Attachment SUS to the

Memorandum of Understanding (LIGO-M 0970077 -00-M)

between the

German/British Collaboration for the Detection of Gravitational Waves (GEO600)

and the

Laser Interferometer Gravitational Wave Observatory (LIGO)

August 15, 2006

This Attachment OUT to the Memorandum of Understanding LIGO-M 0970077 -00-M defines the role of the **German/British Collaboration for the Detection of Gravitational Waves** as a Member of the LIGO Scientific Collaboration (LSC) and a member of the Isolation/Suspension/Thermal Noise Development Group (ISTNDG). The period of performance for the activities in this Attachment is from August 15, 2006 to August 15, 2007.

1. Isolation/Suspension/Thermal Noise Development Group - The Isolation/Suspension/Thermal Noise Development Group (ISTNDG) is the scientific collaboration for defining and developing instruments in optics for use in advanced subsystems for the initial LIGO interferometers or in entirely new advanced interferometers. MOU Attachments define the roles and responsibilities of groups in this development group.

2. During the period August 15, 2006 to August 15, 2007, the members of **GEO600** will participate in ISTNDG in the following areas:

a) Coating Losses

Coating Losses for Advanced LIGO and beyond

a.1.) Measurements of multi-layer coatings applied to fused silica substrates
Reduction of the mechanical loss associated with the addition of coatings to substrates and associated thermal noise remains an important research area for Advanced LIGO and is vital for the success of any future detectors that aim to have sensitivities better than Advanced LIGO.
We thus propose to continue to work with our LSC colleagues- Stanford University, Syracuse University, MIT, and Hobart and William Smith Colleges, on studies of the excess mechanical losses associated with adding dielectric coatings to test mass substrates

a.2.) Measurements of multi-layer coatings applied to sapphire substrates
We aim to revisit our studies of multi-layer coatings applied to sapphire substrates once our work on nodal supports has progressed further.

a.3.) Mechanical loss associated with coatings for diffractive optics
(Cumming, Heptonstall, Rowan and Hough)
Investigation of the mechanical loss associated with the coatings for diffractive optics will continue in collaboration with colleagues in Hanover and Jena.
Once the sources of excess loss in the suspension have been identified and minimised, measurements will be carried out on annealed blank disks, a disk with a 50nm etched grating and a multilayer optical dielectric coating, to simulate a complete test mass optic.

a.4.) Coating loss measurements using thin cantilever substrates
(Martin, Reid, Heptonstall, Holt, Cunningham, Rowan & Hough)
The loss of <110> oriented single-crystal silicon cantilevers has previously been studied between 290 and 80 K. Currently, our small cryostat is being adapted for cooling to liquid Helium temperature, which will allow measurement of the mechanical loss around 18 K, where the thermal expansion co-efficient (and hence the thermo-elastic dissipation) goes to zero.
We have recently recruited a new group member with expertise in semiconductor nanofabrication and are working towards being able to fabricate in-house silicon cantilevers for further study. In particular, the effects of crystal axis orientation, doping and surface to volume ratio on the mechanical loss will be investigated.
We intend to study further single layer coatings of tantala and silica on both silica and silicon substrates and investigate the effect of doping and coating thickness on the mechanical loss. We plan to be in a position to carry out these measurements from room temperature down to (or close to) 4K.
Over the next six months a third cryostat facility capable of carrying out mechanical measurements down to (or close to) 4K will be commissioned for measuring similar small cantilever-type samples.

b) Suspension Design for Advanced LIGO

Suspension Design for Advanced LIGO and beyond

b.1.) Activities forming WP1 of UK Advanced LIGO Project – Project Management
(RAL + Glasgow/GEO600 + UK Advanced LIGO Project Team)
Continuing project management and oversight of all of the work packages within the UK Advanced LIGO Project.
Further details of this work package can be found in the UK proposal "Exploring the Dark Side of the Universe: Proposal for UK Involvement in Advanced LIGO", Issue 2, November 2002 and the website for Advanced LIGO UK (RAL) both of which can be accessed via the Advanced LIGO UK (Glasgow) website available via:
http://www.physics.gla.ac.uk/igr/advligo/
The website for Advanced LIGO UK (RAL) gives additional information on this work package and can be accessed via the Glasgow page.

