The SAS primary Seismic Attenuation System for Advanced LIGO

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ABSTRACT

A passive (minimally active) Seismic Attenuation System (SAS) for primary seismic attenuation of the Advanced LIGO optical benches was designed, prototyped and tested in the LIGO HAM vacuum chambers at the LASTI laboratory.

The main design aim, beyond providing the required seismic attenuation using a single attenuation stage, is to guarantee reliability of operation. To do this passive attenuation was optimized, thus limiting the requirements from active attenuation feedback (mainly at low frequencies, below the Hz), and only passive sensor and actuators (without in-vacuum active components) were used. The low frequency flexures used to couple the rigid platforms of the system automatically provide nearly ideal decoupling for effective active control upgrades.

The SAS functions are divided in two parts. An intermediate platform supported by four inverted pendulum legs provides attenuation of the horizontal degrees of freedom. Four GAS filters integrated in this structure, called Spring Box, provide the isolation of the three vertical degrees of freedom. The geometry is such that the horizontal degrees of freedom and the vertical ones are separate and can be treated separately.
Each of the four GAS filter carries coaxially an LVDT position sensor and an electromagnetic actuator. Each leg of the inverted pendulums is similarly equipped. The redundancy is such that failure of one of the four LVDT or e.m. actuator cannot not cripple the system. Eight stepper motors driving parasitic springs, in parallel to the 8 e.m. actuators, provide the static positioning of the system. UHV compatible accelerometers were foreseen (but not built) to boost the system performance if necessary. An important feature is that horizontal inertial sensors mounted on the horizontal stage, upstream of the vertical one, would not suffer from tilt interference effects.

The tests at LASTI showed that the vertical and horizontal degrees of freedom are actually uncoupled and can be treated independently. It was possible to clearly identify the modes of the system and build a set of synthetic position sensors and a set of synthetic actuators, which diagonalize the transfer function of the system. We measured accurate physical plants responses for each degree of freedom and, based on these, designed specific control strategies. For the horizontal degrees of freedom we implemented simple control loops for control of the static position and the damping of the resonances. For the vertical ones, beyond these functions, the loops introduced an electromagnetic anti-spring effect and lowered the resonance frequency.

The overall result was the achievement of the HAM optical bench LIGO seismic attenuation requirements within the sensibility limits of the geophone sensors used to measure the performances. At the low frequency end, the system without LVDT position feedback showed a residual r.m.s. motion consistent with the motion of a mass on a frictionless table, subject to ground tilt noise. Feedback from a low-noise tilt meter could reduce this motion reducing the feedback from the low-pass-filtered LVDT position sensor signals.

The entire project, from the construction to the commissioning, occurred within a very tight time schedule which left scarce possibility to complete the expected mechanical setup. Some of the subsystems (among which the counterweights for the center of percussion of the pendulums and the ``magic wands'' for the GAS filters) could not be implemented and several operations of optimization (i.e. the lower tuning of the vertical GAS filters' resonant frequencies and the tilts' optimization) had no chance to be completed. Nonetheless the performances measured on the HAM-SAS prototype were in agreement with the simulations with the same configuration and the obtained results prove that, with completed mechanics, proper tuning and low frequency feed back, the system can provide the seismic attenuation required by any of the Advanced LIGO optical benches. This table, or scaled versions of, can be an useful test bench for accelerometers and seismometers.