New AURIGA Cryogenic Suspension System

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Abstract

The new cryogenic suspension system of the gravitational wave detector AURIGA is presented. This was designed to achieve at least -240 dB of vertical gain at $1kHz$ in a cryogenic environment preserving a high mechanical quality factor. We used FEM methods to fully simulate the design. We also show room temperature measurement of mechanical attenuation of a single stage and of the last stage of the suspension: comparison with expected results from the simulation is also given.

1. Introduction

After the AURIGA first run [1], it was realized that the sensitivity of this resonant detector was limited by read-out noise and by a number of unpredicted noises originating from both the cryogenic apparatus and the mechanical suspension system [3]. During the two years of data acquisition (1997-1999) the detector reached the best sensitivity of $S_{hh}^{1/2} \approx 4 \times 10^{-22} Hz^{-1/2}$ within a bandwidth of $\sim 2Hz$ around the resonant mode frequencies 911 and 929 Hz and a total duty cycle of $\sim 1/3$ of the total acquisition time. A new upgraded readout [2] with at least an order of magnitude of gain in sensitivity will be equipped in the second AURIGA run. To exploit the predicted sensitivity improvement, AURIGA will be equipped by a new cryogenic suspension system which can perform a suitable wideband mechanical attenuation.

2. Methods

The basic seismic isolation design concept consisted on borrowing a still tested spring-mass geometric shape used in a working Facility[4] for the AURIGA new readout system test, and then adapting its performance for the detector (see Fig. 1). We achieve the best arrangement between maximun admitted stress v.s.

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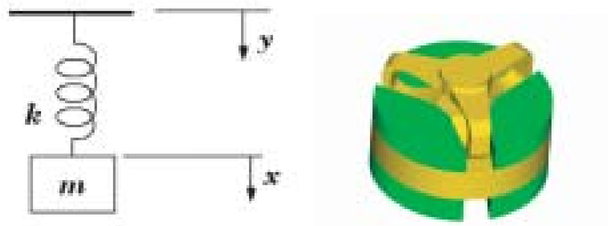

Fig. 1. Single lumped mass-spring B stage.

maximun mechanical attenuation, by carrying on some parametrized mechanical modal simulations.
We heavily used the Finite Element Modeling (FEM) program PRO/Mechanica, integrated with a CAD geometric builder (PRO/Engineer) to reach a target vertical attenuation of at least $-40dB$ per stage at $1kHz$. We succeed in keeping the working frequency band ($800Hz - 1200Hz$) free of mechanical resonancies.
A multistage cascade of six mass-spring oscillators made of an high quality factor material (alluminium 7075, already used on the facility [4]) form the main stack for the new AURIGA suspension system (see Fig. 2). The thermal constraint consists on keeping the antenna cilinder at $1K$ temperature while the geometric one consists on nesting the full suspension system + thermal shields inside the $4K$ toroidal vessel of the original cryostat. The antenna is supported on a conical surface of the suspension tube whose mechanical stress doesn't achieve 20% .

3. Solutions

The fundamental idea persued for design the new suspension system was to produce a spring-mass element (B Stage) modelled by the following vertical transfer function:

$$\frac{\tilde{x}}{\tilde{y}} = \frac{\omega_0^2}{\omega^2 - \omega_0^2} \tag{1}$$

where

$$\omega_0^2 = \frac{k}{m} \tag{2}$$

and k is the equivalent vertical stiffness of the material, m the effective lumped mass of one stage,$\tilde{x}$,$\tilde{y}$ are the displacement in the frequency domain. Each spring element provides an attenuation of $-40dB$ at $1kHz$, operating with a static internal stress less than 25% of the yield stress of the material at working temperature ($1.5K$). The main parts of the suspension system are the four columns (each made of 6 stages) suspended by an holder mass that works as first reference plane(Fig. 2). The holder mass is supported by a frame hanged through four beams to the $4K$ vessel.