b.2.) Activities forming WP2 of UK Advanced LIGO Project – Main Suspension Science
(Glasgow/GEO600 + RAL + UK Advanced LIGO Project Team)
Continuing scientific input to the suspensions for Advanced LIGO based on the development of the triple suspension systems for GEO 600 and development of the Advanced LIGO quadruple suspension controls prototype which is currently being tested at LASTI. Provision of the reaction masses, penultimate masses and silica ears for the main suspension systems of Advanced LIGO.
For further details on this work package refer to the UK proposal "Exploring the Dark Side of the Universe: Proposal for UK Involvement in Advanced LIGO", Issue 2, November 2002 online via the Advanced LIGO UK (Glasgow) website via:
http://www.physics.gla.ac.uk/igr/advligo/

b.3.) Activities forming WP3 of UK Advanced LIGO Project – Main Suspension Systems
(RAL + Glasgow/GEO600 + UK Advanced LIGO Project Team)
Continuing development of the final mechanical designs for the main suspension systems based on the controls prototype and earlier GEO600 suspensions. Finalise the design and manufacture the noise prototype for delivery to LASTI. Commence with the process of finalising the designs for the final article suspensions for delivery to the two LIGO sites.
For further details on this work package refer to the UK proposal "Exploring the Dark Side of the Universe: Proposal for UK Involvement in Advanced LIGO", Issue 2, November 2002 online via the Advanced LIGO UK (Glasgow) website via:
http://www.physics.gla.ac.uk/igr/advligo/
The website for Advanced LIGO UK (RAL) gives additional information on this work package and can be accessed via the Glasgow page.

b.4.) Activities forming WP5 of UK Advanced LIGO Project – Optical Material
(Glasgow/GEO600 + UK Advanced LIGO Project Team)
This work package towards provision of four silica blanks each of 40 kg for the mirrors of one interferometer was successfully completed in February 2006.

Further details of this work package can be found in the UK proposal "Exploring the Dark Side of the Universe: Proposal for UK Involvement in Advanced LIGO", Issue 2, November 2002 accessed via the Advanced LIGO UK (Glasgow) website via:
http://www.physics.gla.ac.uk/igr/advligo/

b.5.) Control and noise prototype suspensions
(Glasgow/GEO600 + RAL + Birmingham (with Strathclyde) + Advanced LIGO SUS Project Team)
Design and experimental checks will continue during the ongoing development of the noise prototype quadruple suspension. Results from the LASTI controls prototype tests which are currently underway will continue to be reviewed and fed back into the design process. The SUS preliminary design review (PDR #3) has recently been successfully completed and we have now entered the final design phase. The assembly/installation and testing of the quadruple noise prototype at LASTI is planned to commence in March 2007.

b.6.) Suspension support structure and mass catcher/installation jig design
(RAL + Glasgow/GEO600 + Advanced LIGO SUS Project Team)
Modal frequency investigations and FE analysis will be imminently completed at RAL with Glasgow's input to check the lowest modal frequency and dynamic behaviour of the noise prototype structure (upper structure + lower structure/mass catcher). The mechanical design of the earthquake stops is relatively mature and these will be prototyped in the near future. Work will continue in interfacing the functionality of the lower structure as an assembly tool and a mass catcher for the final silica monolithic stage.

b.7.) Steel cantilever blade development
(RAL + Glasgow/GEO600 + Advanced LIGO SUS Project Team)
Work on blade adjustment will continue using the pre-noise prototype "marionette" suspension constructed at RAL for advanced testing of various aspects of the noise prototype suspension design. Any further lessons learned from both the controls and noise prototype suspension assembly/tests at LASTI will be fed back into the final suspension designs.

