UHV Monolithic Sensor for Baffles' Displacement Monitoring in AdVIRGO

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EGO EUROPEAN GRAVITATIONAL OBSERVATORY

INFN Istituto Nazionale di Fisica Nucleare

Motivation

The purpose of the Advanced VIRGO baffles is that of blocking the stray-light generated by the scattered light from interferometer moving parts preventing its coupling to the main optical mode. However, although very effective, the motion of the baffles introduces residual scattered light (baffles displacement noise), that, polluting the interferometer output signal, may have effects on its strain sensitivity. Therefore the importance of an effective diagnostic system for a quantitative and continuous monitoring of the baffles displacement is evident.

Sensor Requirement

The requirements in terms of sensitivity and measurement band are based on analysis made by Irene Fiori regarding spectral accelerations of several structures attached to the ground near the Cryotrap.

- Displacement Noise: parts of 10^{-12} m/Hz$^{1/2}$
- Frequency Band: 40-400Hz
- Directionality: Mono-axial (perpendicular to baffle side)
- Total weight: < 300g, max size: < 20x20x10 cm^3
- Vacuum: material, design, electronics UHV compatible
- Baffle tilt vs. gravity: ±3° (initial) ±0.5° (long term drift).

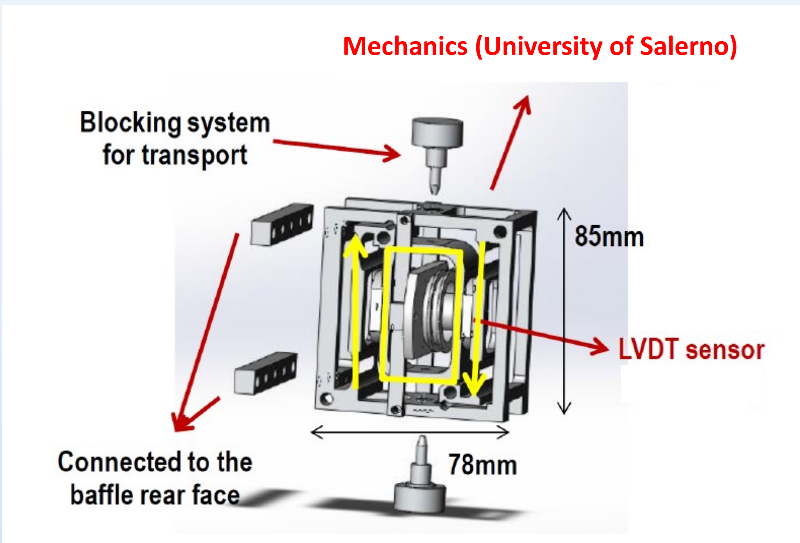
Commercial accelerometers, although satisfying the Advanced VIRGO requirements in terms of sensitivity, frequency band, weight and dimensions, do not guarantee the required UHV compatibility.

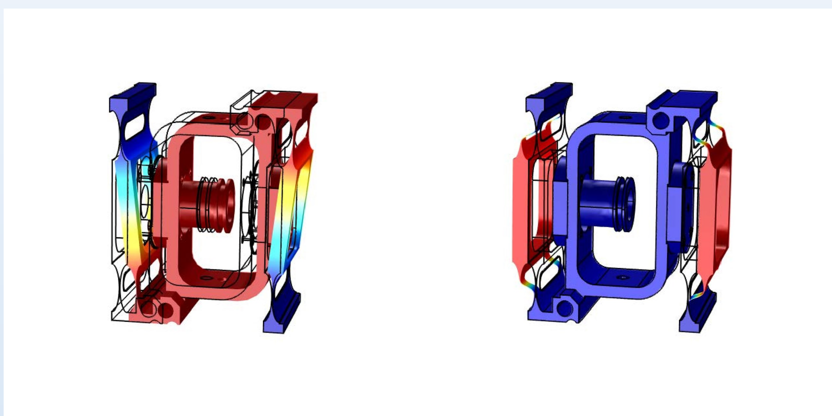
Sensor Prototyping and Realization

The satisfaction of all the requirements is obtained with a customized version of the horizontal UNISA Monolithic Folded Pendulum developed at the University of Salerno. In fact, its UHV compatibility is guaranteed by the material (AL 6082-T6) and by no force feedback (open loop) mechanical configuration: the absence of any electromagnetic control system simplifies the installation, removes any problem of maintenance, minimizes coupling effects with environmental noises and with interferometers active components, maximizes the sensitivity, the latter limited only by the mechanics and readout performances.

