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# VIRGO Collaboration

# Mirror Suspension Control Commissioning Progress Report

*Commissioning Report MSC-402*
*SA TF Measurement*

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## *Table Of Contents*

# 1. INTRODUCTION

## 1.1 *Purpose*

This document was written as report about last six months activities related to the Mirror Suspension Control group. Chapter 2 is supposed to become part of the November 2009 "Commissioning progress report for the STAC" by the Virgo Collaboration, edited by Commissioning coordinator on behalf the Virgo Collaboration.

## 1.2 *Scope*

In the last months we performed several measurements of the transfer functions of Superattenuator filters chain injecting sinusoidal excitations to the top stage (both in vertical and horizontal) with the interferometer close to its best sensitivity. This document shortly reports measurement results presented in a devoted paper submitted recently to the Virgo Editorial Board (VEB) by Stefano Braccini [RD1]. All the content of chapter 2 was extracted (and adapted) from the paper by Stefano. Measurements were taken with the support of Paolo Ruggi.

## 1.3 *Acronyms*

This document contains several abbreviations and acronyms to refer concisely to an item after it has been introduced. The following list is aimed to help the reader in recalling the extended meaning of each short expression.

| | |
|---|---|
| MSC | Mirror Suspension Control |
| SA | Super-Attenuator |
| VEB | Virgo Editorial Board |

## 1.4 *References*

[RD1] S.Braccini et al, *"Superattenuator Seismic Isolation Measurements by VIRGO interferometer: a comparison with the future generation antenna requirements"* to be submitted to Astrop.Phys. Available at <https://www.ego-gw.it/editorialboard/publications/192.pdf>,

# 2. MEASUREMENTS REPORT

## 2.1 *Measurement of the Superattenuator Transfer Functions*

The residual mirror displacement at the mirror level is extremely small even if strong excitations are applied to the Superattenuator (SA) top stage. This makes a direct measurement of the SA total transfer function impossible with usual instrumentation.

In the past we made an experimental evaluation of the SA attenuation on a prototype by mechanically exciting one by one all the SA filters. Combining at the end measurements we were able to provide an estimate of the total attenuation which turned out to be in excellent agreement with the Lagrangian simulation.

An attempt to measure the attenuation of the SA filter chain was also made a few years ago with the Virgo Central Interferometer and the 4.1 Hz excitation peak was not distinguished at the mirror level from the interferometer noise floor (about 2 x 10^-12 m/SQRT(Hz)). An upper limit of vibration transfer function of a few 10^-8 was set in this way at 4.1 Hz.

In the last months the VIRGO interferometer approached the low frequency design sensitivity. Thus the mirror residual displacement can be now monitored with a much better accuracy

## 2.2 *Attenuation Measurement in VIRGO interferometer*

In the last months several measurements of filter chain transfer functions were performed by injecting sinusoidal excitations to the top stage (both in vertical and horizontal) in the Hz and tens of Hz range with the interferometer close to its best sensitivity. Each measurement requires the interferometer locked for several hours with an excellent sensitivity. Even if the measurement can be made in parallel on the four cavity Superattenuators, the entire set of measurements required a long commissioning time. It is important to stress that we are measuring only the filter chain transfer function and that an additional attenuation is provided by Inverted Pendulum (Z and X) and Filter Zero (Y).

The result of a typical measurement is reported in the following picture.

