Advanced Virgo (?)

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• The current detector sensitivity is improving and approaching the nominal one.
• The improvement speed had a exceptional boost in the last month
• We are still far from the fundamental limits (*not so much at high frequency*), but, sometimes, we are approaching the technical limits of the current design
Advanced Design Now?

• It is the right moment to design the first upgrades of Virgo:
  • “Easiest” fundamental noises can be reduced
    – Shot noise at high frequency
    – Suspension thermal noise
    – Mirror thermal noise?
  • Technical noise are showing up
    – Actuation noise (DAC&Coil drivers)
    – Modulation noise (phase noise)
    – Electronic & control noises (Benoit talk)
Main Fundamental Noises

Mechanical performances of the SA: $x_{\text{seism}} \leq x_{\text{therm}} @ 4\text{Hz}$

Monolithic FS design of the last stage

Shot noise:
High power laser

Controls must be optimized almost everywhere!

• Intermediate upgrades
  – Last stage suspension
  – Laser
  – Controls and electronics (detection and actuation)
Monolithic fused silica suspensions

- To reduce the suspension thermal noise there is a well established design developed and adopted in GEO
- At the same time, a multi-year R&D program, supported by INFN Commission 2 and then by EGO (eng. Phase) has been completed by the Virgo-Perugia group
- Fused silica fibers are the first ingredient of the future low noise suspensions in ITF GW detectors
- But, what have we to do to use them in Virgo?
The Virgo SA

• The Virgo suspension is by far the most complex filtering system adopted in ITF GW detectors

• The filtering performances of the SA correspond to the design

• But the complexity of the system requires a last stage suspension system that
  – Is reliable
  – Is robust against shocks
  – The cleanliness of the production and installation is compliant with the requirements
  – The installation procedures are compatible with the Virgo infrastructures
Cleanliness specs

- Mirrors are prepared in Class 1 bench with faces protected
- Payload are assembled in class 10, minimizing the exposure time of the mirror
Transport Procedures
Engineering activity at the site

• A long (2 y?) engineering activity is necessary at the site to define the procedures to be used to prepare the payload, to transport it and to hung to the SA

• Modification foreseen to the SA:
  – Marionetta
  – Reference mass
  – Filter #7 (?)

• The LAB where to perform this study activity should be delivered by EGO at the end of September

• Two machines to produce the fibers will be available:
  – H2-O2 flame fully automated machine (already in Cascina, produced by Perugia)
  – CO2 laser machine provided by Glasgow
High power lasers

- Almost no direct R&D activity is present in the Virgo LABs to realize an high power laser
  - We are strongly interested to the development made by the GEO-Hannover group
  - From the Benno’s talk at the Amaldi conference we learned that a laser having more that 100W and compliant with our noise requirements is “almost” available
  - What should we change to use it?
  - Let suppose to adopt first a 50W laser:
    - Are the main optics compliant with this power?
    - Is the injection optics compliant with this power?
  - Current Virgo mirrors respect stringent absorption constrains (<1ppm/cm)
    - Thermal lensing should not to be a strong issue for such a power, but what about reflectivity tuning?
    - A study on a thermal stabilization system is just started in the Naples group and the LIGO and GEO experiences are well taken under consideration
... high power lasers

- Can the current injection optics support a 50W laser?
- New Injection Bench
  - Thermal lensing is not an issue for the Faraday Isolator with the current laser (at least in air)
  - Room has been left to use FK51 glass or other crystal to compensate TGG rotator lensing
  - Many more studies needed to certify our injection system for an high power laser
    - G.Mueller talk
    - Input Mode Cleaner (larger mass)
Mirror Thermal Noise

• The Virgo nominal sensitivity is realized adopting a constant in frequency model for the mirror Brownian noise

• S.D. Penn et al. shown that this correspond to an over-estimation of that noise and they proposed a model for Suprasil 312:

\[
\phi\left( f, \frac{S}{V} \right) = C_1 \left( \frac{V}{S} \right)^{C_3} + C_2 \left( \frac{f}{1\text{Hz}} \right)^{C_3} + C_4 \phi_{th\text{-elastic}} \approx 6.5 \times 10^{-12} \frac{S}{V} + 7.6 \times 10^{-12} f^{0.77}
\]

• But the current Virgo Mirrors are made in Suprasil 311-SV and S-312-SV
  – Reducing the other noises we should have an “advanced” performance level

\( \phi_{bulk} \approx 10^{-9} \)

FIG. 2: Suprasil 312 mechanical loss data with best fit surface.
New Mirror Thermal Noise Evaluation

- (a) Total mirror thermal noise (new model)
- (b) Total mirror thermal noise (old model)
- (c) New bulk Brownian noise evaluation
- (d) New coating Brownian evaluation