In order to guarantee a general global VIRGO standardization and compatibility with the electronics already developed and/or being developed for Advanced VIRGO, the inertial sensor was equipped for this task with a high sensitivity LVDT readout (coils in Kapton coated wires and related supports in Peek30). In particular, the sensor mechanics was optimized to solve the problem, typical of a LVDT readout, of sensitivity loss caused by a not perfect centering of the primary coil with respect to the secondary ones, generated, for example, by angular misalignments of the inertial sensor with respect to the ideal local horizontal position, consequence, for example, of a slow angular motion of the baffles and/or of the tube during the Advanced VIRGO operation.

First Step (3D model designing — Comsol© FEA Analysis — Matlab© simulation program)

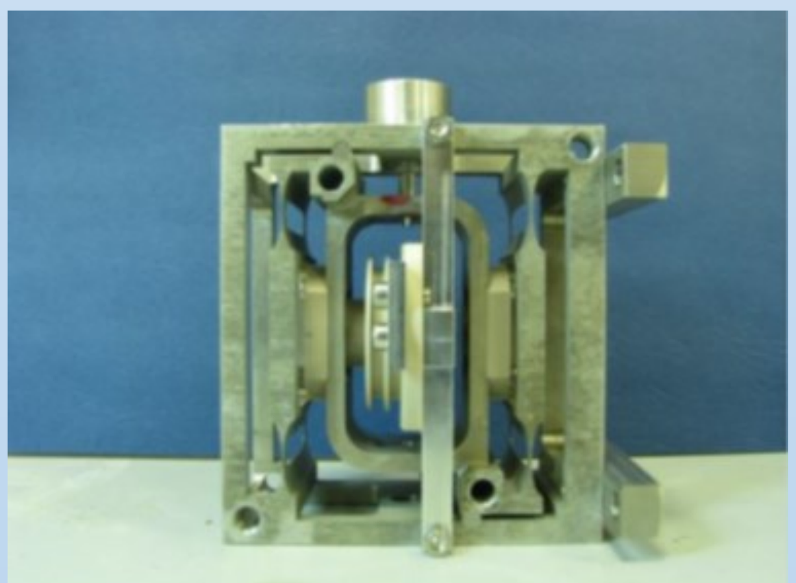


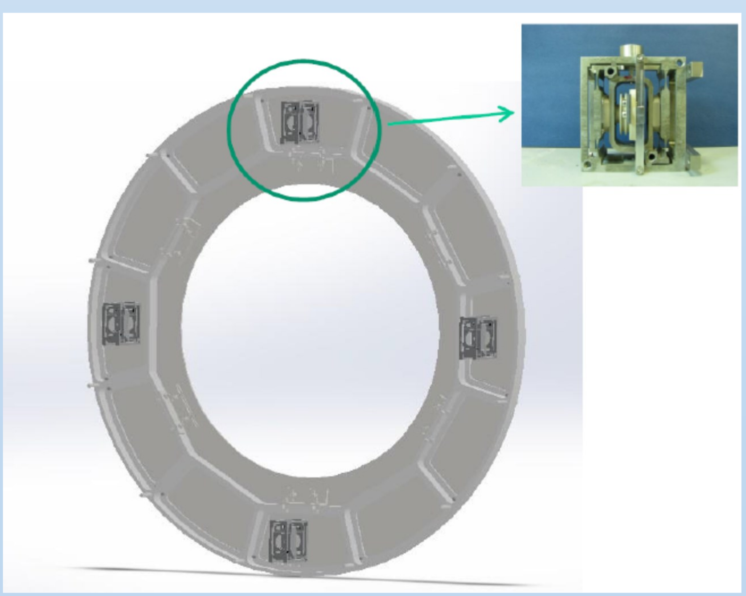


For the projected FP UNISA sensors, the second resonant frequency is above 500Hz, out of measurement band.