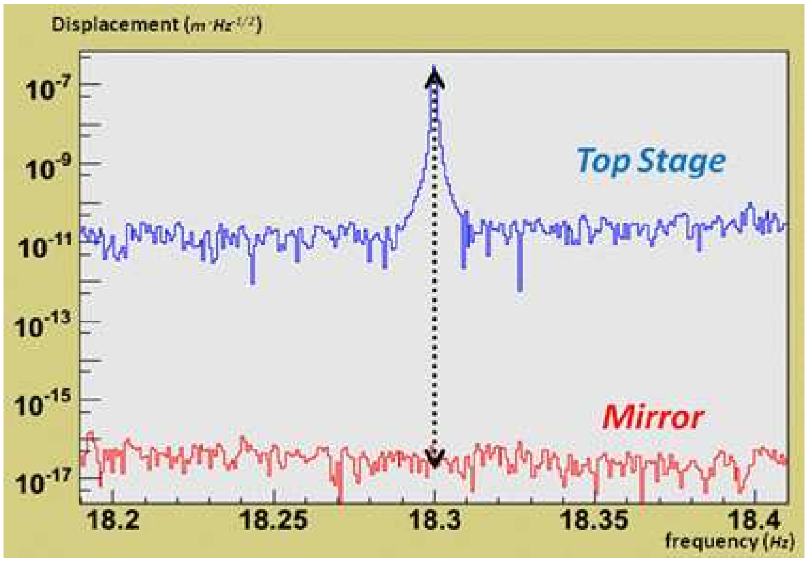


**Figure 1 Spectral density of the top stage horizontal displacement of the West End SA. The blue curve is the excitation line as measured by top stage accelerometers. The red curve is the mirror displacement as detected by the VIRGO interferometer. The integration time of all the experiments is reported in Table 1**

Since no peak was distinguished at the mirror level, the ratio between the noise floor and the top stage peak amplitude gives the attenuation upper limit at this special frequency.

In almost all cases no signal was detected at the level of the interferometer. Only in three cases around 30 Hz (where the interferometer sensitivity is remarkable) and with very long integration times (several hours) a corresponding peak at the interferometer level was detected. However, also in this case, the measured transfer function was around one part on 10^11, small enough to guarantee a negligible residual seismic noise.

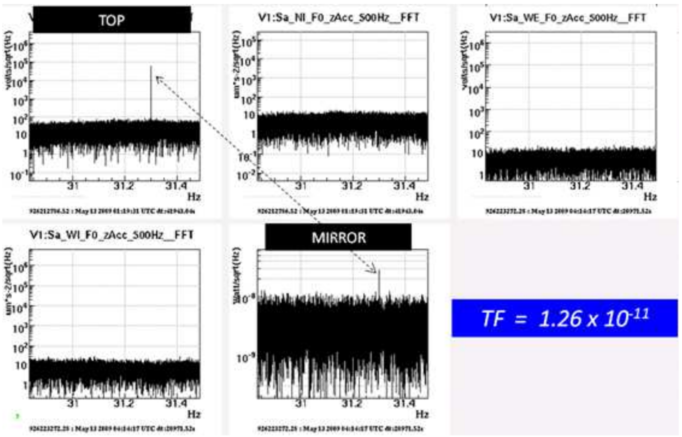


**Figure 2 The experiment at around 31.3 Hz performed on the NE SA. A residual peak was distinguished at the mirror level from the interferometer floor allowing a measurement of the transfer function.**

Due to the extremely high attenuation introduced by the SA chain we suspect that mechanisms other than the mechanical transfer function could cause the thin residual mirror motion (for instance thin transmission between the top stage actuation coils and the payload magnets could be present).

In order to investigate better this point the measurement was repeated exciting the top stage along the horizontal axis perpendicular to the beam direction. In this case the mechanical transmission should not produce a measurable mirror displacement since coupling between the different directions is estimated to be in 1% range, vice-versa a peak was again distinguished from the noise floor. This evidence shows that even when a peak appears in the mirror displacement spectrum, what we measure is an upper limit of the SA mechanical transfer function.

The results of all the measurements are summarized in Table 1. The transfer function upper limits (or their "direct measurements") are reported in Figure 3 and compared with the requirements for Advanced Virgo (same as Virgo+ and monolithic payloads at low frequency) and for the next generation detector (Einstein Telescope – ET). One can notice that transfer function of the filter chain for the investigated frequencies above 10 Hz turned out to be inside the requirements for all the future detectors. The additional attenuation given by the pre-isolator stages in both directions will give a good safety margin.

