THE ULTRACRYOGENIC GRAVITATIONAL WAVE DETECTOR AURIGA

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We discuss the latest results of the AURIGA gravitational wave detector at the INFN National Laboratories of Legnaro, Italy. AURIGA is an ultracryogenic resonant bar detector, whose design is similar to the other INFN ultracryogenic detector NAUTILUS. The first cryogenic run of AURIGA is currently in progress. During these first months of operation we tested the performances of the cryogenics, of the mechanical suspensions and of the data acquisition system. The transducer output has been monitored through a room temperature port either to calibrate the detector or to measure the antenna noise. Here we present preliminary results on calibration and diagnostic of the antenna at liquid helium temperatures. In particular, the antenna noise performance has been thermal over a long time span at about 6K.

1 Introduction

AURIGA [1] is a resonant bar detector for gravitational waves, which has been set up at the Laboratori Nazionali di Legnaro of the Istituto Nazionale di Fisica Nucleare. The experimental activity on AURIGA started in 1990 and the first cryogenic run of the complete detector is currently in progress from May 1995. The first months of operation at liquid Helium temperature have been dedicated to test several components, to calibrate the detector and to check the antenna noise temperature. In the near future we plan to operate the antenna at $\sim 0.1K$; at that temperature the present configuration of the detector should allow a burst sensitivity of $h_{min} \sim 3\ 10^{-19}$ with a post detection bandwidth $\Delta\nu \sim 1Hz$. This performance is similar to that expected for the present configuration of NAUTILUS [2]. The perspectives for future improvements in sensitivity rely mainly on a lower noise d.c.SQUID amplifier, on a better coupling between transducer and SQUID by means of a tuned LC resonator and on an optimized transducer with higher mass and capacitance. In order to maximize the chances of detecting in coincidence, AURIGA is parallel to the other resonant antennae [3] NAUTILUS, ALLEGRO and EXPLORER and within a few degrees from NIOBE.

The general designs of the liquid Helium cryostat, of the mechanical suspensions and of the resonant displacement transducer are derived from the other INFN ultracryogenic antenna NAUTILUS [2]. The most important differences are in the set up of the internal mechanical suspensions, of the $^3He-^4He$ dilution refrigerator, of the ultracryogenic thermal links and of the signal amplification chain [1]. In each stage of the cryogenic suspensions the elastic rods have been equally tensioned, and the room temperature stacks of rubber disks has been loaded by additional lead masses. For what concerns the refrigerator, we implemented additional features in order to improve the availability of the detector, such as twin condenser lines, and to provide for vibration isolation, such as mechanically soft pipelines and thermal links. A cryogenic switch connects the signal leads from the transducer either directly to an external test port or to the internal d.c.SQUID amplification chain. Up to now the measurements have been made through the test port with room temperature electronics both for calibrating the detector and for monitoring the antenna noise. An external auxiliary dewar is also provided at the test port in order to house an alternative SQUID amplification chain outside the detector main cryostat.

2 Experimental results

The first cool down of the AURIGA detector to liquid helium temperatures took about 40 days, including about 10 days for testing at liquid nitrogen temperatures. About 10000 liters of liquid nitrogen and 3300 liters of liquid helium were needed. In the first 6 months of operation from June 1995, the antenna was cooled to $6-10\ K$ by exchange gas in the experimental chamber, with a tipical pressure of $2\ 10^{-5} mbar$. In the subsequent months the antenna has been cooled to $2\ K$ by pumping out the helium exchange gas and by operating the 1 K pot of the dilution refrigerator. The average liquid helium evaporation

