Statement of Work: Evaluation of TAMA SAS at the 3m Interferometer
– DRAFT (ver.0.1.1) –

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1 Objectives/Scope

In order to install and operate the Seismic Attenuation System (SAS) at the TAMA300 interferometer, it is required to evaluate its performance by operating a Fabry-Perot cavity suspended from the system. Especially, establishment of the control scheme by merging signal from local and global sensors is the most important subject. The scope of the experiment is to:

- Design of SAS mechanics/controls for TAMA300
- Implementation and evaluation of new components designed for TAMA SAS
- Prototype fabrication and partial evaluation with local sensors
- Full evaluation of prototype SAS at the 3m inteferometer

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2 Procedure

A general strategy of the experiment is described in this section.

Since the SAS is originally proposed by LIGO group (Caltech), and they are interested in early test of this technique. This work will be done in a close collaboration of TAMA and Caltech group.

2.1 Design of Mechanics

The design of mechanics for every subsystem will be done at Caltech. Validation and some improvements of the real prototype for TAMA may be done by TAMA team during the 3m interferometer experiment, in a collaboration with the Caltech team.

2.2 Fabrication of Mechanics

To save time and efforts to find and train a factory, entire production will be done following the same procedure as the SAS prototypes for LIGO II. All components will be machined and finished in Italy. This may also help to minimize the budget for this project. Caltech team will maintain contacts with the company.

2.3 Prototype Test

Except for the mixing of local and global controls, all performance tests feasible in the air would be done at Caltech by using LIGO SAS prototype and TAMA SAS prototype. After this process, two TAMA SASs will be installed in the 3m interferometer for the global control experiment.

2.3.1 Prototypes

There will be three prototypes in this experiment. The first one (LIGO SAS prototype) is a prototype of the SAS for LIGO II. This contains a full scale inverted pendulum (IP) for LIGO BSC, a vertical pre-isolator (Filter Zero), and a passive attenuation chain with local sensors and actuators. The standard Geometric Anti-Spring Filters (GASFs) of this prototype are in old configuration with links between GAS blades and payloads, but may be replaced by the new configuration later on.

The second is a prototype Geometric Anti-Spring (GASF prototype) Filter. This would be used to investigate the new link-less configuration of GASF.

The third one is a prototype of SAS for TAMA300 (TAMA SAS prototype). This includes an IP, Filter Zero, and a standard GASF that holds a TAMA double pendulum. This is a final prototype for 3m experiment which will be designed and built at shared cost. TAMA SAS prototype will be used at Caltech to make performance tests out of vacuum.

Caltech team will keep all of these prototypes, after the use for TAMA, Caltech will modify them for LIGO use. Two SASs designed for TAMA will additionally be fabricated to install in 3m interferometer.

2.4 3m Interferometer Experiment

Two SASs will be installed in 3m interferometer at University of Tokyo. Assembly of these units may be done either at Caltech or Japan according to the best convenience. Merging of the local and the global controls will be focused on in this experiment.

3 Tasks

Required tasks with details are explained in this section.

3.1 Vacuum

Since this experiment will be performed with the SASs that fits into TAMA vacuum vessels, the vessels of 3m interferometer have to be modified to accept the SAS. Necessary modifications are the following:

- Extension of the vessels : Existing vessels are not tall enough to put the SAS in, so it is mandatory to extend their height. To have comfortable clearance between the top the SAS and the flange of the vessel's cap when the vessel is opened, the height of the crane might be incresed. Counter weight assemly may be studied as well.

- Rearrangement of an arm duct: The beam height of the present 3m interferometer is about 100 mm from the bottom of the vacuum vessels. But the system for TAMA has a beam line of 860 mm higher than the bottom. So the arm has to be rearranged.

- Signal port : We have to have adequate number of ports to connect the local sensors and actuators for the SAS in addition to the existing devices for the 3m interferometer.

3.2 Optics

TBD

3.3 Mechanics (TAMA SAS prototype)

3.3.1 SAS

Mechanics of SAS includes an inverted pendulum, two GASFs, and local sensors/actuators.

3.3.2 Suspension

For a mirror suspension, the basic geometry of the TAMA double pendulum will be adopted. But some desirable modification (listed below) should be done.

- Removal of redundant control devices: The original TAMA suspension has movable statges for DC positioning of the mirror. All of their function will be realized by SAS controls except for the mirror tilt control. To avoid sprious mechanical resonances close to the test mass, these stages should be removed. The mirror DC tilt can be controlled by repulsive magnetic force as done for LIGO I.

- Replacement of the vertical springs: The present TAMA suspension has welded bellows as vertical springs. The merit of the bellows is their compactness, but by holding the suspension from SAS, this subject is not important any more. Also the transversal internal resonance of the bellows degrades the longitudinal isolation performance in the low frequency band, around 30Hz. This would be a good occasion to replace them with simple cantilever springs. Caltech can assist with the design.

