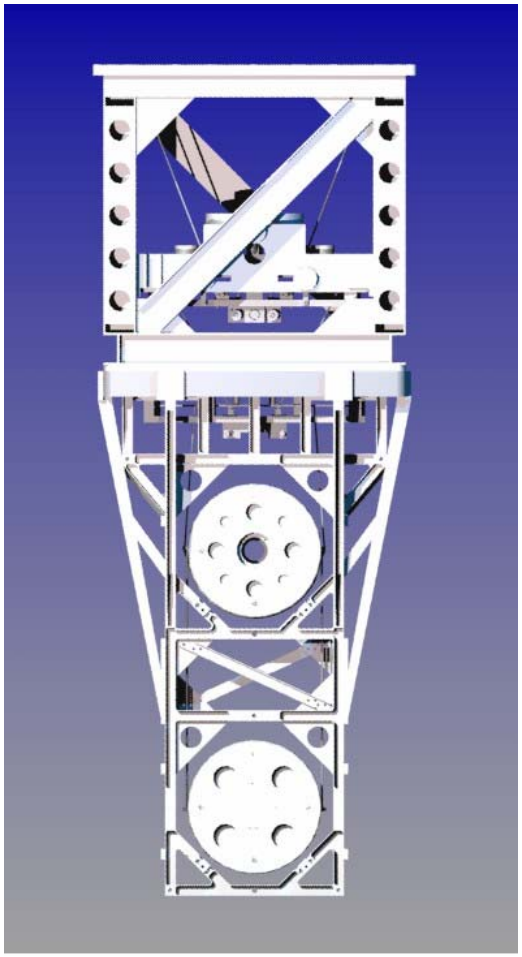
- Parameters for suspension
  - Test and penultimate masses : each 40 kg, 34 cm (diam) x 20 cm, silica
  - Other masses: 22 kg, 22 kg
  - Final stage: 60 cm silica ribbons, 1.1 mm x 0.11 mm, Vertical bounce mode: 8.8 Hz, first violin mode: ~490 Hz
  - Overall length (suspension point to optic centre): 1.63 m
  - Local control at top mass
  - Global control between main chain and reaction chain
  - Target noise level: 10^{-19} m/$\sqrt{}$ Hz @ 10 Hz



Lower support structure removed for clarity

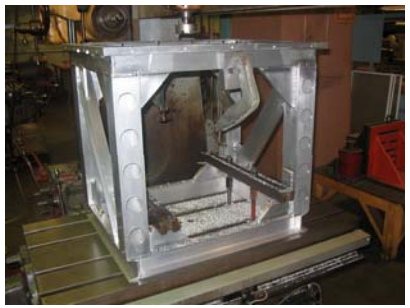
Controls Prototype Quad Suspension: Current Status

- All-metal prototype to test mechanical design, control aspects, and installation and alignment procedures
- Initial assembly underway at Caltech - to be followed by clean and bake before shipment to LASTI
- Electronics (analog plus digital) being prepared for damping tests
- Visitors to Caltech in past few months from Glasgow, RAL, Stanford, MIT to assist with assembly and gain hands-on experience



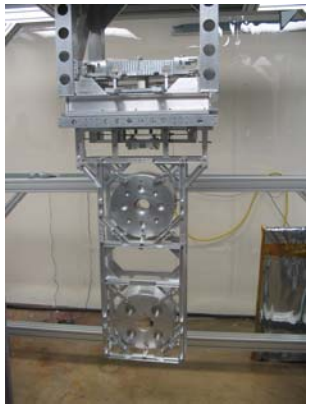
Support Structure Fab and Assembly

- Upper Structure
  - Design required modification to allow successful full penetration (vacuum compatible) welding: various radii and fillets added and connection locations simplified.
  - Surfaces finished after welding to give fiducial reference points
- Lower structure
  - 4 large Al plates rough cut with water jet machine
  - Pockets cut on large bed mill for lightweighting
  - Blanchard ground on both sides, then nitronic 60 inserts added for low galling and dust
- Completed Structure
  - Interface ring used to allow relative height adjustments between upper and lower sections while suspending the pendulum
- Copies of upper and lower structures are being manufactured for tests of coupled resonances and control behaviour on the ETF at Stanford