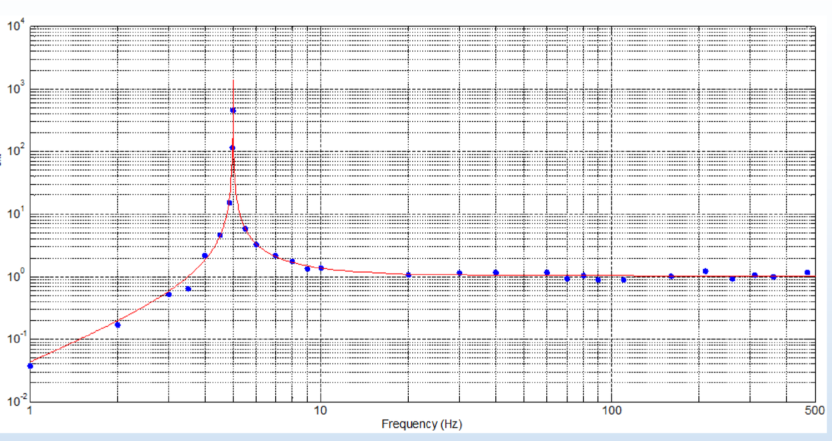
Second Step (Maching — Analysis of optimal positioning on baffle)

Production of three prototype (volume: 7.75x8.5x4 cm^3, total weight < 300g, resonant frequency: 5Hz, 10Hz, 15Hz) by BENEFORTI DONATELLA & C. SNC, (PI), Italy.

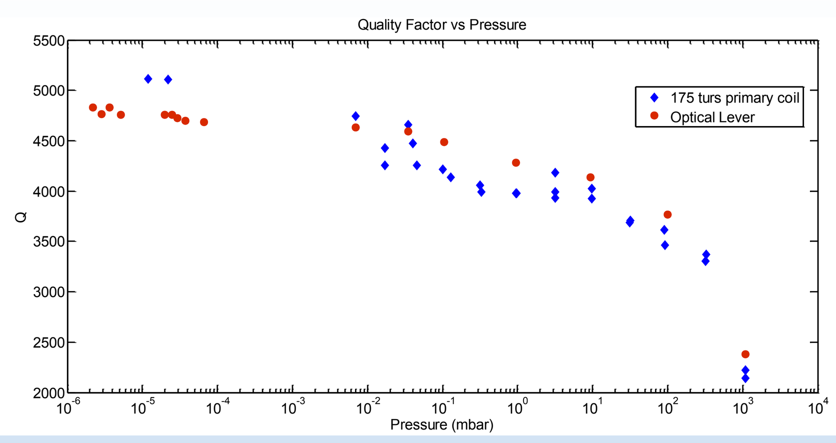




Sensor Mechanical Characterization



The Transfer Function measurements confirm that the realized Folded Pendulum is well described by second order system in the measurement band (40 - 400Hz).



The measurements of Quality Factor under moderate vacuum confirm the low mechanical thermal noise of the FP oscillator equivalent to displacement noise of $5.7 \cdot 10^{-17}$ m/Hz$^{1/2}$ @ 279K @ 100Hz.

Sensitivity Studies

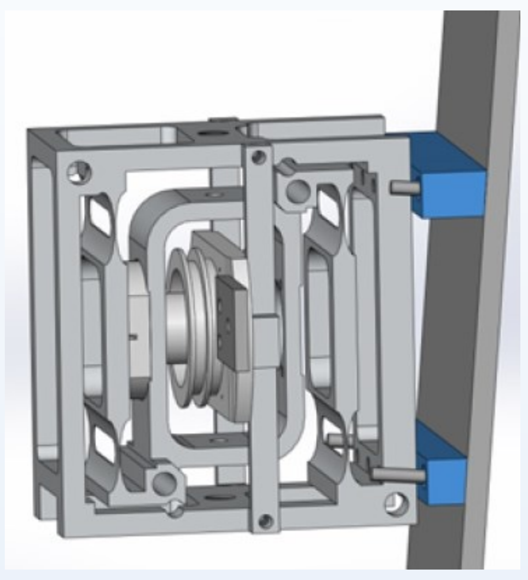
Due to low thermal noise the sensor minimum noise is mainly related to the displacement noise of the LVDT readout system. Several primary coils have been tested the understand the relation between sensitivity, dynamic range and dissipated power.

