Fused silica suspension for the Virgo optics: status and perspectives

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Pendulum Thermal Noise

\[ X^2(\omega) \approx 4k_B T \frac{g}{\omega^5} \left[ \frac{1}{L_w^2} \sqrt{\frac{E g}{4 \pi \eta n}} + \Theta g^2 \frac{E}{m L_w} \right] \frac{\phi_{wire}}{T_b C_S} \]

Wire loss angle:
\[ \phi_{wire} = \phi_0 + \phi_{th} + \phi_e \]

\( \phi_0 \) : Material loss angle
\( \phi_{th} \) : Thermoelastic loss angle
\( \phi_e \) : Excess loss angle

- Thermoelastic loss angle
  \[ \phi_{th} = \Delta \frac{\omega \pi}{1 + (\omega \pi)^2} \]

\[ \Delta = \frac{E \alpha^2 T}{c} \]
\[ \tau = \frac{d_w^2}{\pi^2 D} \]

- Excess loss angle
  - Frictional processes in the marionetta-wire clamps
  - Frictional losses in the wire-mirror contact point

Present solution

The Virgo present solution for the suspension last stage uses four 200 µm diameter C85 steel wires.

In these conditions:

- $f_0 \sim 10^{-4}$
- $\Phi_{th} (max) \sim 10^{-3}$ (at 680 Hz)
- $C_S = 0.6$
- $T_b \sim 2.9$ GPa

Excess loss angle

- Frictional losses in the upper clamps
  - High pressure clamping system

- Frictional losses in the wire mirror contact point
  - Fused Silica spacers

What can we do best?

Find a wire material with smaller loss angle and larger breaking strength!
Measured losses of materials

\[ \phi = 10^{-4} \]

\[ \phi = 10^{-6} \]


Production facility

- Pure O$_2$-H$_2$ flame
- No fiber-support contact
- Direct measurement of the fiber diameter

- Directly tested the fiber breaking strength

FS Breaking strength (I)

The breaking strength of FS fibers depends on material purity, production and handling procedure.

\[ T_b^{SiO_2} = 4.05 \pm 0.55 \text{ GPa} \]
\[ T_b^{C_{85}} = 2.90 \pm 0.02 \text{ GPa} \]

\( \phi_w/T_b \) is a factor 200 lower for FS fibers, but \( C_s \) is lowered by the large \( T_b \) fluctuation.

M.Punturo et al, talk to the GREX meeting (Grasse, 2000)
FS Breaking strength (2)

- Very strong under elongation (and compression)

- Very fragile for shocks

- The Breaking strength is dramatically reduced by:
  - Cracks on the fiber surface
    - contact with metals or other hard surfaces
  - Humidity
    - some worry for ageing caused by humidity
      - no statistical evidence for this effect in our labs, but some “alarms”
      - this effect is reported by optical fiber producers (closest to the theoretical FS breaking strength)
      - good news from Glasgow for fibers under vacuum
      - more tests needed
Coating of the wire surface

- Surface coating could prevent FS ageing
- Effect of a Carbon coating (with Nitrogen contaminations) on loss angle has been tested
- An evident increase of the wire loss angle has been measured
- More tests are needed with different coatings and better thickness control.
Monolithic solution

- With FS fibers we can gain in
  - $\phi_0$
  - thermoelastic damping because of
    $$\alpha_{SiO_2} \approx 0.5 \cdot 10^{-6} \frac{1}{K} < \alpha_{c_{ss}} \approx 17 \cdot 10^{-6} \frac{1}{K} \Rightarrow \Delta_{SiO_2} < \Delta_{c_{ss}}$$
  - clamping losses
  - breaking strength

- On the other hand we lose in $C_S$ due to the dispersion of the breaking strength
Clamp with FS fibers

Clamping losses:
- Wire-marionetta clamp friction
- Wire-mirror lateral side friction

- The upper head can be welded to a larger head (a FS ring) that can be easily clamped to the marionetta (see later):
  - few tests made in Perugia
  - some problems with stresses accumulated in the head
  - annealing procedure to be implemented (well known by the FS component producers)

- For the lower clamping we cannot “hot-weld” the wire to the mirror
  - large thermal stress
- We cannot use glue
  - Vacuum compatibility and substrate pollution

- We need to chemically bond the wire to the mirror without any pollution or thermal stress

Potassium silicate bonding

- Silicate bonding is a Hydroxide-Catalysis chemical process.
- Test are made in a class 10000 clean room, under a class 100 laminar flux.

It is important a:
- control of the purity of H$_2$O and KOH
- accurate cleaning of the SiO$_2$ samples

In this conditions the breaking strength vs time of samples with different flatness quality has been investigated ($\lambda/4$, $\lambda/7$ and $\lambda/10$).

For $\lambda/10$ samples we are dominated by the clamping
- Mean $\lambda/4 = 2.5 \pm 0.6$ MPa
- Mean $\lambda/7 = 3.3 \pm 0.8$ MPa
- Mean $\lambda/10 = 3.9 \pm 0.5$ MPa

$\lambda$ = xxx nm

Possible Implementation

- 2 flat strips
- 4 40×40mm λ/10 polished region

Transportation of the payload is an (almost) easy task
Hanging procedure will be very crucial (and difficult)

Virgo sensitivity with FS suspension

- C85 steel wire (total)
- Fused Silica wire (total)
- FS pendulum thermal noise
- Mirror thermal noise

Conclusions

- FS suspension can improve our sensitivity in the low frequency range up to a factor 10
- Strength of FS fibers satisfy our requirements
- but more experience needed in:
  - ageing of FS fibres
  - storage conditions, handling and mounting procedures
  - welding strength
- Silicate bonding is the right solution to attach the wires to the mirror, but we need to define the bonding area and ear shape
- A full scale test is foreseen in autumn at the Virgo site