LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

- LIGO –

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My considerations on the choice between the stiff and the SAS (soft) suspension system.

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This is an internal working note
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At Glasgow it was decided to make LIGO II seismic attenuation specifications based on the concept of having a seismically attenuated optical bench from which to hang down up to three multiple pendula or other optical component.
The most complex requirements coming from the last BSC in the short interferometer in Handford that house a folding mirror, an inner mirror and a telescope.
The proposed specifications lead to a fine and internally consistent design, but it has to be considered the long term price for LIGO.
A true optical table has an attractiveness because it gives a degree of flexibility as it allows the re-localisation of the optical components by simply moving them around the optical table surface and repositioning some counterweights.
However, because of the fact that the optical components can be aligned between themselves only up to a certain level, a lot of control authority is required at the multiple

pendulum level. Large authority at this low level in the seismic attenuation chain requires large forces close to the mirrors and the possibility of large re-injected noise. To keep this noise in check it is then necessary to introduce a quadruple pendulum geometry, in which the second (passive) layer is present only to filter out the actuation noise.
Also having large standing forces near the mirror opens the way to possible non Gaussian noise pick-ups either from the electrical cabling and/or from direct coupling to the standing force itself or from the recoil mass from which the test mass chain is actuated. The quadruple pendulum then necessarily looks like a double passive attenuation chain, including the vertical attenuation on both the test and the recoil mass chains.
The optical bench, which is said to simplify the seismic attenuation chain concept, in reality increases the complexity of the suspensions and mixes seismic attenuation issues with thermal noise and actuation ones in a much more profound way. Incidentally the argument that the optical bench is a visible and well-defined interface between seismic isolation and suspension system here fails.
Additionally having feedback loops directly attached to the same suspension table may produce cross talk problems.
It is also worth mentioning that the present LIGO HAM optical benches are quite practical and easy to use because the optical units sit on them and can easily be first aligned and then clamped down. The proposed optical benches for the BSCs would be, like the present ones, overhanging optical roofs from which the multiple pendula hang down. From these roofs it is not that easy to internally align optical elements. The optical bench then does not give much of a simplification to the system. Also in many BSCs the bench may be completely superfluous and eliminating it will entail a significant cost reduction and real simplification.
The Glasgow meeting requirement of an optical bench for the new LIGO seismic attenuation and suspension chains is then clearly a heavy mortgage on the future of LIGO. This is especially true in view of the fact that we are likely to upgrade the seismic isolations only once and it would be difficult to justify a second upgrade later on if the first one is too timid.
It seems to me that having fully separate and independent seismic attenuation systems for all the optical elements with nulled standing forces around the mirrors is an advantage that should not be given away lightly, especially if effortless suspension point positioning and negligible test mass residual motion can be delivered as well. This is one of the main advantages that can be delivered by the soft SAS that we propose. We have already shown how to fit two independent SAS chains within the diameter of 2 meters and three chains can be easily fit within the 2.5 meter diameter of the BSCs. The much criticised attenuation overkill capacity comes as a bonus and should be sneered at.
Note that independent, remote and analogue positioning of all suspension points within 10 mm range is trivial in SAS. This feature may actually make optics tuning easier than having the same elements sitting on a bench, not even mentioning hanging under an optical roof. (Large re-positioning of payloads in SAS can be achieved by simply changing the lengths of the arms between the IP legs and the top filters, this level of flexibility is similar to that of accessing an optical table and moving around payloads and counterweights.)

While we are working to modify a SAS design that fulfils the Glasgow's meeting specs, it seems to me that those specs are outdated and should be re-evaluated by us or by the committee that will have to decide between the two solutions.

LIST of perceived SAS advantages

- Soft systems provide natural pre-attenuation at the lowest frequencies, including at the micro-seismic peak.
- Inertial damping of an IP/F0 unit have already produced measured residual r.m.s. motion of the payload of less than 50 nm integrated above 100 mHz . Even better performance is expected from the use of the advanced LIGO accelerometers on the more advanced LIGO IP.
- The IP and F0 provide a natural platform for the inertial damping accelerometers. These accelerometers, operating on a pre attenuated platform, may be expected to reach better performances, especially at low frequencies.
- The passive filters hanging from F0 effortlessly deliver the required attenuation factor with a comfortable safety margin both in amplitude and in frequency range.
- The inertial active damping controls are all safely relegated outside the frequency range of interest, all the rest is safely passive.
- The passive filters also shield the mirror from possible accelerometer and actuator excess noise (note that in the stiff system the requirements are marginally achieved considering only the sensor's white noise and disregarding any excess noise in sensing, signal processing and actuation)
- The excellent residual IP/F0 motion performance enormously reduces the triple pendulum actuation dynamic range requirements (maximum required dynamic range below the micron) thus allowing the use of electrostatic actuators on the intermediate triple pendulum masses and photon drive on the mirror. The danger of mirror actuation introducing excess noise is proportionally reduced.
- The softness of the movements allows precision positioning of the individual optical components at negligible power consumption levels.
- The capability of interleaving two or even three independent chains in the same tower allows for independent and full control of (for example) inner and folding mirrors and of ancillary optics without reintroducing large actuation dynamic range requirement for trivial static alignment reasons.
- Sub micro metric positioning of the mirrors from the chain head minimise all standing forces near the mirror thus minimising chances of actuation excess noise and external noise couplings.
- The large dynamic range of the SAS allows the rotation of individual optical elements off axis by as much as 10-20 mrad for tuneup reasons. Large longitudinal positioning range is trivial.
- Despite the low dissipation and very small internal damping of the materials used, the low frequencies of the SAS elements naturally generate large effective damping and low oscillation quality factors.
- All metal to metal connections on the stress path are made in a creak free geometry.
- All SAS components are UHV compatible and fully bakeable to relax creep activity from the stressed materials.

- Fully separated chains cannot produce actuation cross feeding between optical components.
- SAS is readily upgradable and reconfigurable in performance and load.
- know-how on soft techniques (Virgo, TAMA, AIGO) is rapidly growing.