THE CALVA FACILITY FOR GW DETECTOR

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The CALVA facility is a suspended optical system installed in Orsay and designed to test new approaches for cavity control or for optical systems using long cavities[1]. The optical scheme is composed by 3 mirrors (2 coupled cavities) which allow to have on the same axis a 50m long cavity and a 5m "recycling" one. The first goal of this facility is to test a technic based on auxiliary lasers to help the lock acquisition of the Advanced Virgo kilometric gravitational wave detector. With the increase of the cavity finesse in the long cavities and the new signal-recycling mirror, such a technic will ease the transition between mirrors being free to a full resonant device.

1 Aim of the CALVA facility

With the upgrade of the gravitational waves detectors Virgo[2,3] (Advanced Virgo (AdV)) and LIGO[4] (Advanced LIGO (AdL)), new difficulties are expected to raise and interfere with the experiment. In particular, two specific points are intended to be studied with the CALVA facility:

- The addition of a fifth cavity with the introduction of the signal recycling mirror will imply the re-coupling of all degrees of freedom error signals. The extraction of each error signal will become more difficult.
- The increase of the finesse ($\mathscr{F}$) of the Fabry-Perot (FP) cavities (length L) from 150 up to 450 in AdV will reduce the critical velocity from 4μm/s down to 0.4μm/s ($v_{cr} = {}^{\pi c \lambda}/_{4L\mathscr{F}^2}$: speed of the resonance crossing above which fields will not have time to build up). This will induce a degradation of the error signal due to the ringing effect[5].

New locking technics need to be studied in order to solve these concerns and the use of an auxiliary laser to lock the two FP cavities independently is the first scheme we want to test on CALVA. First attempts have already been made on AdL[6], achieving a the lock of the cavities, and we plan to use similar technics in AdV. Other independent studies like thermal deformable mirrors[7], frequency dependent squeezing and parametric instabilities are intended to be performed.

2 Description of CALVA

2.1 Configuration

In order to meet the challenge and mimic the Advanced Virgo configuration, CALVA is composed of two suspended coupled FP cavities of 5m and 50m (cf. figure 1). The three suspended mirrors are inserted in three vacuum tanks linked by two vacuum pipes. The suspensions are 40cm long leading to a pendulum resonance at 0.8Hz.

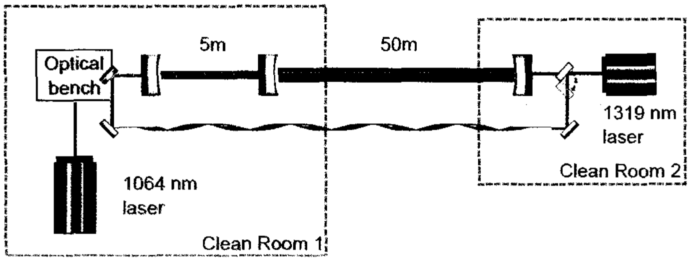


Figure 1: Scheme of CALVA

2.2 Optical systems

CALVA uses three different optical systems:

- The first system is composed of optical levers (red diode/laser with two quadrant photo-diodes) to determine the angular and longitudinal motions of each mirror in the reference of the vacuum tank. It is used in the local control system as the first step for slowing down the mirrors.

- The main system is composed of two lasers and the two FP cavities : the main laser is a Nd-YAG laser at 1064nm with 1W power located in the clean room 1 at one side of the experiment. The auxiliary laser is at 1319nm with 100mW power and is located in the clean room 2 at the other side. The 5m cavity is intended to have a finesse of 15 while the 50m cavity is intended to have a finesse of 620 for the 1064nm laser (it is around 3 for the 1319nm).

- The last system, named reference cavity, is a small triangular silicium monolithic cavity of finesse 50 for the frequency stabilization of the 1064nm laser.

2.3 Control loops

For each optical system, there is a corresponding control loop based on the following architecture which reused as much as possible all the hardware and the software from the Virgo experiment[3]:

- For the optical levers, the error signals (the pitch θ_x, the yaw θ_y and the longitudinal motion z) are generated with two quadrant photo-diodes per mirror and sent to an ADC. These signals are then treated by the Global Control software[8] on a real time PC to be transformed into correction signals with an appropriate filtering. Finally they are sent through a DAC to an actuation system composed of four coil-magnet pairs on the back side of each mirror to act on their position.

- For the optical cavities, we use the Pound-Drever-Hall (PDH) technic[9] to control the cavity or the laser. The error signals are generated by a modulation with an EOM at 2.9MHz for the long cavities and at 80MHz for the reference cavity on the 1064nm laser, and at 4.25MHz for the 1319nm laser. They are obtained by the demodulation - using a home made analog system - of the photo-diode signal in reflection of the cavities and then are sent to an ADC before being filtered with the Global Control. The correction signals are sent either to the mirrors to correct the cavity length or to the piezo actuator and/or the temperature of the laser to adjust the laser frequency.

