Suspension Design for Advanced LIGO

Development Plan and LSC Activities

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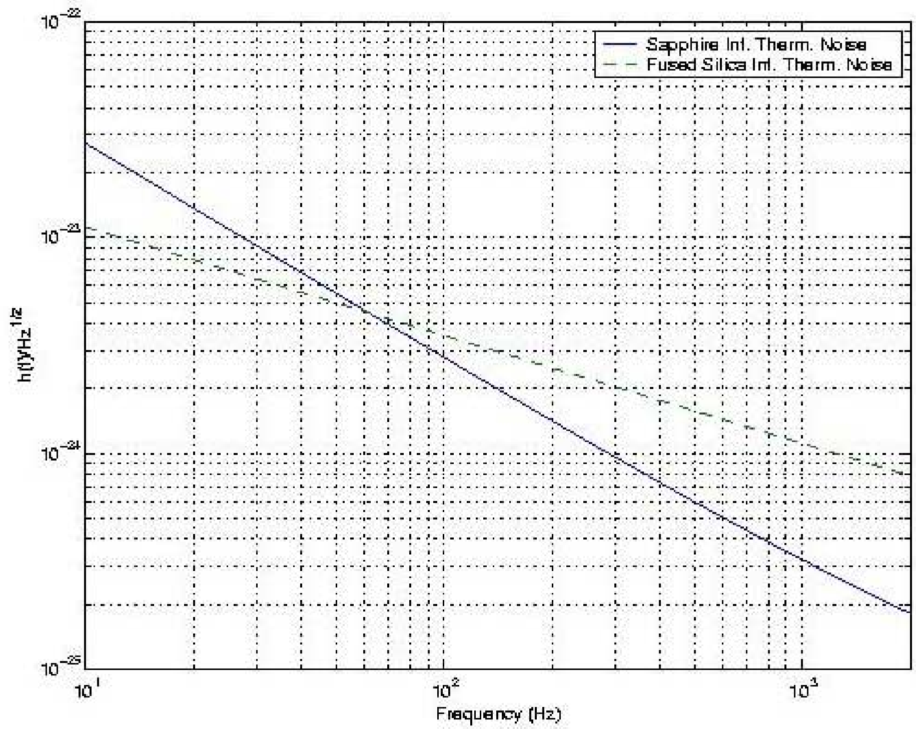
Major Suspension Design Choices Outstanding

- Sapphire vs. Fused Silica Test Masses
  downselect in 2Q2002
- Ribbon vs. Fiber Suspensions
  downselect in 1Q2001
- Style of Penultimate Masses
  downselect in PDR (2Q2002)

Sapphire vs. Fused Silica

- SUS input to decision based upon many factors:
  - -Intrinsic losses of materials
  - -Polishing/coating losses of materials
  - -Silicate bond strength and losses
- Decision impacts SUS design through dimensions of masses and attachments



Comparison of thermal noise for sapphire and silica

Sapphire Test Mass Research

- Quality factors of internal modes of sapphires as high as 4×10^8 measured (MSU/Stanford/GEO/Caltech)
- Silicate bonding of fused silica to sapphire shown not to affect Q adversely (Stanford)
- Strength and reliability of sapphire bonds currently under test (Stanford/Caltech)
- Effect of coatings on sapphire quality factors currently under test (Stanford/GEO)
- Low-frequency losses of sapphire being tested by means of anelastic aftereffect (Syracuse)

Fused Silica Test Mass Research

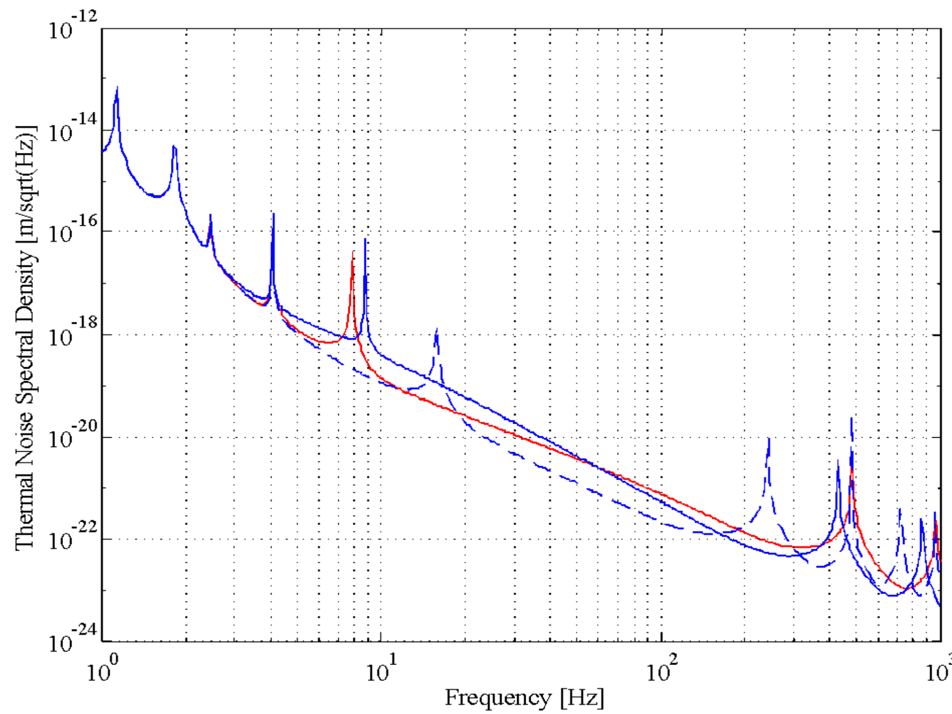
- Quality factors of internal modes of fused silica: Corning 7940 is $2x10^7$, Suprasil SV needs testing (Caltech/Glasgow)
- Silicate bonding of fused silica to fused silica shown not to adversely affect Q (Stanford/Glasgow)
- Surface losses currently being characterized (Syracuse)
- Coating losses currently under test (Glasgow/Syracuse/MIT)
- Low-frequency losses of fused silica being tested by means of anelastic aftereffect (Syracuse)

