LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

- LIGO –

CALIFORNIA INSTITUTE OF TECHNOLOGY
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SAS Prototypes Test Program Plan

Riccardo DeSalvo

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This is an internal working note
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California Institute of Technology
LIGO Laboratory - MS 18-34
Pasadena CA 91125
Phone (626) 395-212
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Laboratory - MS 16NW-145
Cambridge, MA 01239
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

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

No plan, or at least no successful plan, survives the unknown of practical life. The SAS plan has already evolved substantially since the Glasgow meeting. Two new facts have produced these changes:

1) Further thinking have produced new doubts on the assignment of the Glasgow's meeting (see my letter to the TAG chairman of January 11th 2000, attachment 1)

2) The new technical problems at TAMA and the call for help from the TAMA colleagues and collaborators.

The doubts on the necessity of an optical bench in the BSCs, exposed in the letter, mainly question the wiseness of imposing an optical bench common to more optical elements. SAS can effortlessly suspend, isolate and control the 800 Kg optical bench specified at

Glasgow, so this may be regarded as a red herring. Actually suspending an optical bench from which large dynamic range controls are applied to the multiple pendula is a less demanding task than our target, which is to lighten the multiple pendulum dynamic range requirements of each optical element by better low frequency attenuation and control performances. The final goal is to lower the possibility of actuator non Gaussian noise polluting the system.

Concluding that the suspension of an optical bench is just a simplified subset of our SAS general plan, at least for the moment, we kept the focus on the tougher problem. (Incidentally our close collaboration with Virgo[1] is presently focussed on starting up the Virgo optical benches and their control issues).

More urgently, TAMA scientists have found that low frequency attenuation deficiencies of their system prevent a reliable and low noise operation of their interferometer. Having ascertained the necessity of an efficient low frequency seismic isolation system they have been seeking for an advanced isolation system for future upgrades of TAMA. They found that the SAS is the most promising system for that use and they asked us for assistance. The task is to rapidly build a first, shortened version of the TAMA SAS system and, when needed, a full fledge TAMA SAS system. The first part of this work is detailed in the SAS R&D Program Plan and MOU Addendum 5 (attachment 2 and 3 to this letter); the plan outline is the following.

1) TAMA scientists joined the SAS team to use the present LIGO SAS prototype (an IP plus a GASF F0 and two completely passive GASFs supporting a dummy payload) to reproduce in air the Virgo controls and attenuation performances and to develop the control algorithms for TAMA and LIGO II (work ongoing)
2) We have built and are testing a miniaturised and simplified (linkless) GASF that can fit in the TAMA vacuum vessel diameter.
3) We have designed a TAMA compatible SAS system (IP + F0 + one GASF) and are finalising its engineering drawings to start production towards the end of February.
4) We plan to start testing this prototype in air at Caltech with a surplus TAMA double pendulum payload in April.

[1] Virginio is presently in Pisa for a two week work period working on the bench control system.

5) Following the above tests in air, engineering design optimisation and production will follow in the summer.
6) Installation in the 3 meter Fabry Perot interferometer (at the University of Tokyo) and its operation is scheduled for the fall 2000.[2]
7) Following the 3 m validation tests refined engineering design should be used to build the first TAMA SAS chains to be installed in Spring 2001 or whenever convenient to the operation of that Interferometer.

TAMA may later proceed to the implementation of two more GASFs (with a taller IP) for further improvement of the performances, depending on the schedule and budget available.

The testing of the existing and coming LIGO SAS prototypes is being accelerated by the tight TAMA time constraints. SAS for LIGO II will profit from the knowledge that will be acquired by the TAMA SAS and will continue in parallel during its operation.

The increased manpower generated by the TAMA scientists and other collaborators that have recently joined the group -Joe Kovalik (postdoc), Szabolcs Marka (postdoc), Flavio Nocera (electronics engineer), Hareem Tariq (undergraduate full time for one year), Chenyang Wang (undergraduate) or will join in the next few months (Frederick Seve, graduate student in mechanical engineering from INSA Lyon), together with the support from University of Pisa and the growing symbiosis with the Virgo superattenuators group, will allow a speedy testing of the prototypes and verification of the fulfilment of the LIGO II requirements.

After this rather long but necessary introduction, let me give more specific answers to the TAG questions.

The SAS prototype is basically a mature concept, which is already being demonstrated by the Virgo superattenuator group. The LIGO II requirements are actually very similar (if not somewhat less stringent in the low frequency end) to the Virgo ones. The LIGO prototypes are necessary to:

1) Certify the performance of the more advanced components (GASFs, stiffer IP mechanics, accelerometers[3], linkless GASFs, etc.)

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[2] This project is the subject of the doctoral thesis of Akiteru Takamori, of University of Tokyo (MOU addendum xxx).