3 Present situation and results

In order to characterize the limiting factor of the length control accuracy of the 50m cavity, the actual configuration of the experiment is composed of the 5m cavity equipped with the mirrors of the 50m cavity which is not currently used. The expected finesse is then 620 for the 1064nm laser. We also use the auxiliary laser thanks to a fiber that brings the 1319nm laser from clean room 2 into clean room 1 (cf. figure 1).

3.1 Lock acquisition

The first step of the lock is the control of the mirror angular and longitudinal motions with the local controls : they reduce the motion rms by a factor 10 (cf. figure 2). Then the cavity is locked with the 1319nm laser which still reduces the cavity length variations. We search for 1064nm resonances by applying a triangular signal on the 1319nm frequency which leads to a length variation of the cavity. When the 1064nm laser crosses a resonance of the cavity, the final step of the lock can be engaged.

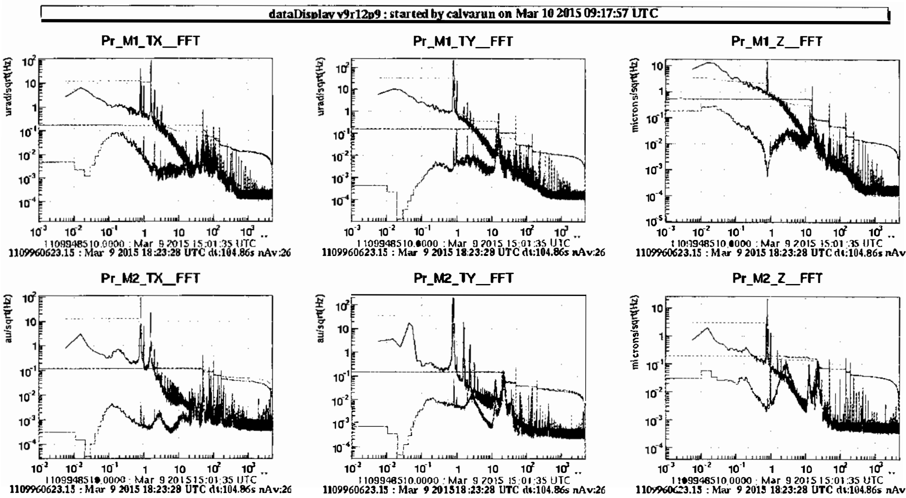
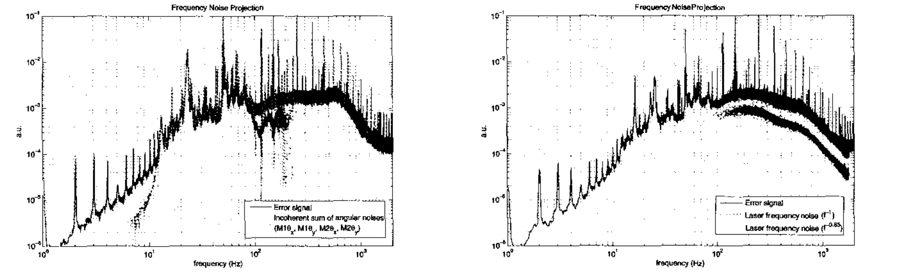


Figure 2: Mirror stabilization by local controls for the 3 dofs, both spectrum and integrated rms are shown when the mirrors are free (black) and under local controls (violet)

3.2 Residual noise on the error signal

The analysis of the error signal while locked tells us what is limiting the length control accuracy. Three main sources of noise have been identified:

- The angular control of the cavity contaminates the length control through the coupling of the degrees of freedom. The contribution of this noise has been evaluated and projected on the error signal (cf. figure 3a). It is the main noise source in the 10-100Hz band.
- The frequency noise of the laser has been evaluated with the usual model in f^{-1} and the calibration of 10kHz @ 1Hz given by the manufacturer. A better projection is with a noise in $f^{-0.85}$ (cf. figure 3b). This noise is the main limitation of the error signal accuracy above 100Hz.
- The DAC noise is known to be the main limitation of the error signal accuracy below 10Hz and shows 1Hz and harmonics peaks



(a) Angular noises projection with the incoherent sum of the 2 angular contributions of each mirror

(b) Laser frequency noise projection for 2 different noise shapes f^{-1} in violet and and $f^{-0.85}$ in blue

Figure 3: Different noise projections

3.3 Optical characterization

The finesse of the cavity has been estimated by fitting the resonance peak with the Airy function and by measuring the FWHM of the resonance peak. Both methods give coherent results and lead to a finesse $\mathscr{F} = 347 \pm 15$. The difference with the expected value can be explained by a low roughness ($\lambda/10$ instead of the usual $\lambda/20$) and a probable contamination of the mirrors during the installation in the 5m cavity.

4 Present work

As it has been shown previously (cf. 3.2), the frequency noise is the main contribution to residual noise on the error signal. It has been shown by simulation that the lock of the 50m would be impossible with such a high frequency noise. In order to reduce it, the reference cavity has been implemented to control the 1064nm laser frequency. This loop is now operating and we will evaluate the impact of the reference cavity on the accuracy of the control signal.

Acknowledgments

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