Seismic Attenuation System (SAS) for Advanced Gravitational Wave Detectors

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Abstract

A Seismic Attenuation System (SAS) for advanced interferometric gravitational wave detectors is under development at Caltech. The SAS is a combination of low frequency passive mechanical isolators and an active inertial damping. It provides sufficient attenuation from few Hz for low frequency gravitational wave detection, and small residual r.m.s. motion of interferometer mirrors. The concepts of the SAS, the experimental results and simulations are presented in this article.

1. Introduction

The SAS is designed for advanced interferometirc gravitational detectors (ex. LIGOII) that need low frequency seismic attenuation and highly stable operation. The SAS can be understood as a modified VIRGO super attenuator. The first aim of the SAS is to provide starting from few Hz, seismic isolation sufficient to drive the seismic noise of the detectors well below the thermal noise. The second aim is to suppress the residual r.m.s. motion of the test masses for easy locking and reliable/stable operation of the detectors. To realize those goals, the SAS consists of cascaded low frequency mechanical attenuators and an inertial damping control system.

2. SAS Overview

Figure1. shows an example of the SAS which has been proposed for LIGO II. An inverted pendulum (IP) for horizontal isolation is fixed on a structure that is supported by two tubes connected to the ground via piers. The IP table hosts an ultra low frequency Geometric Anti-Spring Filter (GASF), which is called Filter Zero, for vertical isolation. The IP and the Filter Zero form a pre-isolator stage. Three GASFs are attached on the Filter Zero, for the isolation in all degrees of freedom. A test mass is supported by a suspension system below the last GASF.

Resonant frequencies of the pre-isolator would be tuned well below the micro-seismic peak to obtain effective r.m.s. displacement reduction in this low frequency range. This soft platform, also allows the use of low power actuators for controls.

Each IP leg stands on an elastic rod (flex joint), which acts as an angular spring. Stiffness of the IP is determined by the flex joints and the anti-spring effect that is provided by the gravity. Ultra low resonant frequency below 20 mHz has been already achieved by the IP prototype at Caltech.

The Filter Zero and the standard GASF utilize the GAS technique. The GAS is basically a cantilever blade spring which is connected to a payload by means of a flexible link (figure 2.). Due to its particular geometry of the blade, which gives the non-linearity, GAS can support heavy load (several hundred of kg) retaining resonant frequency lower than 100 mHz (depends on the configuration). The system has working range of the order of cm, which is several times larger than the earlier system with magnetic anti-springs [1]. Due to this wide range, the GAS achieves easy tuning and high reliability without any active controls. The Filter Zero would have resonant frequency of 100 mHz, while the standard filter few hundred mHz.

The materials and design of SAS elastic components are decided with respect to stress in each component. The stress that exceeds certain level causes plastic deformation and creep, which emits acoustic excess noise.

The GAS blades and the IP flex joints are made of hardened maraging steel. The stiffness of the maraging steel can be easily controlled by precipitation process.

The GAS blades are designed to have uniform stress distribution.

The entire SAS is formed by ultra high vacuum compatible materials.

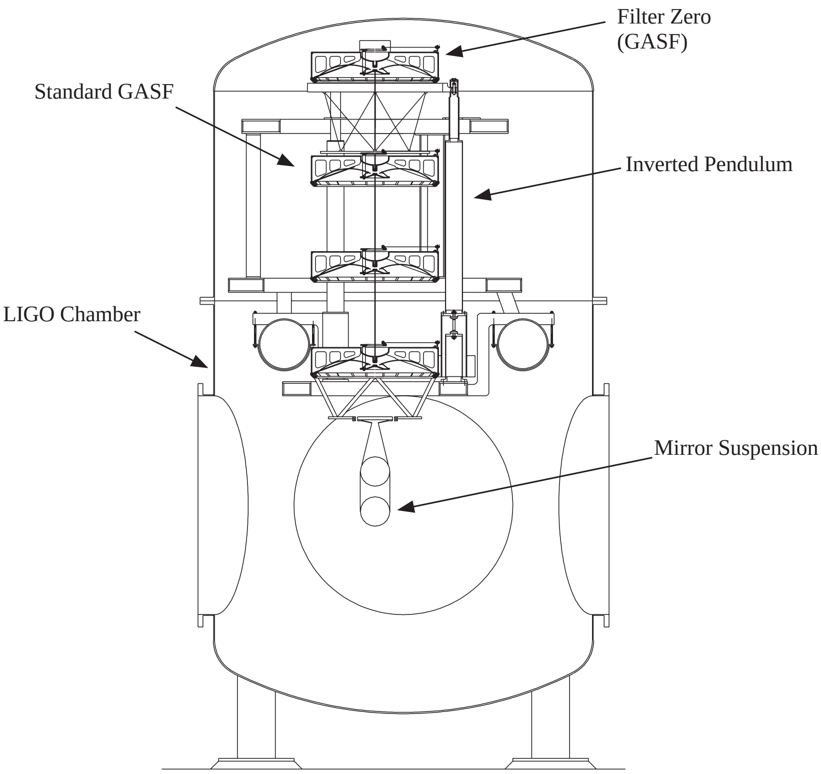

Fig. 1. SAS configuration for LIGO II

3. SAS Control

The SAS has to be actively controlled over a frequency band of up to few Hz in order to damp its own rigid body modes (inertial damping), to generate DC local and global positioning, and to reduce residual r.m.s. motion to acquire the locking of the interferometer.

