Progress Report on Suspensions from GEO600 group: February 2003 – August 2003, for LSC

Suspension developments relevant to Advanced LIGO.

- On March 25 2003 the Particle Physics & Astronomy Research Council approved the UK's £8.7M project for contribution to Advanced LIGO. Funding commenced June 1 2003 and the project will run for approximately six years. The majority of the funding (£7.3M) for suspensions and optics comes through Glasgow University to be shared with Rutherford Appleton Laboratory, with the electronics being funded through Birmingham University (£1.4M). (Glasgow/GEO600)

- The suitability of ribbons for suspending the test masses in Advanced LIGO has undergone preliminary testing with 20kg masses suspended from two ribbons for several weeks. Work is now progressing on the suspension of 40 kg from four ribbons as per Advanced LIGO requirements. Initial testing of ribbon strengths has shown an average strength of about 1.2Gpa. It is believed that shear stresses associated with unwanted bends in the ribbons produced during fabrication can lead to this lower than anticipated strength. Investigations are ongoing. (Cagnoli, Heptonstall).

- Design work and experimental test of methods for adjusting blades in suspensions and analysis and testing of blade deflection is ongoing. Improved design of blade wire and blade clamping method is underway at Rutherford Appleton Lab. A proposal for a Blade Test Facility at Rutherford Appleton Lab has been drafted and is currently under consideration by the UK team. This will enable streamlining of testing of the large number of blades required for the Advanced LIGO suspensions (Rutherford Appleton Lab + Torrie (Caltech), Cantley, Jones, Plissi, Perreur-Lloyd, Cagnoli, Elliffe).

- Work on design and fabrication of electronics and coil former assemblies for controls prototypes at Caltech and LASTI is close to completion (Ward, D Robertson, Jones, Perreur-Lloyd, Elliffe, Grant + Torrie et al (Caltech)).

- Investigation of the suitability of eddy current damping for the Advanced LIGO suspensions is close to completion. A paper on the subject is currently being drafted between Glasgow and Caltech for submission to Rev. Sci. Instrum
- (Plissi, N Robertson (Stanford)), Cantley, Torrie/Barton (Caltech), Jones, Grant).

- Some preliminary consideration has been given to potential application of smart control systems for local damping of suspensions as per Virgo Pisa (Losurdo et al). It was realized that a broader approach may be more appropriate and improved control algorithms/more sophisticated filtering have been considered

more generally. Moderate improvements in rejection of sensor noise have been demonstrated using a simple Matlab model. (Strain et al.)

- The detailed design of the modecleaner triple suspension, the first controls prototype for LASTI, is complete at Caltech, with input from N Robertson (Stanford) + GEO600 Glasgow. A workshop will be hosted in Caltech in October 2004 and part of this will cover assembly, installation and alignment of the MC triple. Detailed design for the recycling mirror suspension is underway and work on quadruple suspension design is ongoing with the Simulink model, taking into account recommendations of document on cut-off frequency. (N Robertson (Stanford)). Preliminary detail design of the quad has also been started using Solidworks. Rutherford Appleton Lab is well underway in the process of integrating with the existing project design team on suspension designs. (Plissi, Cantley, Perreur-Lloyd, Torrie (Caltech) + N Robertson (Stanford)+ Greenhalgh/Wilmut (Rutherford Appleton Lab)).

- Experience on various CAD and finite element packages is continuing to develop to allow easy transfer of information between Glasgow, RAL and LIGO. These include SOLIDWORKS, E-drawings, 3D TeamWorks, ALGOR and I-DEAS. Version and compatibility issues are being addressed. (Jones, Perreur-Lloyd, Cantley, Elliffe working with Romie and Torrie (Caltech) + Greenhalgh/Wilmut (Rutherford Appleton Lab))

- Work is ongoing in investigation of the use of silica blades for enhanced vertical isolation in the final pendulum stage. Preliminary loading tests have been carried out on basic silica blades and protective abrasion resistant coatings for the blades are being investigated (Cagnoli, Heptonstall, Plissi and Cantley)

- Violin and pendulum *Q* measurements are still in progress to characterize the silica ribbon suspensions in full and to tie the fundamental violin mode *Q* with the pendulum *Q* (see materials section). This involves investigation of the charging effects on the test mass (see materials report below). (Cagnoli, Heptonstall, Hough and Strain)

- A replica GEO600 mass catcher has been manufactured by GEO600 Hannover and dispatched to Glasgow where Solidworks drawings are being generated. This system will form the design basis for the mass catchers required for the Advanced LIGO suspensions. A design review is currently underway taking into consideration the variations in suspension design and installation practices between the GEO600 and Advanced LIGO detectors. Experience and lessons learned from GEO600 will also be integrated within the design review. (Jones/Goßler et al. Glasgow/Hannover GEO600 team + LIGO team)

Materials developments relevant to Advanced LIGO

1. Investigation of losses of dielectric mirror coatings, in collaboration with Stanford University, Syracuse University, MIT, and Hobart and William Smith Colleges. (Sneddon, Crooks, Cagnoli, Hough and Rowan).