$h(f)$ [$1/\sqrt{\text{Hz}}$]

Frequency [Hz]
**Virgo + “possible” sensitivity**

- **Virgo range for NS/NS:** 14 Mpc (SNR 6.5)
- **Virgo+ range for NS/NS:**
  - 28 Mpc (old model for mirror th. noise)
  - 56 Mpc (new model)
Controls

• What has been forgot in the previous evaluation?
• Controls!
• Direct and Indirect effects
• Direct effects:
  – Example:
    • DAC noise
Two sections coil drivers

- Large Force needed to acquire the locking
- Smaller force needed to maintain it

Old coil driver configuration

Functional scheme of the new coil drivers
Coil driver noise in Virgo

• Evaluation of the coil driver noise in the C7 run

• We know what to do for Virgo
• But, what about the noise requirements in case of fused silica suspension?
• 24 bit DAC?
• Electrostatic Actuators?
Eddy currents

- The current actuation system has also an indirect effect on the noise budget:
  - Eddy currents
Eddy current noise


- Metallic RM cannot be used with coil-magnet actuators:
  - Dielectric reference mass (easiest)
  - Electrostatic actuators (more interesting)
Reduction of the excess losses

• High mirror Q needs the reduction of any source of excess losses
  – Monolithic suspension
  – Removal of the camera targets
  – Removal of the magnets on the mirror
  • Electrostatic actuators
    – Studies and modeling in Virgo-Napoli
    – Experience in GEO
      » H.Lueck talk at this workshop
Toward Advanced Virgo

• The “Virgo+” is one step (or, better, one sequence of steps) toward the full upgrade of Virgo

• Advanced Virgo, probably, will contains
  – Very high power lasers (~10^2 W)
  – New ITF configuration
    • Signal recycling
    • New beam shape
  – Lower thermal noise in the mirrors
    • Larger masses (it helps also to reduce the radiation pressure)
    • Low dissipation coatings
Signal Recycling

- Signal recycling seems the right tool to gain sensitivity:
  - In a limited frequency range
  - In a broad frequency band  **Low finesse SR/no SR**

Ken Strain WP3 meeting (June 2005)
SR in Adv. Virgo?

- Evaluation for the following configuration:
  - $P_{PR} = 100\text{W}$
  - Finesse = 600
  - P-Recycling = 50
  - $M_{\text{mir}} = 42\text{kg}$
Low dissipation coatings 1/2

- Coating dissipation should limit the sensitivity of the next future detectors (both at room and cryogenic temperature)
- Reduction of the coating loss angle is mandatory
- R&D Activity performed by the Virgo-LMA Lyon group
  - Many partnerships:
    - EGO R&D programme
    - EU ILIAS-JRA3 activity
    - LIGO

- Facility in Lyon, realized by the Perugia group, to measure the loss angle on thin FS slabs with a single layer coating
  - ITF michelson
Low dissipation coatings 2/2

- Current measurements are far to be conclusive
- World-wide leader in the coating production for GW experiment is the Virgo-Lyon group
- The largest experience in the coating characterization is in LIGO
- We already started the exchange of people and knowledge

We must collaborate to solve our problems with the mirror coatings
New Beam Shape

- In the current configuration of Virgo, the beam shape is not optimized to reduce the mirror thermal noise
- Bulk and coatings Brownian and thermo-elastic noises depend on the beam size
- Lensing effects decreases with the beam size

- A certain improvement can be easily attained re-profiling the gaussian beam
- The best way to reduce the effect of the thermal noise on the detector sensitivity seems to use flat beams (D’Ambrosio E and Thorne K)
- A noise reduction factor up to 5 could be attained, but losses must be taken in account
Modeling Flat Beams

• A simulation effort is in progress in the Nice Virgo group
• Software tool developed: DarkF
  – Effects of defects and misalignments
  – Recycling
• Virgo LMA-Lyon groups started a collaboration with LIGO to produce special coating profiles for flat beams
Further advanced sensitivity

![Graph showing h(f) vs Frequency for different systems]

- (a) Nominal Virgo
- (b) Virgo +
- (c) SR+VHP lasers
- (d) Adv LIGO (bench)

Flat beams improvement not implemented
Where are we?

• Activities for Virgo+ are in an engineering phase
• R&D for advanced Virgo are really preliminary
• The design of Advanced Virgo is just starting now
  – EGO council and ILIAS-GWA require that a (set of) document(s) must be written
  – Virgo and GEO (in the ILIAS framework) are attempting to collaborate in this design activity
  – Virgo just set-up 4 working groups to write down the Adv. Virgo document(s)
  – Synergies and relationships aren’t well defined
  – We must better profit of the European contest