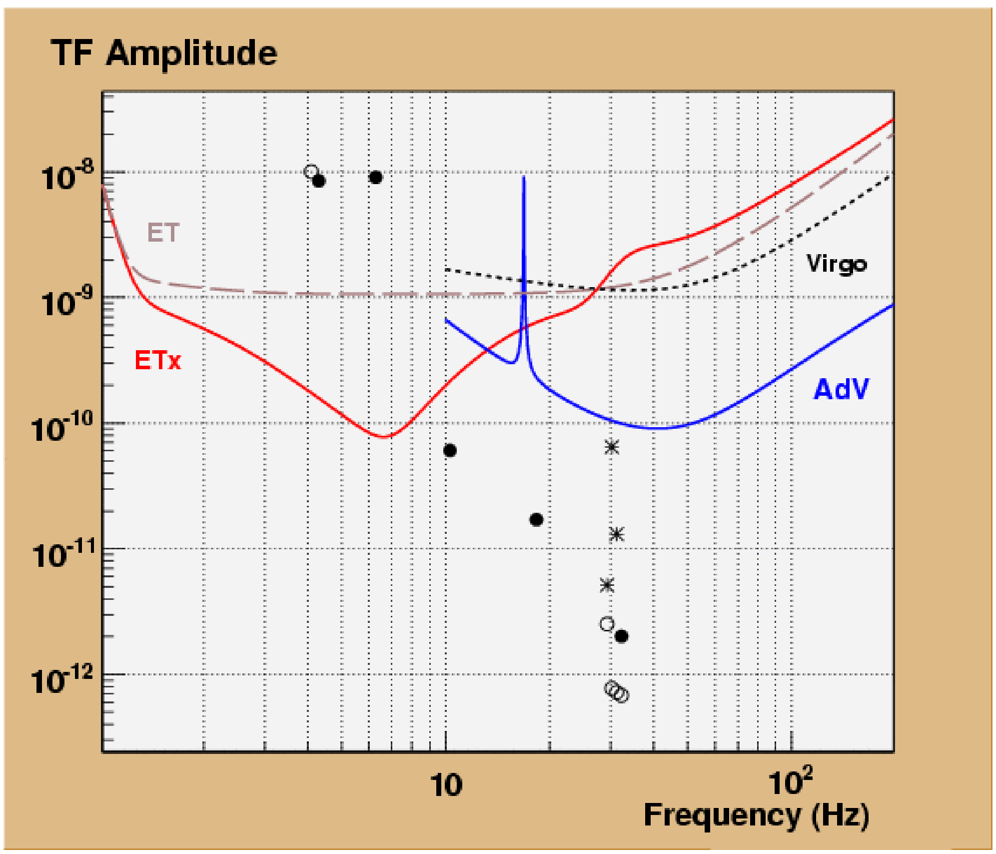


**Figure 3. The measured upper limits and direct measurements of transfer function compared to the required transfer functions of the future generation antennas. White circles denote the upper limit obtained by vertical excitation experiments, black circles the upper limit with excitation along the beam direction and the star the "direct" measurement (i.e. when the peak is distinguished from the floor at the mirror level).**

