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ANALYSIS OF NOISE SOURCES IN THE VIRGO SENSITIVITY

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Abstract. In this paper the analysis techniques used to identify the instrumental noises which limit the sensitivity of the interferometric gravitational waves detector Virgo are presented as well as the present noise budget.

1 Introduction

The Virgo detector is a kilometric laser interferometer which aims at the detection of gravitational waves. This experiment has started its commissioning phase on the second half of 2003. The main goal of commissioning activities is to reach the Virgo nominal sensitivity. To this purpose the instrumental noises which limit the present sensitivity have to be identified and then reduced. Noise analysis techniques are based on two complementary approaches: the analysis of interferometer data and simulation studies. In section 2 the analysis techniques using interferometer data will be presented as well as the noise budget of the C5 commissioning run. Section 3 will explain how the simulation of the interferometer can help the noise analysis. The perspectives will be dicussed in section 4.

2 Analysis of the Virgo sensitivity

A description of the Virgo interferometer (ITF) and of its commissioning can be found in Tournefier, E., these proceedings. The sensitivity obtained during the last commissioning run C5 (shown in Figure 1) is analysed in the following.

The general method for sensitivity analysis can be summarized in this way :

- The first step consists in identifying the source of the noise, by looking for some monitoring or control signals which are coherent with the ITF output port signal (used to reconstruct the sensitivity).
- Once the source is identified, the propagation mechanism of the noise into the output port has to be understood. An analytical model is developped.

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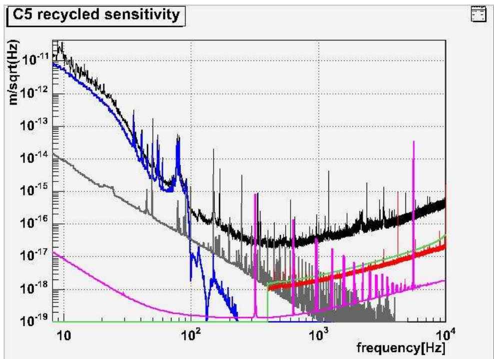

Fig. 1. C5 recycled sensitivity in meters (top) compared to several noise estimations: Beam splitter longitudinal control noise (just below the C5 sensitivity from 10 to 100 Hz), actuator noise (about one order of magnitude below the C5 sensitivity from 100 to 300 Hz), shot noise (more than one order of magnitude below the C5 sensitivity from 500 Hz to 10 kHz) and electronic noise (just below the shot noise). The bottom curve is the Virgo nominal sensitivity. The y axis unit ($m/\sqrt{Hz}$) can be converted into the traditional h/$\sqrt{Hz}$ dividing it by the arm length (3000 m).

- The analytical model gives a noise projection that can be directly compared to the sensitivity curve. If these are in agreement it shows that the propagation mechanism of the noise is well understood, the analysis is validated. Another way to project the noise contribution into the sensitivity consists in measuring the transfer function between the hypothetical source and the ITF output port. This measurement is performed by injecting artificial noise at the source point in order to get a high level of coherence.
- When the noise is identified the sensitivity can be improved by acting directly at the source level or by preventing the noise propagation into the ITF output port.

2.1 *Control noises*

The low frequency part of the sensitivity curve (10-100 Hz) is usually limited by longitudinal and angular control noise of the mirrors. This control noise may have its origin in the sensor itself (readout noise): In this case the noise is propagated by the control loop, as it will be shown in section 2.1.1. Control noise can also refer to the electronic noise of the actuation chain of the mirrors. This will be considered in section 2.1.2.

2.1.1 Beam Splitter longitudinal control noise

In C5 data some coherence was found up to 100 Hz between the output port and the correction signal sent to the beam splitter (BS) mirror to control its longitudinal position. This means some noise enters the ITF by propagating through the BS control loop. The BS motion is equivalent to a length difference of the two arms and is therefore seen at the output port. The analytical model which gives the noise contribution in the sensitivity in meters (δl) can be written as :

$$\delta l \;=\; BSzCorr \;\times\; TF_{act} \;\times \sqrt{2} \;\times\; \frac{1}{n_{FP}} \tag{2.1}$$

where BSzCorr (the input noise) refers to the BS correction signal spectrum, TF_{act} is for the transfer function of the mirror actuators, $\sqrt{2}$ is a geometrical factor and $n_{FP} = 30$ is for the number of round trips made by the laser beam in the resonant Fabry Perot cavity.