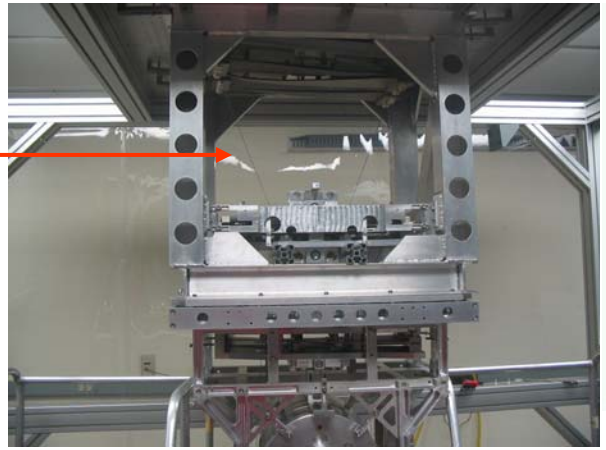


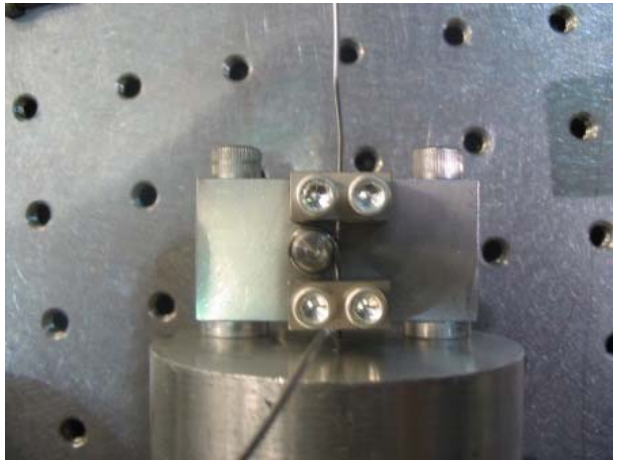




Top Mass Suspension Wires

- Drum-ended maraging steel wires are being developed to replace simple steel wires at top stage - potential advantages, easier to clamp without slip and less creep
- During suspension pitch adjustments a top wire broke close to neck on two occasions (having been load tested prior to use)
- Clearly drum-ended wires need more research - will be pursued for the noise prototype
- Modified clamps for steel wire with friction relief have been tested (to 3 x working stress) and will be designed and fitted into controls prototype to allow completion and delivery to LASTI

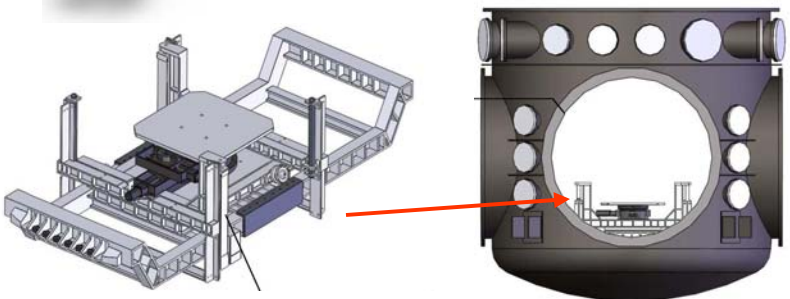




Simplified clamp used for testing revised design

Installation Fixtures

- Two installation fixtures under development
  - Articulated arm for transport of lower structure into vacuum chamber: design complete, fab on hold (not required for LASTI)
  - Adjustable table for translation and lift: manufacturability study underway + expect cost estimates soon
- Large air bake oven obtained
  - Can accommodate upper and lower structures