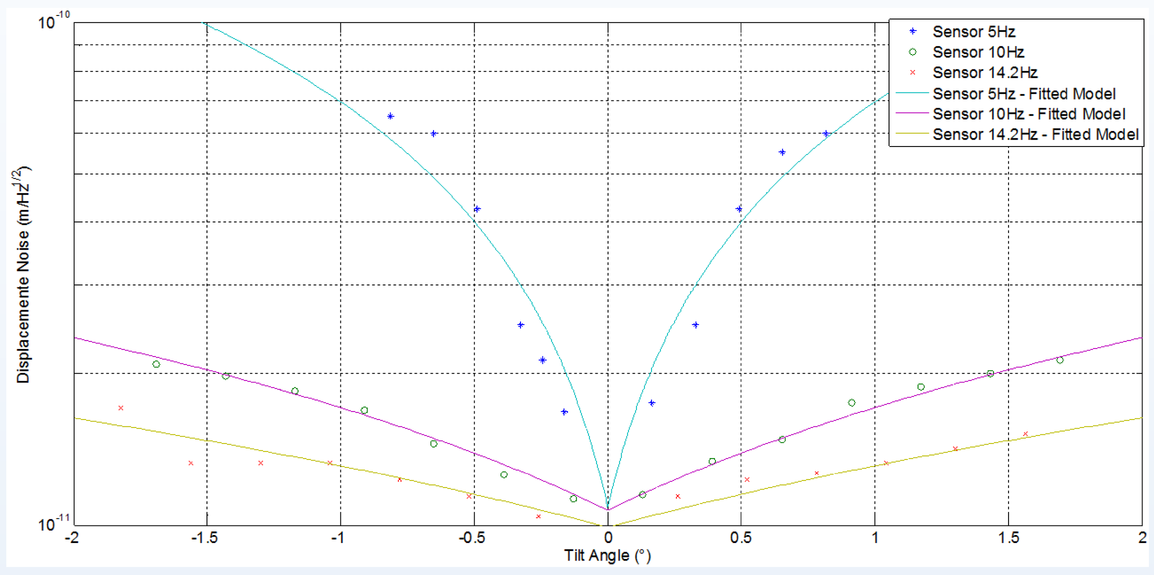
LVDT noise increasing due to not centering of primary coil respect to secondary coils

Because the FP sensor is configured without a feedback control system, an important noise source is the increase of LVDT noise with respect to the equilibrium position of FP central mass, due to the sensor tilt angle with respect to gravity, that can be divided in initial tilt (±3°), defined during the installation procedure, and the long term tilt drift (±0.5°), due to mechanical/thermal stabilization of baffle.

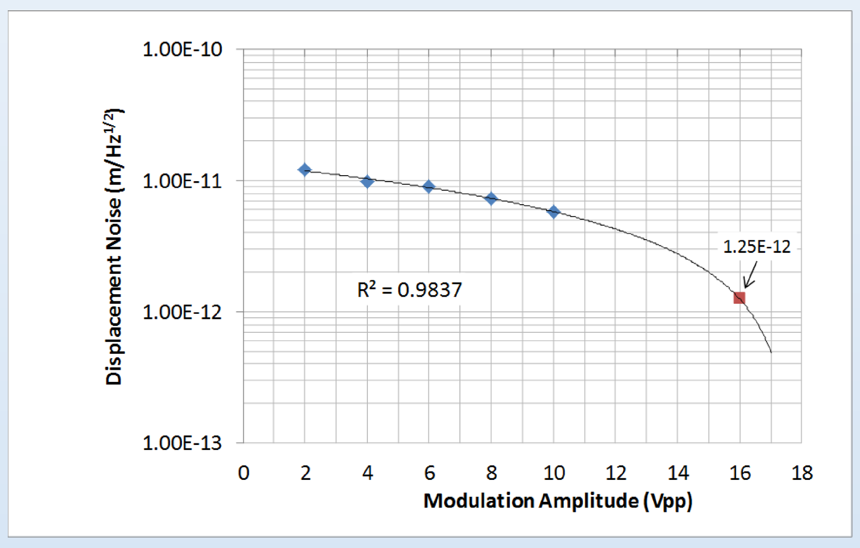
⇒ To minimize the initial tilt, a set of mechanical links to connect the FP sensor to the rear face of the baffle has been designed.