   (a) We have extended our investigation of the mechanical loss factors of SiO_2/Ta_2O_5 coatings, and our publication summarizing the outcome of these experiments has been accepted by Classical and Quantum Gravity: S. Penn, P. H. Sneddon, H. Armandula, J.C. Betzwieser, G. Cagnoli, J. Camp, D.R.M. Crooks, M.M. Fejer, A.M. Gretarsson, G.M. Harry, J. Hough, S.E. Kittelberger, M.J. Mortonson, R. Route, S. Rowan, C.C. Vassiliou, "Mechanical Loss in Tantala/Silica Dielectric Mirror Coatings," *Class. Quantum Grav.* **20** No 13 (7 July 2003) 2917 – 2928

   (b) We have completed a draft publication in which expressions are derived for the levels of thermo-elastic dissipation and thermo-elastic thermal noise associated with coatings applied to test masses. M. M. Fejer, S. Rowan, G. Cagnoli, D. R. M. Crooks, A. Gretarsson, G. M. Harry, J. Hough, S. D. Penn, P. H. Sneddon, S. P. Vyatchanin "Thermoelastic dissipation in inhomogeneous media: Loss measurements and displacement noise in coated test masses for interferometric gravitational wave detectors". This has been submitted to Phys. Rev. D.

   (c) We have used the expressions derived in the draft publication described above to re-analyze the frequency dependence of the mechanical loss factors of coatings containing different proportions of SiO_2 and Ta_2O_5.
   Subtracting the calculated thermo-elastic loss in each case allowed the residual loss to be estimated.
   Our analysis suggests the residual coating mechanical loss is frequency dependent, with the loss decreasing towards lower frequencies. We have modeled this loss for each coating material as having both a constant and frequency dependent component.
   Our analysis is consistent with:
      i. The magnitude of the dissipation being predominantly associated with the Ta_2O_5 in the coatings, and
      ii. The observed frequency dependence being predominantly associated with the SiO_2 present in the coatings.

   (d) We have carried out similar analysis of our measurements of the loss of coatings of Al_2O_3 / Ta_2O_5 applied to silica substrates. This analysis suggests:
      i. That the residual loss of these coatings is predominantly associated with the Ta_2O_5 component of the coatings
      ii. That the residual loss of the Al_2O_3 component is significantly lower than the loss of the Ta_2O_5,
      iii. That the residual loss of the Al_2O_3 component is comparable to the loss of SiO_2.

   Using these results we have estimated the expected residual loss factors of SiO_2 / Al_2O_3 coatings applied to silica substrates and compared these to our experimental measurements of coated samples of this type. We found our

results and predictions are in good agreement, and that the residual loss of SiO_2 / Al_2O_3 coatings is very low at the frequencies of interest for gravitational wave detectors.

(e) We have analyzed the total expected coating thermal noise from each of these types of coating (from both thermoelastic and residual dissipation) and find that:

i. an SiO_2/ Ta_2O_5 coating is best suited for use with a fused silica substrate, and reducing the level of residual dissipation of the Ta_2O_5 component should enable the total coating thermal noise to be reduced.

ii. For a sapphire substrate, using a SiO_2/ Al_2O_3 coating should give the lowest total coating noise level. However, it should be noted that in this case the level of coating thermal noise is dominated by the thermo-elastic noise contribution, which is difficult to reduce. Thus using an Al_2O_3/ Ta_2O_5 coating and attempting to reduce the level of residual dissipation of the Ta_2O_5 component of the coating presents the best strategy for reducing coating thermal noise.

2. Development of a prototype all-fused-silica pendulum suspended using a fused silica ribbon suspension has been carried out. This is currently installed in the pendulum *Q* testing facility in Glasgow, and measurements on the pendulum mode *Q* factor are currently underway. Tests on the effect of charging on the silica pendulum have been carried out showing that the mass tends to have a positive charge. Over a period of a month the charge showed fluctuations as small as 5%. At the moment a run with a light pendulum of 40g is going on. The aim is to evaluate the effect of the recoil losses. Another suspension is under testing in the violin *Q* measurement facility. A new pin in the upper plate has been ground since the previous one broke. A crack could justify the event as well as the low *Q* measured on the rigid body modes of the intermediate mass.
(Heptonstall, Cagnoli, Hough and Strain)

3. Investigations have continued on hydroxy-catalysis bonding techniques. We have carried out investigations into modifying the technique to extend the initial setting time of the bond in a controllable way, to allowing for precision positioning of pieces. Apparatus has been made to test this process. The experiment is ongoing. Initial results look promising.
(Elliffe, Reid and Hough.**)**

4. Our publication on the analysis of the loss factors of hydroxy-catalysis bonding material used to bond silica and sapphire substrates has been accepted by *Classical and Quantum Gravity:* P.H. Sneddon, S. Bull, G. Cagnoli, D.R.M. Crooks, E.J. Elliffe, J.E. Faller, M.M. Fejer, J. Hough and S. Rowan, "The intrinsic mechanical loss factor of hydroxy-catalysis bonds for use in the mirror suspensions of gravitational wave detectors,"

5. We have ordered and received parts to allow the construction of a heavy glass mass of 25cm diameter to form a prototype intermediate mass for Advanced LIGO. A suitable cradle for the composite intermediate mass is currently being designed. **(**Cagnoli and Hough)

Other research developments relevant to Advanced LIGO

Work on an experiment to allow direct measurement of the off-resonant thermal noise of the pendulum mode of a suspended silica mirror continues at Hannover. The experiment was redesigned to achieve higher moments of inertia for the masses of the different pendulum stages. Small changes in the moment of inertia of the pendulums did improve the sensitivity at the frequencies of interest around 10 Hz in agreement with the simulation of the pendulum chain. However additional changes increased the problems caused by the internal resonances of the pendulum masses too much. Mirrors with 10 times higher reflectivity increased the sensitivity in the kHz region but locking the system and remaining in lock became almost impossible due to the small frequency range of the usable error signal. The most recent development was the inclusion of a commercial active isolation that also improved the situation near 10Hz. Planning for another major redesign of the suspension system is in progress. (Leonhardt et al.)

Participation

Participation over period February 2003 to August 2003 was as planned.