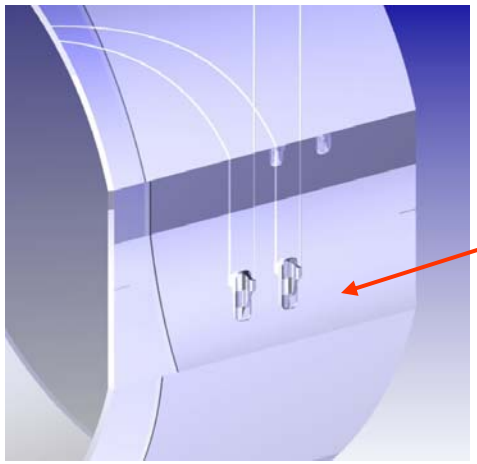


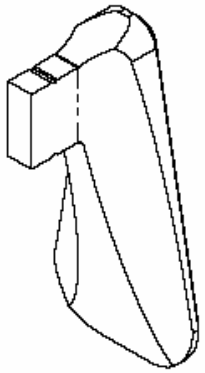
Noise Prototype Quad Suspension

- As far as possible build on experience from controls prototype for mechanical design, but timeline not optimum, some parallel work
- Monolithic assembly design (ribbons, ears, bonding and welding) ongoing
- Development of OSEMS and other electronic and control design optimisation ongoing
- Two major reviews recently:
  - SUS Design Requirements Review Update (June 15th):

    to review Universal DRD, SUS DRD, Mechanical Drawing Guidelines, Interface Control Document, Conceptual Design Update (including silica as test mass), Response to action items from previous review
  - SUS/BSC Electronics Preliminary Design Review (July 12th):
    to review the analog front end electronics (sensor read-out and actuator drivers) for the BSC suspensions

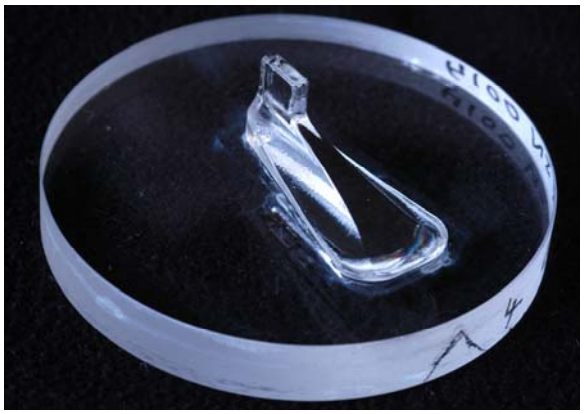
Status of Ears and Bonding

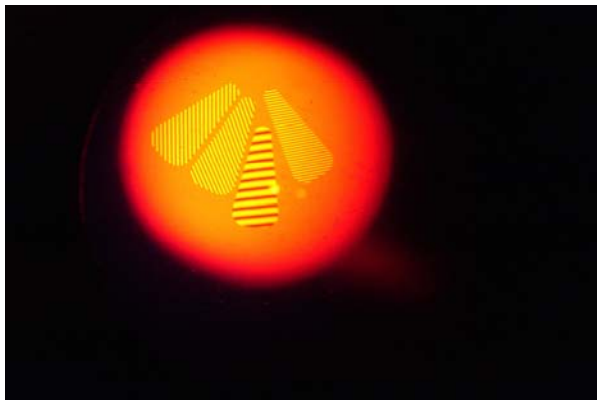




Extended horn
for load tests

- Preliminary design of silica ears for ribbon suspension complete
- 12 silica test ears bonded to silica disks for strength tests
- H Armandula and J Romie visited Glasgow recently to assist