Ribbons vs. Fibers

•Pros of ribbons -low intrinsic loss -potentially high dilution factor for given cross section, thus lower thermal noise	•Pros of fibers -low intrinsic loss -high breaking strength -fabrication techniques already exist
•Cons of ribbons -low breaking strength -require twists to prevent buckling	•Cons of fibers -lower dilution factor than expected for ribbons

Ribbon/Fiber Research

- Fiber strength proven adequate for Advanced LIGO (Caltech/GEO)
- Fiber pendulum quality factors as high as 2.4×10^8, research ongoing (MSU/GEO)
- Fiber violin quality factors as high as 10^8, research ongoing (MSU/GEO/Syracuse/Caltech)
- Fiber surface losses being characterized (Syracuse)
- Ribbon fabrication, strength, quality factors still under investigation (GEO/Caltech)



Penultimate Mass Design Issues

- Impacts suspension design through position of resonant modes, especially vertical bounce-heavier penultimate masses better, though perhaps harder to build
- Current baseline- heavy (leaded) glass mass

  -quality factors, bonding, vacuum compatibility TBD
- Backup 1- composite steel/fused silica mass

  -quality factors, excess noise TBD
- Backup 2- light fused silica mass

  -technology exists, but vertical bounce mode above 10HZ

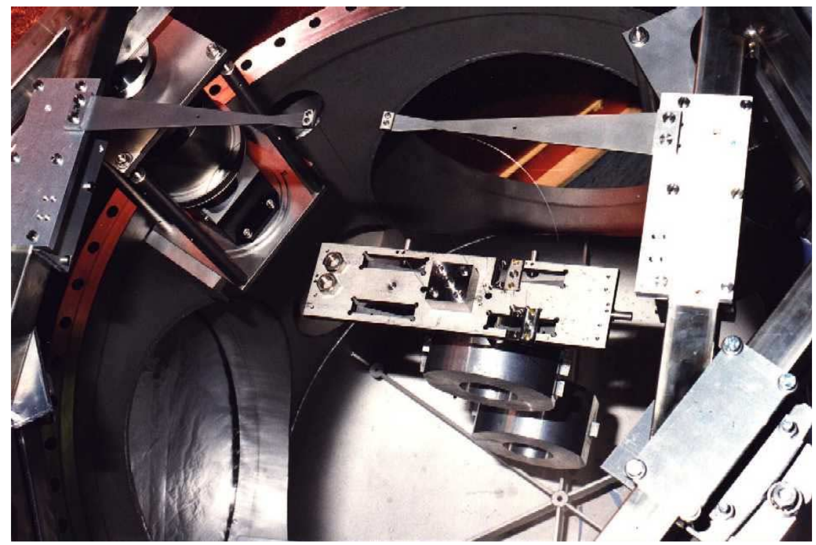
Other Suspension Design Issues

- How do mechanical losses scale to thermal noise at GW frequencies in 40kg test masses?
- What limits can be set on excess noise?
- How will lock acquisition work in these suspensions?
- Can eddy current damping be used?
- How do high-Q violin modes impact on control? (do they require direct damping?)
- Is the electrostatic actuator lossless and linear enough?

…complicated issues such as these require prototypes!