2) At least reproduce the Virgo performances in our mechanics.
3) Test new components and concepts (for example magnetic damping of the passive chain internal modes).
4) Test the HAM chamber SAS systems (see description below).

Most of these tests can be done in air and will be performed at Caltech.

All components and system tests confirm that SAS will exceed all LIGO II requirements in attenuation factors, frequency range, residual speed and integrated residual motion. The measurements also agree with the existing simulations.

Final tests in vacuum are foreseen to be performed in LASTI and/or in the ETF.

Full scale prototypes, integrated with multiple pendula would be tested in LASTI, although shorter wires between GASFs or a smaller number of GASFs could be used to fit within the lower LASTI roof.

ETF would serve for accelerometer, LVDT, actuator testing.

Because of the tight time constrains of the TAMA update project, part of these tests will be anticipated, although to a smaller scale, by the Japanese tests.

There are two LIGO technical requirements, which radically differ from the Virgo or TAMA ones:

1) up to three independent optical units (2 mirrors and a small optical bench or telescope) may be present in a BSC chamber
2) Input and output optics in LIGO are mounted on HAM's optical benches.

We have already performed an engineering study that proves that we can fit two completely independent SAS chains (the 2-in-1 concept) within a two meter diameter vacuum vessel (this exercise was also aimed to prove that in future a second interferometer can be fit inside the existing Virgo vacuum chambers). Fit one or even two additional SAS chains in the 2.6 meter diameter LIGO BSC is a simple engineering exercise especially if the miniaturised TAMA filters are used as well. No further study of

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[3] The advanced accelerometer project is the doctoral thesis of Alessandro Bertolini of University of Pisa, he is a full SAS group member and he is spending his University of Pisa grad student fellowship to develop these accelerometers on SAS specifications.

this problem will be carried out until the specific problem (test Fabry Perot, advanced TNI or actual LIGO mirror assembly) will be formulated.

About the HAM optical table technical problem, this is a somewhat more complex than the simple adaptation of a SAS chain to different space constraints (like in TAMA SAS or in the 2-in 1 concept). The HAM SAS idea is less advanced than the standard SAS and it is based on a supported (as opposed to suspended) optical bench. The bench would be supported on very low frequency stands (2-300 mHz in all three directions) with principally passive attenuation capabilities. The stands would be derived from commercial units (minus-K technologies). The optical bench would be controlled in much the same way as the IP and F0 of the standard SAS chains. This project is still at the demonstration level. We have already measured the performances of the minus-K stands, found them very satisfactory and ordered three units of them. We also designed the optical bench mechanics and control system, which are in the bidding stage and should be ordered shortly and built possibly by the end of March. Although this test system will support the real optical bench recovered from the HAM's mock up, it is not yet designed to completely fit inside the HAM chambers, it is not yet UHV compatible and it is not yet built in the SAS standard of creep and creak free materials and geometry. Unlike the standard SAS chains, HAM SAS has to be considered simply as a capability demonstrator unit as the first GAS filter prototype was in fall 1998[4].

About our readiness level.

We are presently still improving the GASF and IP prototypes, but we have already a perfectly viable and tested version of each SAS chain component. We base the SAS control on the now quite advanced Virgo control scheme[5]. Being ready for a 2004 installation will simply require the freeze of the design of the day and the straightforward engineering adaptation to the individual specifications of the different payloads.

Unlike the standard BSC SAS, we will not have a detailed and fully viable design of the HAM SAS for April fool's day 2000; the development program is underway, with

[4] This project is intended to be the subject of the doctoral thesis of Frederick Seve, of INSA Lyon (MOU and addendum xx)

[5] Reports on the advancement can be found in the Virgo site or in our web page "http://www.ligo.caltech.edu/~citsas/"

adequate resources, and we see no substantial technical obstacle ahead of us. Judging from the past advancement rate on the standard SAS, we believe that we can bring it to production technical readiness level within one or one and a half years.

As for cost limitations we will easily fit within the budget limits foreseen for the Seismic Isolation section of the LIGO II upgrade. In order to allow free choice between the stiff active system and SAS, that budget was tailored on the stiff(er) price tag. The mechanics of the full size, UHV compatible, SAS chain prototype did cost approximately $100,000 and we certainly do not expect higher costs for the production items (TAMA SAS mechanics is expected just above $50,000/chain, $100,000 including most of the control electronics). Similar, but maybe somewhat higher costs, are expected for the HAM SAS system. Even including all the sensor, actuation and instrumentation costs we expect no limitations within the projected cost envelope.

We do not expect any real risk in using the SAS technique. We will take advantage of the experience of other groups, and we will have a field test in an interferometer within the year. That experience will allow us to weed out and eliminate any possible nonessential feature or add any necessary one.