The BS longitudinal control noise is compared to the C5 sensitivity in Figure 1. Several peaks between 30 and 100 Hz can be explained by this model. Improvements in sensitivity have been obtained since then by upgrading the control loop. Between 10 and 100 Hz, the C5 sensitivity is also limited by other control noises such as the BS angular control noise.

2.1.2 Actuator noise

Actuator noise refers to the electronic noise generated by the digital analogic convertors of the mirror actuation chain. It produces a mirror displacement which affects the sensitivity. In Figure 1 the estimation of actuator noise for the C5 run is presented. It has been dicovered since then that non linearities appear when the corrections are sent to the actuators. Therefore this estimation gives only a lower limit so that it cannot be excluded that the actuator noise limits the sensitivity. This noise has been reduced since C5 run by improving the actuator electronics. Other upgrades are foreseen in order to reach the Virgo nominal sensitivity.

2.2 High frequency noise

The contributions of the electronic noise and the shot noise of the ITF output port are presented in Figure 1. The noise limiting the high frequency part of the sensitivity (above 500 Hz) is a factor 20 higher than electronic noise. It has been understood by observing a correlation between the noise level and the amount of signal reaching the photodiode as well as the alignment quality of the ITF. This noise has then been reduced by improving the mirror angular control.

3 Noise analysis with simulation

3.1 Simulation goals

Simulation can be used to confirm the analytical models built to propagate the noises from their sources to the ITF sensitivity. The coupling between the different degrees of freedom of the ITF as well as the control loop effects can lead to complex propagation mechanisms, so that a simple analytical model cannot easily be found. Simulation studies are especially relevant in this case.

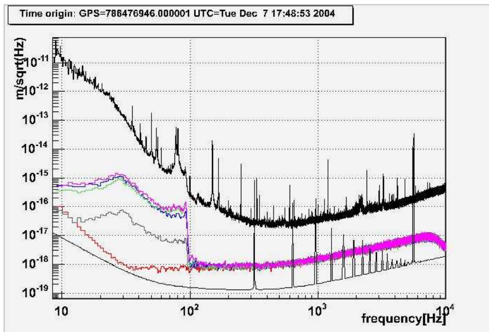

Fig. 2. The C5 sensitivity (top) compared to a simulation of the photodiodes electronic noise introduced by the longitudinal control loops and to the output port electronic noise (the 5 curves below the sensitivity, obtained with 0.7 W). The Virgo nominal sensitivity is also included (bottom curve, 10 W).

3.2 An example of simulation study

The recycled ITF is simulated using SIESTA, a time domain simulation developped by the collaboration (Caron et al. 1999). The mirror properties are described as well as the photodiode electronics. The control loops, the mirror actuators and the suspensions are also included. The simulation has been used to analyse the impact of the longitudinal control loops regarding the introduction into the ITF of the photodiode electronic noises (these photodiodes provide the error signal of the controls). Between 10 and 100 Hz, all the photodiode electronic noises propagate into the ITF output port through the beam splitter longitudinal control loop, which explains the excess of noise seen on the sensitivity curve. Improvements can be achieved by upgrading the control loops.

4 Conclusion and perspectives

The C5 sensitivity was limited by control noises at low frequencies and by a readout noise which couples to the output port through mirror misalignments at high frequencies. Since then the sensitivity has been further improved mainly thanks to the control loop upgrades. An additional tool for the noise analysis is simulation, which permits to anticipate the noises which are going to limit the sensitivity in order to start to prepare solutions. Improvements should be reached after the implementation of the global angular control and after the increase of the laser power to its nominal value.

References

Caron, B., et al., 1999, Astropart. Phys., 10/4, 369-386

Tournefier, E., these proceedings