The control system picks up the signals from local sensors (position sensors and accelerometers) and the interferometer. It generates feedback signals for various actuators on different levels of the SAS chain. The control system is

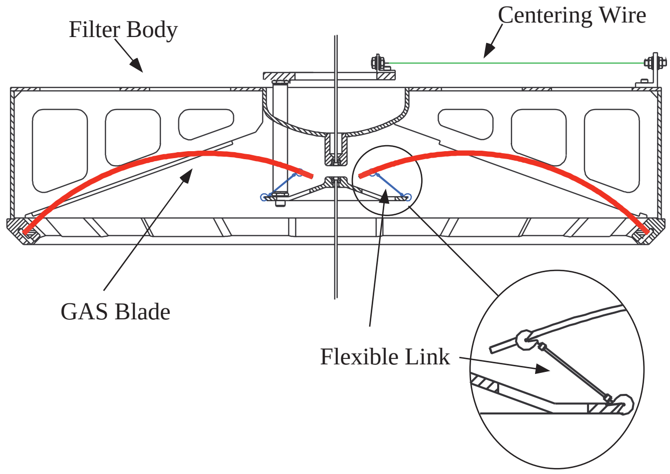

Fig. 2. Geometric Anti-Spring Filter (GASF)

organized in a hierarchical scheme (figure 3.). A large dynamic range is provided at the pre-isolator stages of the SAS. The inertial damping cools the internal modes of the system to minimize requirements for the suspension control.

The control system is a Multiple Input and Multiple Output (MIMO) that can be resolved to simple Single Input and Single Output (SISO) feedback systems by using a digital control system [2]. SAS controls are limited to a frequency band well below 10 Hz, to avoid noise injection in the gravitational wave band. Above this frequency, the SAS behaves as a completely passive seismic attenuator. According to simulated SAS performance based on measured seismic noise, achievable residual r.m.s. motion of SAS is a few tens of nm above 100 mHz. A similar system for VIRGO has already achieved 50 nm r.m.s. displacement [3].

4. GASF Experiment

Prototype SAS has been built at Caltech to investigate its isolation performance. The prototype contains an IP, a Filter Zero, and two standard GASFs.

Vertical isolation performance of cascaded standard GASFs are measured in a test tower. The Filter Zero is rigidly fixed on a safety structure, suspending two standard GASFs and a lead block payload (about 100 kg). Both standard GASFs are individually tuned to 450 mHz. The Filter Zero is used to excite the passive attenuation chain with a magnetic shaker. Vertical motion of each stage is detected by commercial accelerometers.

Figure 4. shows the result. The transfer function between the upper filter and the lower one is -43 dB around 20 Hz. Attenuation plateau comes from the

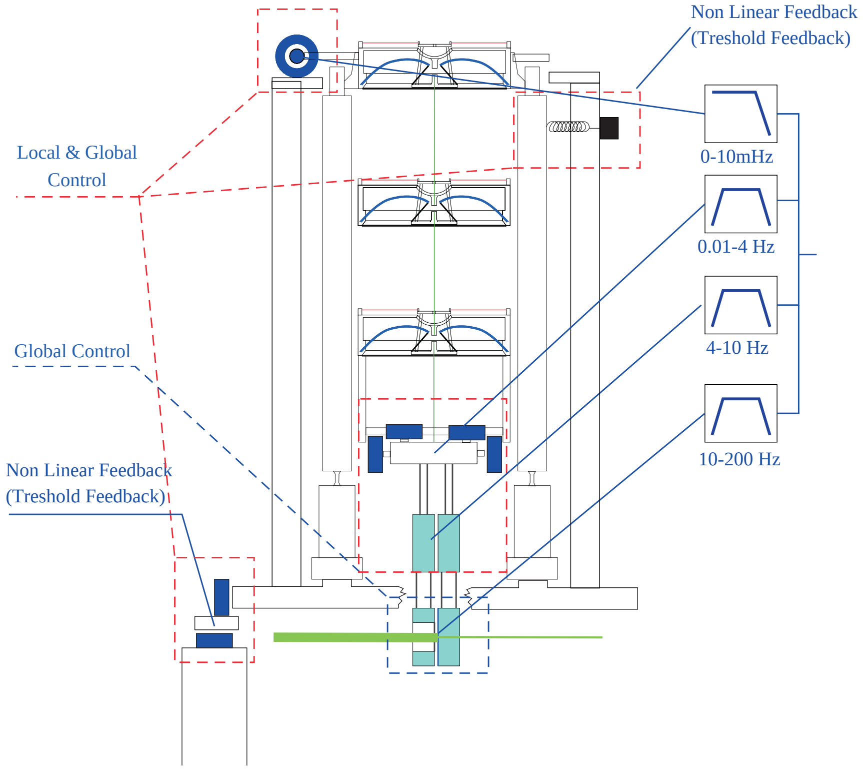

Fig. 3. SAS Control Scheme (example)