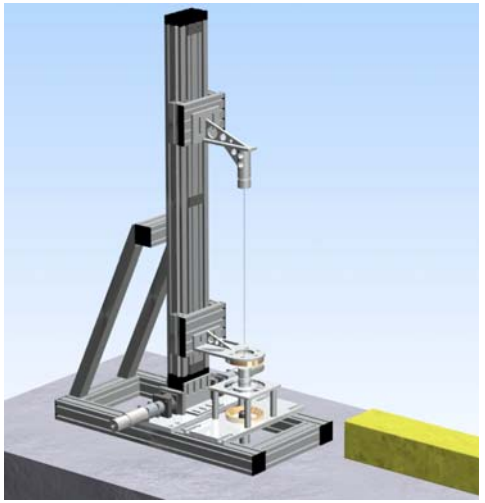


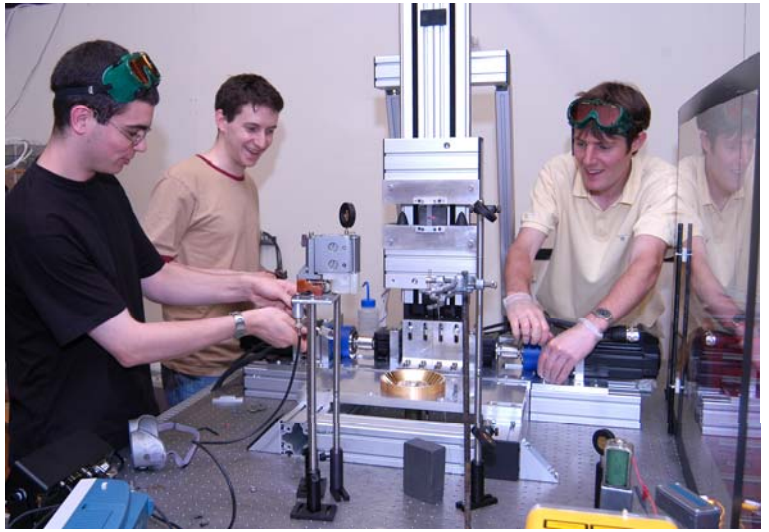


Interferogram of ears indicating good flatness

Ribbon Pulling, Welding and Testing

- Current measurements on ribbons produced via hydrogen/oxygen flame: average breaking stress 2.6 GPa. Expect to achieve better tolerance and repeatability using CO_2-based machine
- Variable feed-pull ratio CO_2 fibre/ribbon pulling and welding machine currently being assembled at Glasgow, expected to be running in next few weeks. This is next phase in laser-based pulling developments
- Design of single and multiple ribbon suspensions for ribbon and weld strength investigations ongoing
- Ribbon/Fibre/Ear/Bonding Preliminary Design Review scheduled for 19 October 2005

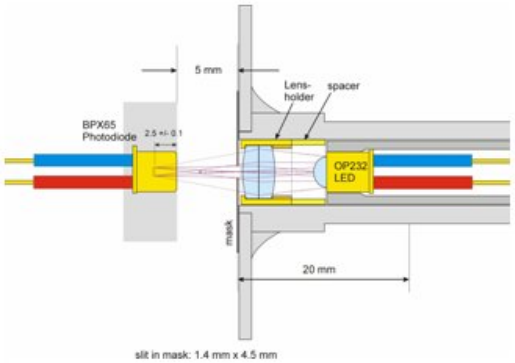




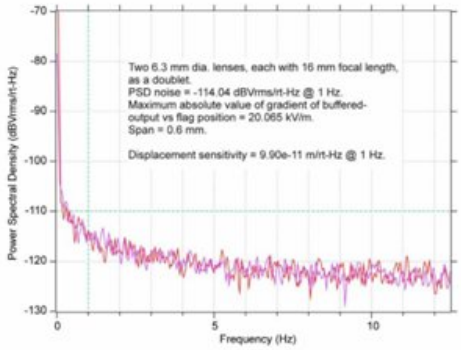
See talk by A Heptonstall for more details on ribbon work.

Sensor Development

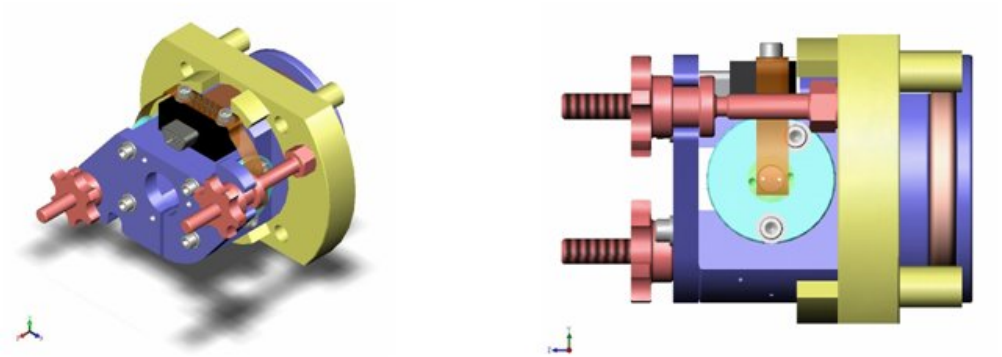
- Development of compact, robust shadow sensor/ electromagnetic actuator units (OSEMS) for local control
- Sensor performance: 0.6mm (peak-peak) working range
  sensitivity 1 x10^{-10} m/√ Hz at 1 Hz



