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# Status of Virgo

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**Abstract.** The gravitational wave detector Virgo commissioning started in autumn 2003. The main commissioning goal is to reach stable operation at the design sensitivity, significantly extended to the low frequency range starting from 10 Hz. However, the Collaboration's efforts during the last commissioning phase will also be aimed at the data exchange with other detectors operating with comparable sensitivity. The present status of the detector and the short term planning are outlined in this paper.

## 1. Introduction

All the currently running detectors have similar features. Typically, their detection bandwidth is limited by two intrinsic noise sources over a bandwidth from about 100 Hz up to few kHz: thermal noise of the test masses (mirror and suspension) and read-out shot noise. The Virgo detector is aimed to reach the intrinsic noise limit over a larger bandwidth. At 10 Hz the seismic noise, namely the major external disturbance, is at least $10^{12}$ times larger than any expected signal. Thus, a sophisticated suspension system to hung each interferometer test-mass was designed in order reduce the seismic noise at the predicted level of thermal noise [1, 2]. The target sensitivity of Virgo [3] is confined at 4 Hz by the intersection of the Newtonian noise, at the Earth's surface, and the attenuated seismic noise. This allows the detection of signals due to metric tensor perturbation $h \simeq 10^{-21}$ Hz$^{-0.5}$ at 10 Hz and $3 \cdot 10^{-23}$ Hz$^{-0.5}$ at 500 Hz. From the about 500 Hz up to 6 kHz the shot noise, drives the sensitivity slope.

It naturally arises that the three main items of the detector design were focused on a) seismic isolation; b) reduction mechanical dissipation at the level suspended test mass coordinate; and c) the technical noise in optical transduction (electrical, power, frequency) [4, 5]. As the design was implemented and the detection commissioning started, activating step-by-step its partitions, a fourth item, related to control noise re-injection in the detection bandwidth, became, as expected, more and more critical. In parallel to the latter item, concerning the achievement of the target sensitivity, improvements of operation stability and automation algorithms were successfully developed.

## 2. Virgo commissioning

Setting-up the operation of an edge-of-technology detector is necessarily a partitioned activity. Once demonstrated the feasibility of an interferometer whose optical elements are suspended through the Virgo standard suspension under digital electromechanical control [6], the commissioning started (Sept. 2003). Each partition of the interferometer was "commissioned" when all the main servo-loops involved in its operation were successfully activated at the level required to integrate it into a larger partition. The overall commissioning was scheduled in three blocks: I) full operation of the interferometer with preliminary sensitivity; II) shutdown grouping hardware improvements and restart; and III) full operation of the interferometer and noise hunting. Then the installation of Faraday isolator in the injection system, in order to stop the the back-scattering from the interferometer into the mode cleaner, was postponed. Hence the first part of the commissioning was completed injecting into the interferometer 700 mW, 1/30 of the laser output. In such a way all the main servo-loops to operate the interferometer (at regime $\sim$ 150) have been tested and remarkable stability reached without investing major hardware-related efforts in noise hunting. The interferometer restart for the third commissioning phase is foreseen by the end of 2005.

Once the injection system is in operation, the variable-finesse strategy [7] for interferometer's lock acquisition, managed by the Virgo Global Control [8], is activated. The process is scheduled through an automated dealing with the control of the four coordinates along the beam axis of a Michelson interferometer with Fabry-Perot cavity arms and power recycling (Fig 1). To

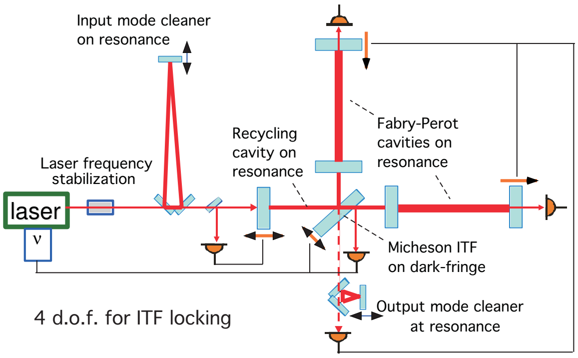


**Figure 1.** Scheme of the main servo-loops involved in locking operation. The laser frequency stabilization is performed in two stages: first through a reference cavity an then through the common arm mode (sketched).

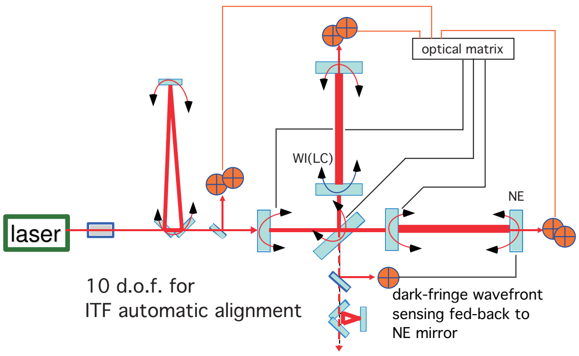


**Figure 2.** Automatic alignment during last commissioning run (C7). West Input mirror (WI) is under local control. Both pitch and yaw are controlled for each mirror.