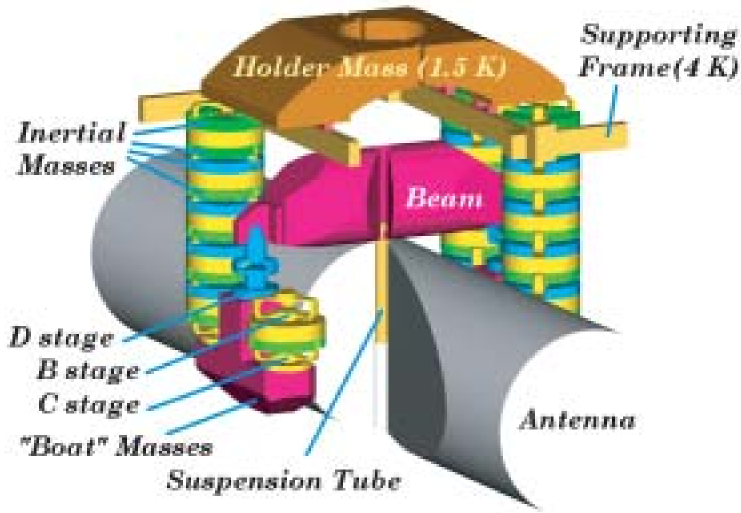

Fig. 2. New AURIGA Suspension System.

Table 1. Table of Materials.

Part	Material	Part	Material
Holder	2017 A T452	Inertial Masses	Brass G- Cu Sn10
Supp. Frame	Stainless Steel	Beam	Al 5056
B Stage	Alumold I-500	Susp. Tube	CuBe
C Stage	Alumold I-600	Antenna	Al 5056
D Stage	Alumold I-500 T651	"Boat" Masses	Al 5056

The lower part of the system consists of a support of two masses, connected by two compressive springs (D stage) to a big beam that hangs the suspension tube of the antenna. The suspension tube is hanged by the big beam through a bayonet coupling. All the materials had been selected thorugh the ones that perform the highest quality factor at cryogenic working temperature.

4. Results

We measured the resonancies of the main stage to check the predictions. In Tab.2, the measured ones have an error less than 5%, while the predicted ones, had been simulated with a maximun convergence of 5%. We reported in Fig. 3 the power spectral density of the first stage measured exiting vertically the holder mass.It is worthwhile to observe that no resonancies are found in the working band (800-1200 Hz).

Table 2. Comparing Frequencies.

Mode	Pred.Freq.Hz	Meas.Freq.Hz	Mode	Pred.Freq.Hz	Meas.Freq.Hz
1	38.4	38.8	5	86.5	86.9
2	38.6	40	6	86.6	87.7
3	74.6	74.2	7	1852	1815
4	86.1	82.5	8		

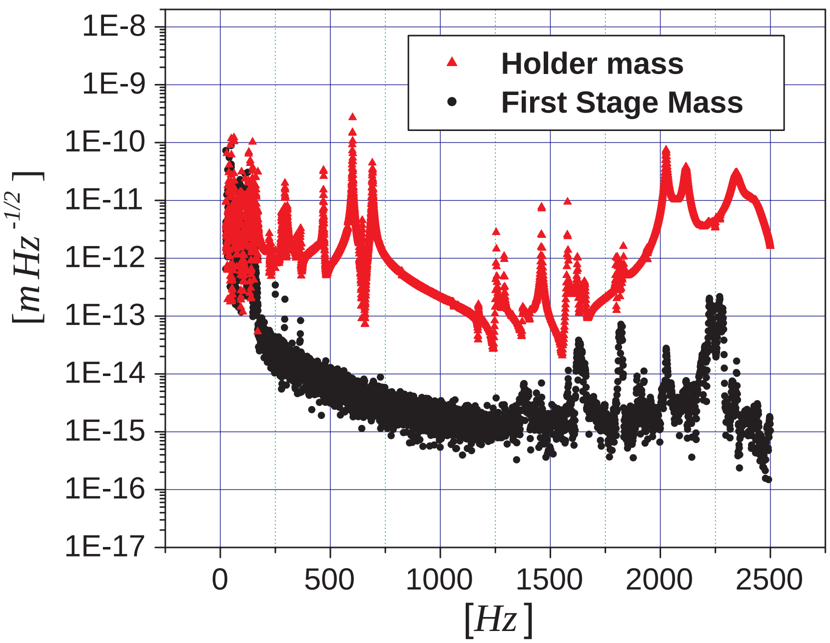

Fig. 3. First Measurements: vertical displacement spectrum

5. References

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