LED and Photodiode Assembly



Noise Performance

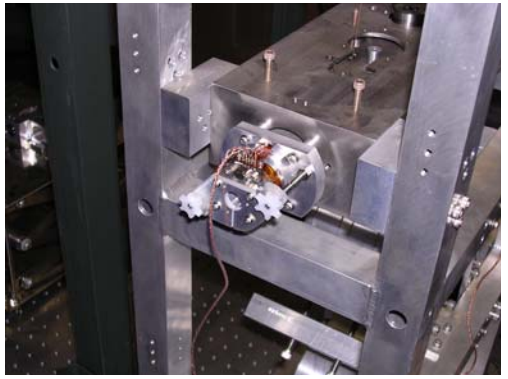


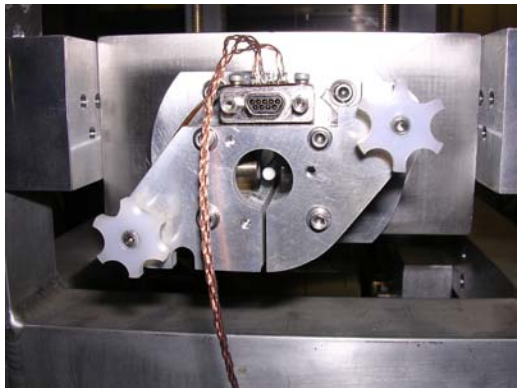
Mechanical Assembly with Positional Adjustments

Prototype Unit

Sensor Development contd

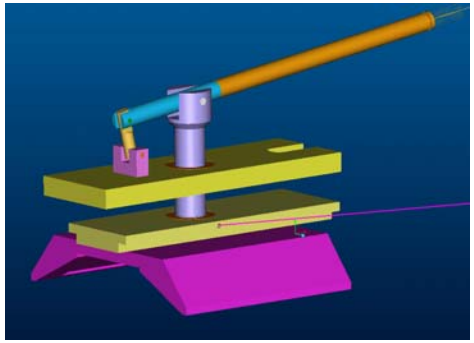
- Successful form fit and function test of OSEM carried out at Caltech:
  - Unit mounted in modecleaner triple suspension + structure
  - OSEM connected to controls prototype electronics and dSPACE controller
  - Alignment optimised - flag centred
  - Damping achieved
  - Redesign of flag for more clearance being studied

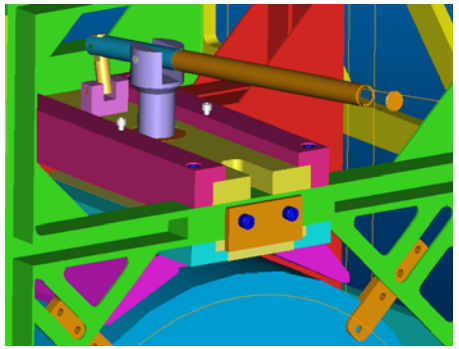


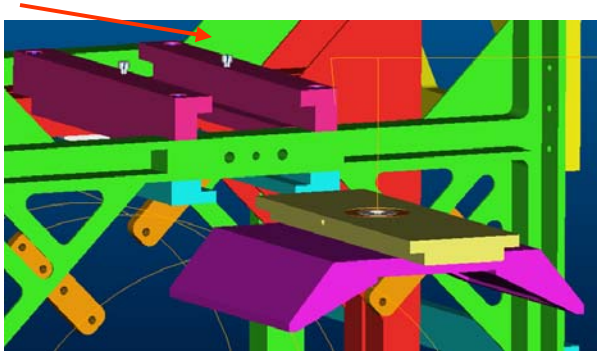


Noise Prototype: Mechanical Design Work

- UK team gaining experience from controls prototype work – e.g. RAL design engineers have visited Caltech to assist in the build, and also to work on other issues such as thermal compensator suspension with US colleagues
- Discussions with UK manufacturers already started, building on experiences in US
- Decision taken on overall chain spacing and mass sizes for ETM with respect to keeping sapphire back-up feasible
- Work started on overall layout, design of suspended masses, and tooling for assembly and loading of monolithic stage
- Research on drum-ended wires will be pursued and search for UK manufacturer ongoing