⇒ To solve the problem related to decreasing of sensor sensitivity due long term tilt angle drift the FP sensor resonant at ≈ 15 Hz has been chosen. In fact, even if the tilt sensitivity rate drops off from $5 \cdot 10^{-11}$ m/Hz$^{1/2}$/° to $3 \cdot 10^{-12}$ m/Hz$^{1/2}$/°, the sensor response in the measurement band, above the resonant frequency, does not change.





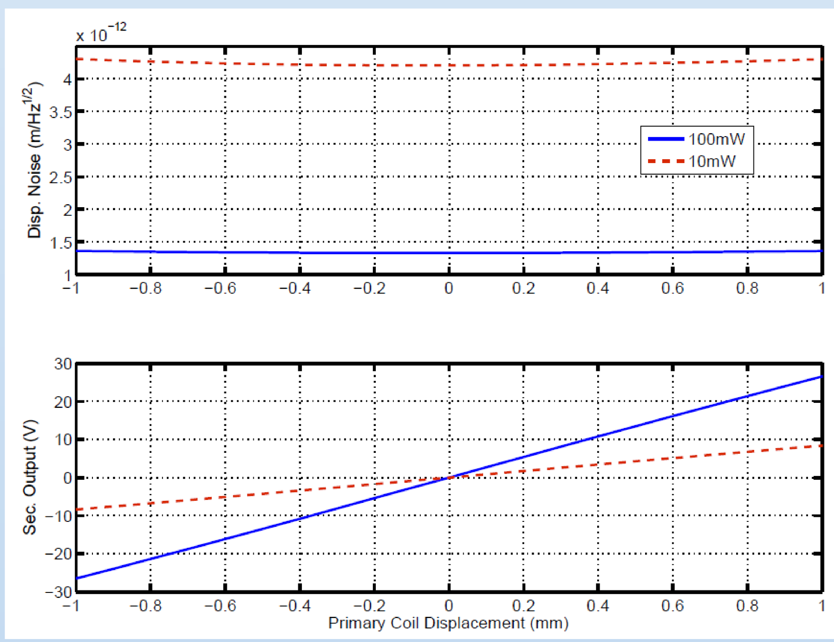
FP sensor minimum noise in function of modulation amplitude and dissipated power.



Mod. Ampl. (V_{pp})	Disp. Noise ($m/\sqrt{Hz}$)	Circ. Current (mA)	Diss Power (mW)
2	$12 \cdot 10^{-12}$	93	3.2
4	$9.8 \cdot 10^{-12}$	185	13
6	$9.0 \cdot 10^{-12}$	278	30
8	$7.3 \cdot 10^{-12}$	371	52
10	$5.8 \cdot 10^{-12}$	465	81
16	$1.2 \cdot 10^{-12}$	743	208

Also if the coils characteristics not correspond yet to the optimal one, a displacement noise of $1.2 \cdot 10^{-11}$ m/Hz$^{1/2}$ for 2V_{pp} modulation amplitude while, using a modulation amplitude of 16V_{pp} a displacement noise of $1.2 \cdot 10^{-12}$ m/Hz$^{1/2}$ can be obtained.