b.8.) Active damping of suspensions – optically sensed electromagnetic actuator (OSEM) development
(Birmingham (with Strathclyde) + Glasgow/GEO600 + RAL + Advanced LIGO SUS Project Team)
The mechanical drawings for the OSEMs will be released and approved. Orders will be placed with external contractors for fabrication of the mechanical parts. Assembly of the noise prototype OSEMs will be carried out in-house at Birmingham in a controlled clean environment. A number of complete OSEM units shall be shipped to RAL for a test assembly on the quadruple suspensions. The OSEM electronics and monitoring and diagnostic will be completed, tested and built for delivery. The tests and assembly of the electrostatic drive electronics will be completed.
The OSEM production units and all electronics shall be shipped to the LASTI test facility

Support will continue to be provided for assembly, installation and testing of OSEMs, OSEM electronics and electrostatic drive electronics at LASTI from spring 2007 onwards.

b.9.) Passive damping of suspensions – eddy current damping (ECD)
(Glasgow/GEO600 + RAL + Advanced LIGO SUS Project Team)
Feedback from the performance of the ECD units in the controls prototype at LASTI will continue to be incorporated into the final noise prototype design. Feed back from the noise prototype tests will subsequently be incorporated.

b.10.) Electrostatic drives
(Glasgow/GEO600 + Birmingham (with Strathclyde) + RAL + Advanced LIGO SUS Project Team)
Experimental and design work on ESD drive electronics will be completed between Birmingham with Strathclyde and other UK collaborators, specifically the low noise front-end electronics and the revised PCB for the high-voltage driver. We will continue to provide our support in this area. This work will be completed for application to the installation of the noise prototype at LASTI in spring 2007.
The mask required for the gold coating of the noise prototype reaction mass has been designed by Glasgow and will be manufactured by Caltech. The reaction mass and its spare will be delivered to Caltech at the end of 2006 for application of the gold coating.

b.11.) CO2 laser pulling and welding of silica fibres and ribbons
(Glasgow/GEO600 + Advanced LIGO SUS Project Team)
The basic development phase of the CO2 fibre pulling and welding machine is complete. Refinement and optimization of machine design details and the pulling/welding processes for application to LASTI and Advanced LIGO will continue at Glasgow in the run-up to the noise prototype installation at LASTI in spring 2007. Glasgow has started to transfer the design and procurement information package for RAL to order the machine components to be delivered to LASTI early next year. This transfer will be complete within the next few months.
Development of the optical profiling device for silica fibres and ribbons is already mature and will continue to be refined for application during the LASTI noise prototype installation.

b.12.) Characterisation of silica ribbon suspensions
(Glasgow/GEO600 + Advanced LIGO SUS Project Team)
The CO2 laser machine is capable of pulling ribbons and fibres of variable taper length ranging from a few mm to tens of mm. The thermal noise and flexure point calculations for the tapered ribbons will be completed for the noise prototype to determine the optimum taper design. The Glasgow fibre/ribbon strength testing jig is currently being upgraded and this will be complete within the next few months. Quality factor measurements in tapered silica ribbons and fibres will continue in parallel with this work.

b.13.) Silica ear design for Advanced LIGO
(Glasgow/GEO600 + Advanced LIGO SUS Project Team)

The refined silica ears for the noise prototype will be delivered to the US towards the end of the year. The ear bonding area has been shown to be sufficiently strong for application to Advanced LIGO. The ear design work will be fully completed for the noise prototype installation at LASTI in spring 2007.

b.14.) Fabrication of dummy final monolithic stage for quadruple pendulum
(Glasgow/GEO600 + Advanced LIGO SUS Project Team)
Construction of this will take place towards the end of the year as a pre-assembly for the LASTI installation scheduled in spring 2007. Silica plates will be embedded in the 40 kg metal masses. Silica ears will be silicate bonded to the plates on the masses and the masses will be positioned within a dummy lower structure. The full assembly/welding procedure will then be further refined using this set-up.

