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Lock acquisition of the resonant cavities for the Advanced Virgo experiment

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Summary. — The Advanced Virgo (F. Acernese, *Class. Quantum Grav.*, **32** (2015) 2) experiment will join in 2016 the international network of interferometric detectors, after the (currently ongoing) upgrade and commissioning of the detector. One critical point of the commissioning of the experiment is the development of a lock acquisition strategy for the arm cavities, *i.e.* the procedure which brings the cavities into their resonant condition, which is a requirement for the correct operation of the apparatus. In this short communication I will present a brief introduction to the problem of locking a cavity, with the purpose of describing a set of time-domain simulations for the arm cavities of Advanced Virgo, prerequisite to the definition of a locking strategy which will be used during the forthcoming commissioning of the detector.

1. – Interferometric detection of gravitational waves

In the linear approximation of Einstein's equations, gravitational waves arise as plane waves with a suitable gauge choice:

$$\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right) h_{\mu\nu} = 0, \tag{1}$$

where $|h_{\mu\nu}|$ is the gravitational wave's amplitude. Such amplitude is a very faint signal to be detected: for a benchmark binary system of two neutron stars, located in the Virgo cluster ($r \approx 10$ Mpc), such amplitude is $h \approx 1 \times 10^{-21}$. As these waves travel as ripples of the space-time metric, their effect is to locally change the macroscopic distance between objects, such as $\Delta L = \frac{1}{2}hL$.

The technique which is most promising for such a detection is laser interferometry: it is possible to measure ΔL by means of measuring a phase difference between the two laser beams travelling along different arms of an interferometer.

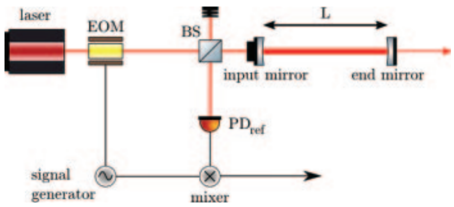

Fig. 1. – Fabry-Pérot arm cavity [1].

2. – Resonant cavities and *locking*

The main difficulty of the technique is that the interferometer, and in particular the Fabry-Pérot arm cavities, must be brought and kept in their *resonant condition*, in order to have coherent light stored in the machine and an effective phase-to-length transduction. With "resonant condition" it is intended that the length of the cavity must be an integer number of laser wavelengths, and that allows the light to build up *in phase* inside the cavity. Bringing a cavity into this condition is a process called *locking*. A Pound-Drever-Hall locking scheme [2,3] has been used, by which an electro-optical modulation is applied to the laser field, in order to extract an error signal which is used in a feedback control loop that keeps the length between the two mirrors properly controlled (fig. 1).

3. – Time-domain locking simulations

A set of time-domain simulations of the North Arm cavity of Advanced Virgo have been developed; the configuration of the detection, mechanical, actuation and optical systems of the real detector have been taken into account, including shot, electronic and seismic noises. Both error signals in *reflection* and *transmission* have been simulated, foreseeing the different configurations that will be used during the commissioning of the detector. A state machine feedback controller has been developed: it uses the error signal to estimate the relative velocity of the two mirrors; then, a single extended impulse slows down the cavity, and finally a linear filter is engaged and the lock is acquired (fig. 2). This is an implementation of the *Guided Lock* technique [4]. These simulations have successfully proved that this is a viable strategy to lock the arm cavities of the forthcoming Advanced Virgo experiment.

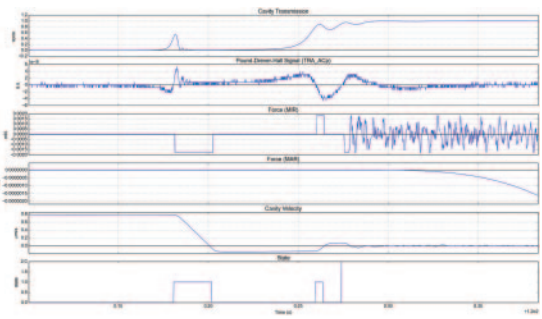

Fig. 2. – Lock simulation of an arm cavity.

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