GEO600 as Suspension "Proving Ground"

- The GEO600 gravitational wave detector will operate concurrently with advanced LIGO research
- Valuable limits on fused silica, coating, and fused silica fiber thermal noise will be measured, and lock acquisition and control perfected



Suspensions Prototypes at LASTI

- LASTI will be dedicated in part to investigation of suspensions <u>beyond</u> GEO600: quad pendulums with 40kg sapphire masses, photon drive actuators, and fused silica ribbon suspensions
- Proposal calls for prototyping of quad pendulum test mass, triple pendulum recycling mirror, and triple pendulum mode cleaner mirror suspensions

Summary of Advances over LIGO Suspensions

LIGO	Advanced LIGO
• 10kg test masses →	• 40kg test masses
• Fused silica mirrors →	• Sapphire mirrors
• Single pendulum →	• Quadruple pendulum
• Direct actuation on mirrors through lossy magnet/coil assembly →	• Magnets moved to upper masses Actuation on mirrors by quiet electrostatic and photon drives
• Steel suspension wires on standoffs glued to test masses →	• Fused silica suspension ribbons silicate bonded to test masses
• Control forces applied from relatively noisy platform →	• Control forces applied from seismically isolated reaction pendulum

Advanced Research in the LSC

GEO	Conceptual design completed; will lead preliminary design and support final design Continued measurements of quality factors of fused silica, sapphire, coating losses, bonding research, ribbon research GEO600 research and operation
LIGO/Caltech	Will support preliminary design and lead final design Continued measurements of quality factors of fused silica, strength of bonds, ribbon manufacture Thermal noise measurements at TNI

Advanced Research in the LSC (cont.)

Syracuse University	Losses of fused silica, including bulk, surface, coating, bonding
Moscow State University	Losses of fused silica and sapphire, losses due to electrostatics, surface charge effects
Stanford	Losses of coated and uncoated materials, manufacture and loss of bonds
Penn State	Control of suspensions, cross-couplings
Iowa State University	Theory of thermal noise
LIGO/MIT	LASTI, controls, coating losses

“Advanced” Advanced SUS Research

Stanford	Research on novel test mass materials, e.g. YAG, silicon
ACIGA	Measurement of thermal noise in niobium flexure
CEGG	Magnetic levitation of test masses, coupled suspension systems design, high-Q paramagnetic crystals
LSU	Losses in cryogenic suspension wires
Caltech	Cryogenic test mass development

Suspensions Development Plan

- "Rough" quadruple pendulum prototype suspension
  - » 30kg test mass prototype now developed and ready to build at GEO: uses dummy masses and metal wires
  - » Assembly and early testing at University of Glasgow
  - » Delivery and reinstallation in PNI vacuum tank at MIT as 'permanent' test fixture 3Q2001
- "Controls" prototype suspensions
  - » 40kg mirror suspensions with dummy masses and metal wires
  - » Will incorporate latest sensor/actuator designs and allow global controls testing
  - » 1 TM, 1RM, and 1 MC suspension to test at LASTI 1Q2002-3Q2002
- "Noise" prototype suspensions
  - » Existing controls prototypes will be upgraded with core optics and fused silica suspension wires
  - » Additional TM and 2 additional MC suspensions will be built for full mode cleaner and arm cavity thermal noise tests

Suspensions Development Schedule

ID	Task Name	Start	Finish
1	**SUS Design**	**Mon 03/01/00**	**Tue 15/02/05**
2	Conceptual Design/Requirements	Mon 03/01/00	Thu 30/11/00
3	SUS R&D	Mon 03/01/00	Thu 07/10/04
4	30kg quad prototype construction	Fri 09/02/01	Fri 27/07/01
5	30kg quad prototype tests at MIT	Mon 30/07/01	Thu 07/10/04
6	**Preliminary Design**	**Thu 30/11/00**	**Fri 14/06/02**
7	Ribbon/fiber research	Thu 30/11/00	Thu 31/05/01
8	Sapphire/fused silica research	Thu 30/11/00	Mon 04/03/02
9	Penultimate mass research	Thu 30/11/00	Mon 04/03/02
10	**Preliminary Design Review**	**Fri 14/06/02**	**Fri 14/06/02**
11	**Controls prototype tests at LASTI**	**Tue 05/03/02**	**Wed 22/10/03**
12	MC controls standalone tests at LASTI	**Tue 05/03/02**	**Thu 31/10/02**
13	RM controls standalone tests at LASTI	**Tue 05/03/02**	**Tue 21/05/02**
14	TM controls standalone tests at LASTI	**Mon 02/09/02**	**Fri 20/06/03**
15	TM-RM cavity tests at LASTI	Mon 23/06/03	Wed 22/10/03
16	**Final Design**	**Mon 17/06/02**	**Fri 28/05/04**
17	Final design R&D	Mon 17/06/02	Fri 28/05/04
18	**Final Design Review**	Fri 28/05/04	Fri 28/05/04
19	**Noise prototype tests at LASTI**	**Thu 23/10/03**	**Tue 15/02/05**
20	ITM/ETM noise prototype tests at LASTI	Thu 23/10/03	Mon 23/02/04
21	MC cavity tests at LASTI	Thu 23/10/03	Fri 13/08/04
22	PSL-MC integration tests	Wed 31/03/04	Tue 15/02/05