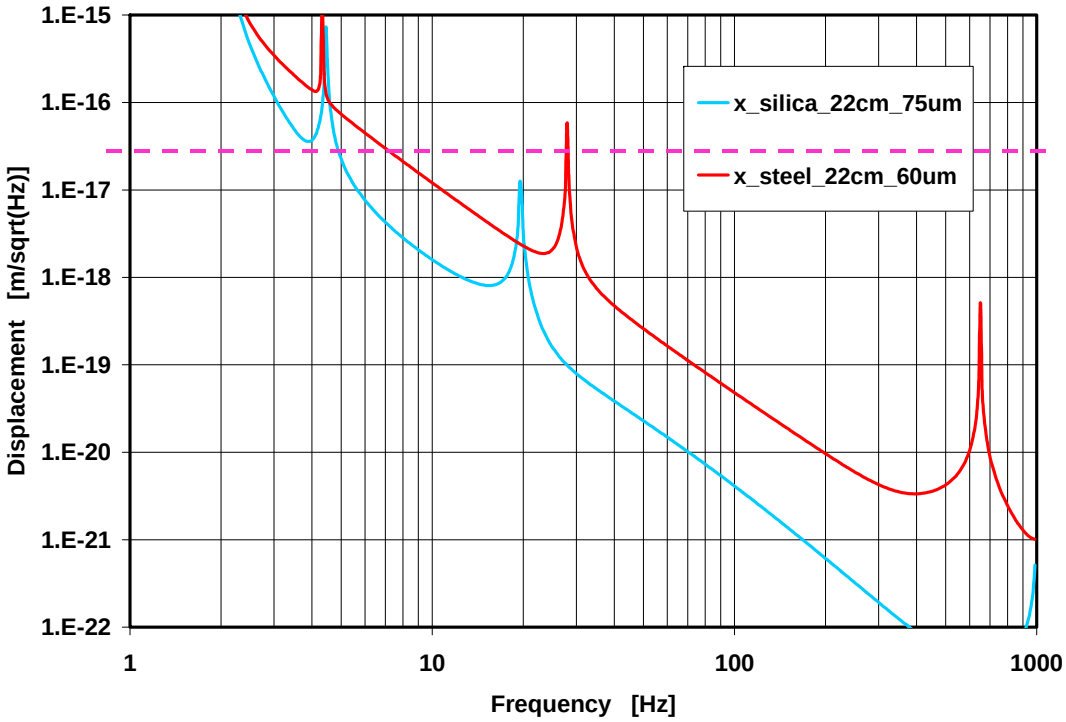




Possible concept for testing assembled monolithic stage to 20% above working load

Modecleaner (MC) Update

- At recent HAM review, it was agreed that steel wires rather than silica fibers in final stage should be good enough - RODA will be written
- Second MC currently being disassembled for clean and bake at Caltech prior to shipping to LASTI (first MC already there, characterization complete)
  - Purpose: to investigate reduction of OSEM noise coupled into the GW Band using modal controller for damping
  - Requirement: need a quiet reference as close to inertial space as possible. Hence the need for the other triple



Suspension thermal noise.
Blue: silica, 75 micron radius (stress 0.4 GPa).
Red: steel, 60 micron radius (stress 0.65 GPa)

Dotted magenta line = current noise requirement
3×10^{-17} m/√ Hz @ 10 Hz

Graphs from G Cagnoli

- More information including pictures of the quad build and summaries from SUS and design telecons are available at the SUS website

http://www.ligo.caltech.edu/~ctorrie/