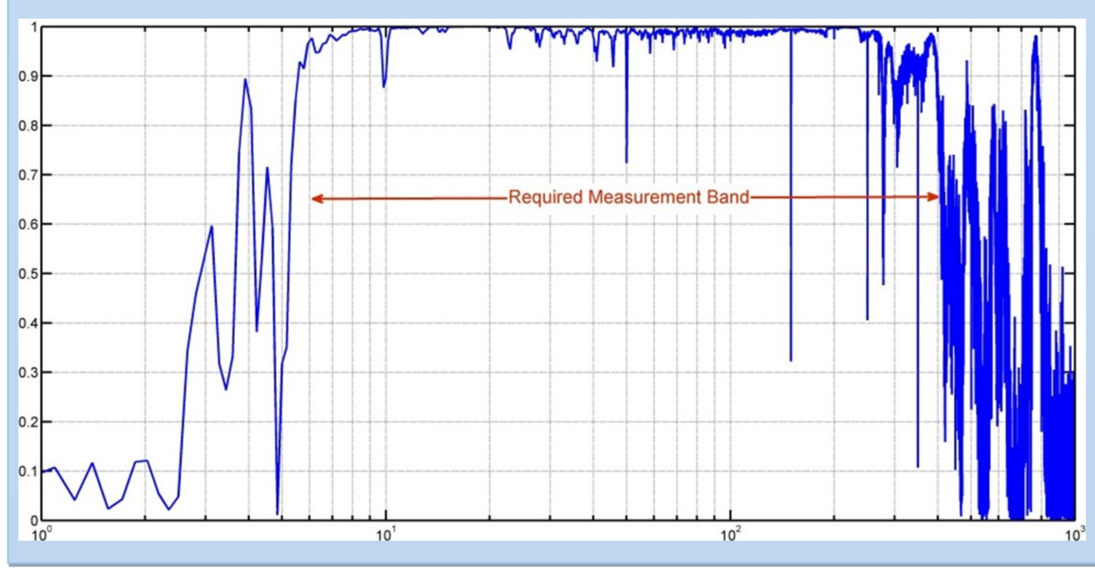
Optimal LVDT parameters



Primary Coil	Secondary Coils
Diameter: 16mm	Diameter: 32mm
Wire's diameter: 0.4mm	Wire's diameter: 0.100mm
Wire's lenght: 0.8m	Wire's lenght: 44.24m
Turns: 16	Turns 441
Theoretical Resistance: 0.12 Ω	Theoretical Resistance: 100 Ω
Theoretical Inductance: 32 μH	Theoretical Inductance: 70.2 mH

Using a modulation amplitude of 16 V_{pp} at modulation frequency of 57 kHz, we expect a displacement noise of $4.2 \cdot 10^{-12}$ m/Hz$^{1/2}$ dissipating a power of 10 mW , while, increasing the electric power dissipated in Joule effect to 100 mW , the displacement noise decreases to $1.3 \cdot 10^{-12}$ m/Hz$^{1/2}$.

Coherence analysis of example of baffle displacement measurement



The coherence between the FP sensor and a commercial piezo accelerometer (356A17 by PCB©) fixed to a baffles is shown.

The loss of coherence for frequency below 6 Hz is due low sensitivity of piezo accelerometer at low frequency. The loss of coherence above 400 Hz is because the FP sensor have been designed to be sensitive in the required frequency band (40-400 Hz).

Conclusions

Preliminary analysis about the effects of stray light on the sensitivity of Advanced VIRGO detector show the need to monitor the baffles vibrations. At the moment there are not commercial accelerometers that satisfy at the same time the requirements in term of noise, measurement band, weight and, in particular, UHV compatibility.

An inertial sensor, based on monolithic FP UNISA model and equipped with high sensitivity LVDT readout system, has been developed for this aim. The choice of materials, of sensor mechanical schema and of its production design, permits the open loop configuration, without feedback control system in order to cancel the control noise, to maximize the sensitivity, to simplify the installation and the maintenance, and to satisfy the UHV requirements.

The measured performance, summarized as a minimum displacement noise of $1.3 \cdot 10^{-12}$ m/Hz$^{1/2}$ dissipating a power of 100 mW in the frequency band 40-400Hz, show the requirements are fully satisfied.