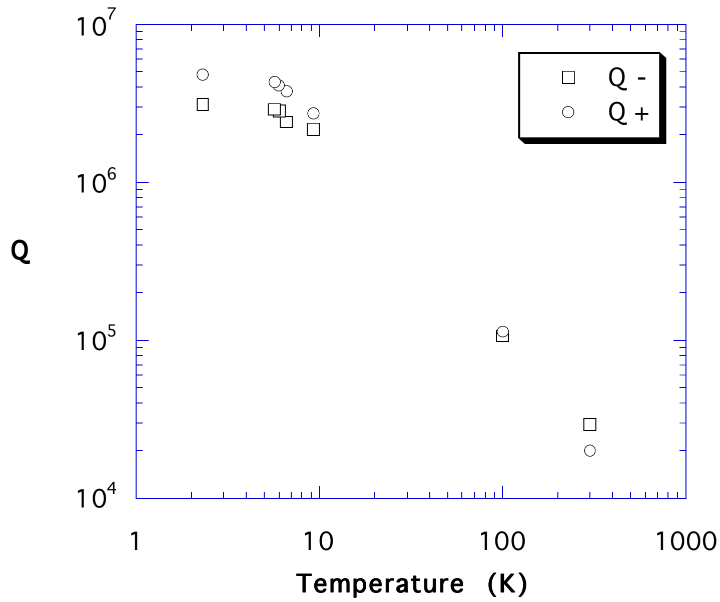

Figure 1: mechanical quality factors of mode - , $913 Hz$, and mode +, $931 Hz$, as a function of temperature.

rate was about 90 $liters/day$. The typical bias field of the transducer was $\sim 0.3 - 0.6\ MV/m$ and the electric charge showed a negligible leakage over 2 months. The quality factors of the antenna-transducer resonances at 2 K are 3 and 5 millions respectively for the 913 Hz and 931 Hz modes, see fig.1.

The vibration attenuation of the mechanical suspensions has been measured at both resonances of the detector by a monochromatic excitation applied to several positions on the building floor and on the external vacuum tank. We measured the acceleration of the external flanges, to which all the internal suspensions of the detector are hung, and we monitored the resulting oscillation amplitudes of the transducer output at steady state. The latter can be converted to the corresponding excitation at input of the antenna, since we calibrated by separate experiments the relationship between transducer output and thermal vibration of the antenna-transducer system. The resulting mechanical attenuation of the internal suspensions referred at antenna input is $\sim 245dB$, with an uncertainty of about $\pm 10dB$, including the repeatibility for different excitation positions and amplitudes. This performance should provide for sufficient vibration isolation of the present detector under normal ambient vibrational noise in the frequency bandwidth around resonances. Moreover, the overall attenuation is not far from the product of the attenuations of the single stages as measured at room temperature when the dilution refrigerator was not yet installed.

In all the measurements described the transducer output has been connected to the external test port. This allows an absolute calibration procedure for the noise of the detector. In fact, the two sharp and well separated mechanical resonances can be approximated by distinct oscillators close to each resonant frequency. From the test port, these oscillators can be modeled by two *parallel LCR* resonators, which can be fully determined by measuring the resonant frequencies $f_{0\pm}$, the quality factors $Q_\pm$ and the maxima of the real impedance at resonance $R_\pm = max\{Re[Z_\pm(f)]\}$. The Nyquist prediction of the thermal noise of each resonator gives a mean square value in potential of $\sigma^2_\pm \;=\; 4\ K_B\ T\ R_\pm\ /\tau_\pm$, where $\tau_\pm$ is the decay time of the amplitude, T the thermodynamic temperature and K_B the Boltzmann constant. Typical values for our detector are $\tau_\pm \sim 10^3 s$ and $R_\pm \sim 10^6 - 10^7\Omega$. In particular, since $R_\pm$ is proportional to $Q_\pm$ and to the square of the transducer bias field, we have chosen to operate with bias fields such that $R_\pm$ results in the region of lowest noise figure of the FET amplifier used to monitor the antenna noise.