perform this task the relative speeds of the mirrors have to be reduced to $v \leq 0.5\mu m/s$. This is done by combining the performance of Virgo Seismic Isolation and Local Control [9] systems in order to shield the mirrors from external disturbance and to prevent excitation of the last stage suspension modes during operation transients. Once the lock is achieved the automatic alignment regime is activated. This uses a measured optical matrix that expresses the relation between the misalignment normal coordinates of the interferometer and the wave-front sensing provided by the Anderson-Giordano technique [10, 11]. Finally, most of the local control servo-loops, acting through ground-based devices close to the mirror suspension, are opened (Fig 2). The goals of the first commissioning part are shown in Tab 1. A remarkable performance improvement was performed between the last two steps shown in Tab. 1. In order to measure the optical matrix and to implement the automatic alignment of the recycled interferometer it was needed to improve the stabilization of the power stored into the recycling cavity. Expectedly, this goal was attained compensating the cavities misalignments by feeding-back dark-fringe wavefront sensing to one mirror (Fig 1,3). The other automatic alignment servo-loops, using signals at transmission and reflection ports of the interferometer, are used to remove the further misalignments of the mirrors versus the beam due to local control drifts ($1 - 2\mu$m/h). The control bandwidth of Virgo angular controls, automatic for 10 d.o.f. and local for 2 d.o.f., is 3 Hz at the end of the first commissioning phase.

**Table 1.** B=beam, BS=B.splitter and PR=power rec., N(W)I(E)=N(W) Input(End) mirrors.

| ITF partition | time | aligned mirrors | ctrl mode: bold=Auto,plain=Local |
|---|---|---|---|
| North Cavity | Oct. 2003 | BS,NI,NE | B,PR,BS,WI,WE **NI,NE** |
| West Cavity | Nov. 2003 | BS,WI,WE | B,PR,BS,NI,NE **WI,WE** |
| Recombined ITF | Feb. 2004 | BS,NI,NE,WI,WE | B,PR,BS **NI,NE,WI,WE** |
| Recycling ITF | Oct. 2004 | PR,BS,NI,NE,WI,WE | B,BS,NI,NE,WI,WE |
| Recycling ITF | Jul. 2005 | PR,BS,NI,NE,WI,WE | B,WI **PR,NI,NE,WI,WE** |

In Fig 4 the progression of Virgo strain sensitivity in terms of linear spectral density $h(f)$ is reported. Each curve was obtained through a dedicated calibration of the interferometer response. The standard length of commissioning runs was 4-5-days. Run C6, focused on stability performance, was 15-day-long.

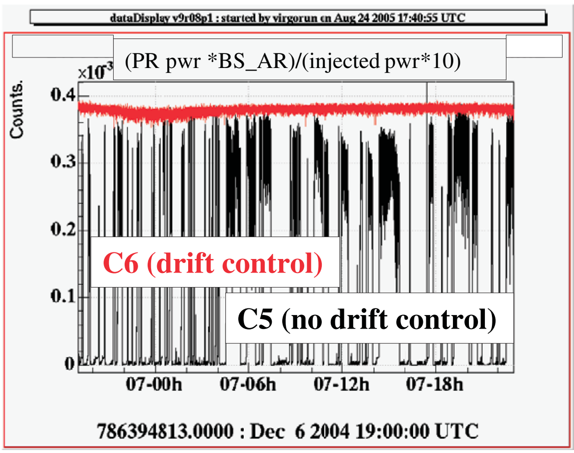


**Figure 3.** Pick-up of recycling cavity power normalized to the injection: improvement between Dec 2004 and Jul 2005.

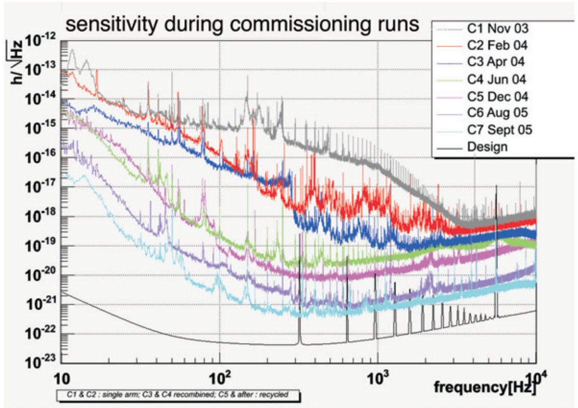


**Figure 4.** Commissioning runs; before the shutdown phase (C7) the sensitivity was limited by longitudinal control noise up to 500 Hz and by frequency noise from 500 Hz.

## 3. Conclusions

The first part of the Virgo commissioning has been successfully completed. Major improvements are being implemented. They are designed to restart the interferometer with full injection power and using a new local oscillator to reduce the phase noise, in order to reach the target sensitivity at $f > 500$ Hz. The improved mechanics of the suspended injection bench will improve the sensitivity at low frequency, where, also, a smarter control design strategy is needed to reduce technical noise re-injection.

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