blades' mass and the first internal resonance of the GAS blades at 50 Hz. A peak at 90 Hz is an internal resonance of the wire between filters. These peaks would be damped by passive damper (under development). The transfer function of two attenuation stages (from the upper filter to the payload) reaches -80 dB at 5 Hz. Above this frequency, the measurement is limited by the sensitivity of the accelerometers except for the still undamped peaks.

5. Simulation

Finite element models are used for the design and analysis of the IP leg and GASF. It gives a good agreement with the measurements.

6. Summary/Perspectives

The SAS is designed to achieve low frequency isolation desirable for the next generation interferometric gravitational wave detectors. The SAS is basically a passive attenuation chain, with active controls limited for DC movement and modal damping. The vertical isolation would be achieved by unique GASF

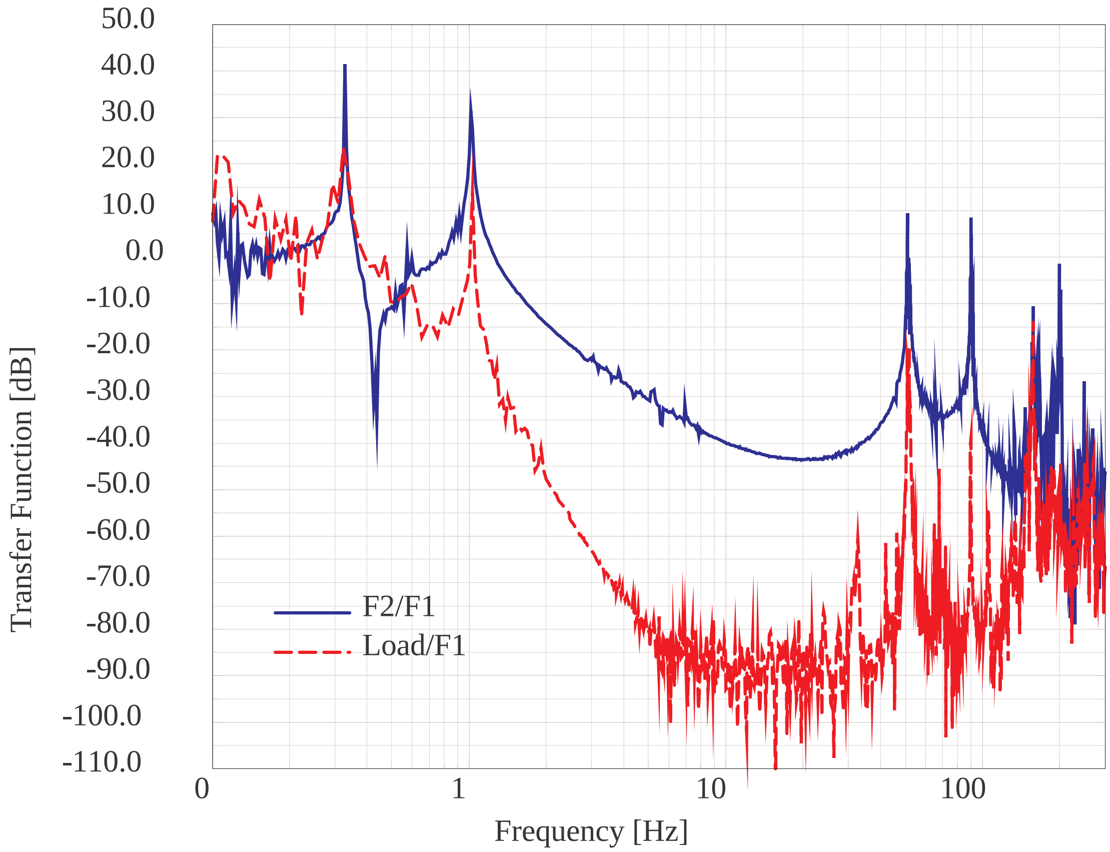

Fig. 4. Vertical Transfer Function of GASF Chain

mechanics, which showed sufficient filtering effect above a few Hz. To finalize the design of the system, the steps listed below are planned.

- Optimization of mechanical design
- Design and Implementation of the controls
- Performance investigation in a test interferometer

7. References

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8. Title of the Paper

Seismic Attenuation System for Advanced Gravitational Wave Detectors

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