**HORIZONTAL**

| Integration Time (s) | Kind of Measurement | Frequency (Hz) | Disp Top (Lines LSD) (m Hz^-1/2) | Disp Mirror Upper Limit (LSD) (m Hz^-1/2) | TF |
|---|---|---|---|---|---|
| 10485 | Central interferometer | 2,30 | 4,80E-05 | 2,50E-10 | **5,21E-06** |
| 10485 | Central interferometer | 4,10 | 3,30E-05 | 2,00E-12 | **6,06E-08** |
| About 20000 s | West Input Cavity Mirror | 4,30 | 4,31E-06 | 3,6E-14 | **8,36E-09** |
| About 20000 s | West Input Cavity Mirror | 6,30 | 6,02E-06 | 5,4E-14 | **8,97E-09** |
| 10485 | Central interferometer | 9,80 | 5,70E-06 | 4,10E-13 | **7,19E-08** |
| About 20000 s | West Input Cavity Mirror | 10,30 | 3,00E-06 | 1,8E-16 | **6,00E-11** |
| About 20000 s | West Input Cavity Mirror | 18,30 | 2,85E-06 | 4,8E-17 | **1,68E-11** |
| 41943 | North Input Cavity Mirror | 29,30 | 2,95E-06 | 1,50E-17 | **5,08E-12** |
| 41943 | West Input Cavity Mirror | 30,30 | 9,39E-07 | 6,00E-17 | **6,39E-11** |
| 41943 | North End Cavity Mirror | 31,30 | 1,42E-06 | 1,80E-17 | **1,26E-11** |
| 41943 | West End Cavity Mirror | 32,30 | 1,22E-06 | 2,4E-18 | **1,97E-12** |

**VERTICAL**

Included H-V Coupling

| Integration Time (s) | Kind of Measurement | Frequency (Hz) | Disp Top (Lines LSD) (m Hz^-1/2) | Disp Mirror Upper Limit (LSD) (m Hz^-1/2) | TF |
|---|---|---|---|---|---|
| 2620 | Central Interferometer | 2,25 | 1,70E-04 | 2,60E-10 | **1,53E-06** |
| 2620 | Central Interferometer | 4,10 | 3,00E-04 | 3,00E-12 | **1,00E-08** |
| 25165 | North Input Cavity Mirror | 29,30 | 1,22E-06 | 3,00E-18 | **2,47E-12** |
| 25165 | West Input Cavity Mirror | 30,30 | 3,88E-06 | 3,00E-18 | **7,73E-13** |
| 25165 | North End Cavity Mirror | 31,30 | 4,14E-06 | 3,00E-18 | **7,24E-13** |
| 25165 | West End Cavity Mirror | 32,30 | 4,43E-06 | 3,00E-18 | **6,77E-13** |

**X-AXIS**

| | | | | | |
|---|---|---|---|---|---|
| 8388 | North Input Cavity Mirror | 29,30 | 1,18E-06 | 3,9E-17 | **3,30E-11** |
| 8388 | West Input Cavity Mirror | 30,30 | 6,08E-07 | 1,26E-17 | **2,07E-11** |
| 8388 | North End Cavity Mirror | 31,30 | 6,3E-07 | 3,9E-18 | **6,19E-12** |
| 8388 | West End Cavity Mirror | 32,30 | 7,53E-07 | 2,31E-17 | **3,07E-11** |

**Table 1 Measurements Summary. A blue entry means that no signal was distinguished from the floor at the interferometer level (upper limit only), while red one means that a line was detected (direct measurement). The purple entry means that the upper limit is too large to be useful.**

## 2.3 *Conclusions*

The top stage of the VIRGO SA was excited both in vertical and along the beam direction at several special frequencies by sinusoidal forces for several hours. In almost all the experiments the residual mirror motion at the excitation frequency was too small to be distinguished from the interferometer noise floor. Only transfer function upper limits were thus provided. In three cases around 30 Hz along the beam axis a peak was distinguished from the floor at the interferometer level and a direct measurement of the transfer function was performed. An indication that the extremely small detected residual mirror motion at the excitation frequency could be induced by other mechanisms, bypassing the SA mechanical transfer function, was given by additional measurements. In all case (upper limits or direct measurement) the measured transfer function of the filter chain turns out to be compliant with the requirements of Advanced VIRGO. Above 10 Hz the measured performance are enough also for the third generation antenna Einstein Telescope. The additional attenuation by pre-isolator stages in both horizontal and vertical direction (Inverted Pendulum and Filter Zero) will provide a good safety margin.

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