b.15.) Violin mode damping of silica ribbons
(Glasgow/GEO600 with Strathclyde + Advanced LIGO SUS Project Team)
Since passive damping has been shown to be unsuitable the most suitable active method for violin mode damping of the final stage suspension ribbons will continue to be investigated. Experimental development will commence early in the forthcoming period. It is ultimately intended that the developed violin mode damping system can be tested in the noise prototype at LASTI. Suitable interface design features are currently being incorporated in the lower structure to accommodate such a system.

c) Other Contributions

c.1.) Investigations of charge mitigation techniques
(Reid, Rowan, Hough & Cunningham)
An evaluation of the use of a Kelvin Probe for measuring the work function in semi-conductors and charge distribution in dielectric materials will continue. Over the next period a calibration process will be used to enable the Kelvin Probe signal to be related to the magnitude of the charge on a surface. A study of the charging and discharging of fused silica substrates can then be carried out.

c.2.) Improved suspension techniques development for bulk mechanical loss measurements
(Chalkley, Murray, Cumming, Faller, Hough & Rowan)
The development of improved suspension techniques for bulk mechanical loss measurements will continue. Aspects of the performance of the nodal support will be tested by varying the support force applied to the test substrate and use of materials with different hardness characteristics as spherical contacts.
The nodal support, with some adaptations, is also planned for use with the measurement of coating loss in thin silica discs.

c.3.) Measurements of silicon ribbon flexures
(Reid, Martin, Cunningham, Rowan & Hough)
We will continue our studies of the mechanical loss of silicon cantilevers as per the discussion in a.4) above.

c.4.) Silica cantilever blade development
(Cantley, Heptonstall, Cagnoli)
Investigation and development of silica cantilever blades has not progressed over the previous period so that research and development effort could be focussed on direct requirements for the Advanced LIGO noise prototype. This work will be resumed in the forthcoming period. In addition to blade strengthening by flame polishing, or coating we will also investigate application of the CO2 laser polishing technique to silica blades. This work will commence following installation of the noise prototype at LASTI in spring 2007.

c.5.) Thermal noise experiment in Hanover
(Ribichini, Lueck & Danzmann)
Based on experience within the Laser Zentrum Hanover it is considered to be technically feasible to produce an etalon with the required specification to serve as an ultra-short resonator for directly measuring the thermal noise of an optical coating. However, the production of such an etalon is proving to be a challenge. Communications will be maintained with the etalon coating companies to continue to investigate a method of obtaining a suitable low loss, high throughput etalon.

3. Resource Sharing: The LIGO Laboratory will contribute resources including allocation of appropriate scientific and engineering personnel, research facilities and funding in support of the effort in Item No. 2, as indicated below.

   a) Research accommodations for GEO600 group members while on LIGO research assignment at any LIGO Laboratory site,
   b) Access to LIGO data through established LSC channels in support of this work.
   c) Not Applicable

4. Coordination and Reporting -

   GEO600 will perform this research within the structures established by the LIGO Laboratory and the LSC where appropriate. In particular activities described in Item 2 will be carried out within the Isolation/Suspension/Thermal Noise Development Group of the LSC. Coordination will include keeping the Group leaders informed of activities and plans, reporting to the group at meetings and telecons, and through technical documents submitted to the LIGO Document Control Center.

   In addition, an annual report will be submitted with the update to this Attachment, giving a summary status on research by topic as indicated in Item No. 2, including progress against the milestones if any, significant accomplishments such as new insights/discoveries or publications, issues of concern if any, and an indication of invested time. This Attachment will be updated at least annually with a plan of activities for the succeeding on-year period. These documents will be due one month before the close of the period of performance under this Attachment.

5. All computer code delivered to the LSC under this Attachment must be developed in consultation with the LSC Data Analysis Software Working Group (DASWG) and archived, documented and reviewed as determined by that group.

Approved:

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