- Simplification of the frame structure: The outer frame of the TAMA suspension will not be necessary, because the suspension doesn't settle on the ground in the new configuration. To simplify the system, it might be better to remove it.

3.3.3 Interface

An interface between the SAS and the suspension should be defined by detailed simulations.

3.4 Controls

3.4.1 Control Topology – simulations

The scheme of controls will be defined by simulations. Main objects are listed below:

- Strategy of local controls: There are two options for the controls. One uses just displacement sensing to position the system and damp the fundamental resonances. The other one employs additional inertial sensors for the higher mode damping to minimize residual motion of the test mass.

- Sensing/actuating points: It is necessary to figure out where to put the devices for the controls.

- Distribution: To define range and band for each control point. It includes merging of the local and the global controls.

- Simulation tools: These simulations would be done with mechanical simulation engine (MSE) for end-to-end model of LIGO. Some small simulations would be done exceptionally with the other applications (Mathematica, Maple, etc.).

3.4.2 Devices for Controls

Sensors

As the displacement sensors, LVDT technology seems to be the best solution. The LVDT shows wide range ($\sim$ 10 mm) with good linearity and sufficiently low noise.

For inertial sensing, couple of alternate options exist.

- Commercial accelerometer

- VIRGO accelerometer

- Advanced accelerometer

Commercial and VIRGO accelerometers are available at present. VIRGO's one should have better sensitivity than the commercial one, and it works well down to 10 mHz, which is not realized by usual commercial accelerometers. The selection should be based on the sensitivity requirement and the budget for this project. The last item is not available yet, but is expected to be available in summer 2000 with better sensitivity and much wider band even more than the VIRGO accelerometer. For the future improvement, this factor must be considered.

Actuators

There are just two kinds of actuators. One is for DC positioning and the other is for AC controls.

The former should be realized by mechanical stepping motors moving springs attached to the top of SAS.

AC controls will be done with normal coil-magnet actuators.

Electronics

Since the nature of SAS control is MIMO (Multiple Input and Multiple Output), it is necessary to resolve the system to independent SISO (Single Input and Single Output) systems. This process needs flexibility of the logical filters for the controls, which is achieved by the digital system developed by VIRGO that is specified to this purpose. It should be used for this experiment too. The software for this system is also available from VIRGO. The electric units are produced by private companies under licenced from VIRGO.

4 Workforce

A name list of the manpower with a short description is the following:

TAMA SAS team

Seiji Kawamura (*Supervision of the entire project/Management*)

Kimio Tsubono (*Supervision of 3m experiment*)

Ryutaro Takahashi (*Coordination of the project*)

Mitsuhiro Fukushima (*Engineering*)

Gerhard Heintzel (*TBD*)

Akiteru Takamori (*Mechanics/ Simulations/ Controls*)

Kenji Numata (*Mechanics/Controls*)

Caltech SAS team

Riccardo DeSalvo (*Mechanics/Supervision of Caltech experiment*)

Virginio Sannibale (*Mechanics/ Simulations/ Controls*)

Szabolcs Marka (*Mechanics*)

Hiroaki Yamamoto (*Simulations*)

Other collaborators

Giancarlo Cella (*Simulations*)

Hareem Tariq (*TBD*)

Some additional people should be listed up for the collaboration.
From author: *Need any advise for this name list.*

5 Schedule

At present, only rough schedule is available.

- Evaluation of novel link-less GASF configuration will be done by the end of January 2000. (*Caltech team*)
- Design of the TAMA SAS prototype will be completed in about two weeks after end of the evaluation. (*Riccardo, Gennaro*)
- Fabrication of TAMA SAS prototype : 4-5 weeks
- Sensor assembly??
- Actuator assembly??
- Design of the control scheme (simulation of the control scheme for the TAMA SAS and the LIGO SAS) will be done by the end of February. (*Giancarlo, Virginio, Akiteru*)

- Design of the interface and the new configuration of TAMA suspension will be done by the end of February. (*Kenji, Akiteru(supervision)*)
- Experiment on the controls with LIGO SAS prototype will be performed from January to March?. (*Caltech team*, *Akiteru*, *Kenji*)
- TAMA SAS prototype will be fabricated from February till the end of March.
- Prototype of the interface/modified TAMA suspension??
- Electronics for TAMA SAS prototype/real model??
- TAMA SAS prototype test??
- 3m F-P operation??

January 2000	
February 2000	
March 2000	
April 2000	
May 2000	
June 2000	
July 2000	
August 2000	
September 2000	
October 2000	
November 2000	
December 2000	

6 Reference

Coming soon