The FET amplifier that we developed shows the following voltage and current bilateral noises : $V_n \sim 1.85\ nV/\sqrt{Hz}$ and $I_n \sim (0.8 \pm 0.4)\ fA/\sqrt{Hz}$. These correspond to a noise temperature $T_n \sim\ (0.10 \pm 0.05)\ K$ and to a noise resistance $R_n \sim\ (2.4 \pm 1.2)\ M\Omega$. While monitoring the antenna, the total noise in potential seen by the amplifier includes the additive contributions of V_n^2 and of $I_n^2\ \mid Z_\pm(f) \mid^2$, which are wideband and narrowband respectively. The input impedance of this amplifier does not affect the resonators since it was measured at about $1KHz$ to be $R_{in} = -12G\Omega$ in parallel with a $C_{in} \sim 30pF$; in particular, since $R_\pm \ll \mid R_{in} \mid$, the quality factor of the mechanical resonators are not affected by the presence of the FET amplifier.

The preamplified signal of the antenna is then demodulated at each resonance by means of lock-in with an averaging time $\tau_{li} = 100s$, close to optimum. The resulting mean square of a component of the lock-in output, σ^2_x, is determined from the record of the acquired data; in fact, $2\ \sigma^2_x$ is equal to the σ^2 of the distribution of the antenna mode energy, which is given by the sum of the squares of the two lock-in components. The data taking must be many hours long in order to get statistically significant results, because the energy correlation time is $\tau_{\pm}/2$.

Since the prediction for σ_x^2 is $\sigma_x^2 = 2K_B T_{\pm} R_{\pm}/(\tau_{\pm} + \tau_{li}) + \sigma_{ampli}^2$ where $\sigma_{ampli}^2 = V_n^2 + I_n^2 R_{\pm}/(\tau_{\pm} + \tau_{li})$, we can determine the noise temperature of each mode from measured parameters:

$$T_{\pm} \;=\; \frac{\tau_{\pm} + \tau_{li}}{2K_B R_{\pm}}\,(\sigma_x^2 - \sigma_{ampli}^2). \tag{1}$$

The typical contribution of the amplifier in our experimental conditions has been $\sim 0.5\ K$ from the wideband and $\sim 0.1\ K$ from the narrowband noises respectively. Over a 31 day span while the antenna was kept at a thermodynamic temperature of $(6.5 \pm 0.5)\ K$, we could take data for 12.8 days. The acquisition was not continuous mostly because of the calibration measurements and cryogenic maintenance. The measured data give mean antenna noise temperatures $T_+ \sim 9.8\ K$ and $T_- \sim 8.1\ K$ for the + and - modes respectively, with a root mean square deviation of the data $\sim \pm 3\ K$. Therefore, we can conclude that the antenna noise was quite close to a thermal behaviour. We notice, however, that the fluctuations of the measured noise temperatures $T_{\pm}$ around the mean are greater than the contribution due to calibration accuracy, usually accounting for $\sim 5\%$ of $T_{\pm}$. These data have also been filtered with a zero order prediction filter, taking energy innovation over a time span equal to τ_{li}: the results are average effective temperatures $\sim 3.4\ K$ and $\sim 2.7\ K$ for the + and - modes respectively, with a r.m.s. deviation of $\sim \pm 2\ K$. The hystograms made with the counts of the energy levels follow the expected Boltzmann distribution, apart from a few events per day.

While running the antenna in the subsequent months at $2K$ by operating the 1 K pot of the dilution refrigerator, the mean noise temperature of the antenna over 1.5 days reached about $3\ K$. By applying the zero order prediction filter to these data we found effective noise temperature of $\sim 0.9\ K$ and $\sim 0.7\ K$ for the + and - modes respectively. However, in the last months we had problems with plugs in the 1 K pot refill line which caused the detector to loose the cryogenic working point several times.

References

1. M.Cerdonio *et al.* in *Proc. of the 1th E. Amaldi International Meeting on g.w. Experiments* (World Scientific, Singapore, 1995), p. 176.
2. E.Coccia *et al.* in *Proc. of the 1th E. Amaldi International Meeting on g.w. Experiments* (World Scientific, Singapore, 1995), p. 161.
3. see elsewhere in these Proceedings.