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Advanced Virgo suspension: study of the back up solution

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Abstract

After the several suspension failures on the NI and WI payloads, we have made and evaluation of the sensitivity of Advanced Virgo for the scenarios in which the mirrors are suspended with steel wires or with more robust, thicker silica fibers.

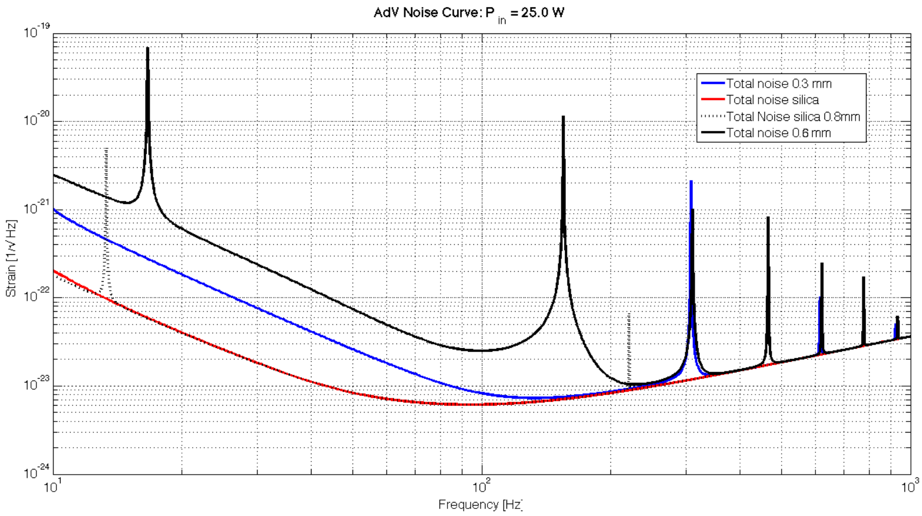


Figure 0-1: Comparison between the sensitivities for the three cases.

	Silica opt	***Steel 400 μm***	Steel 300 μm	***Silica 800 μm***	Steel 600 μm, ϕ=1e-3 (ϕ=1e-4)	VirgoPlus 250 um silica wires
Violin (Hz)	**440**	***231***	307	***220***	155	430
Bouncing	**8.0**	***11.1***	8.3	***13.3***	16	15
BNS Horizon (Mpc)	**109.9**	***45.4***	61	***109.8***	21 (25)	46
BBH Horizon (Mpc)	**1023**	***202***	315	***1026***	83 (109)	393
Stochastic	**$5.7\ 10^{-9}$**	***$2.1\ 10^{-7}$***	$8.4\ 10^{-8}$	***$5.8\ 10^{-9}$***	$1.4\ 10^{-6}$	$1.9\ 10^{-8}$

1 The optimized silica wires.

In the optimized configuration the silica fiber profiles are shaped with the aim to:

- Cancel the thermoelastic losses so that the wire losses are minimal at the pendulum frequency;
- Have the frequency of the fiber bouncing mode below 10 Hz, outside the sensitivity bandwidth;
- Have the frequency of the $theta_x$ mode (pitch) lower 1.5 Hz.
- Keep the violin modes frequency above 400 Hz, outside the control bandwith;

In this scheme, the fibers, pulled starting from a rod of 3 mm diameter, have two tapered neck sections decreasing in diameter to the 800 μm, then most of the fiber length has a diameter of 400 μm, thus setting the bouncing and violin frequencies at values suitable for the AdV purposes.

The thermal noise of the monolithic suspension of $5.8\ 10^{-23}\ 1/Hz^{1/2}$, where the upper clamping part is not negligible and is included (n.b. the optical noise is $1.5\ 10^{-22}\ 1/Hz^{1/2}$).

The resulting horizons are:

BBH Inspiral Range (30-30 MS): 1027.57 Mpc

Stochastic Omega: $5.71\ 10^{-9}$

2 Temporary solution: the steel wires

To allow the north arm commissioning activity to start, we have suspended the NI mirror with the C85 steel having a diameter of 0.6 mm. The NE mirror is suspended with optimized silica wires.

The NI suspension set up is not optimized for a steel wire so we expect a loss angle of the order of 10^{-3}. However, an optimized set up could give a loss angle not better than 10^{-4}. Moreover, in the steel material the thermoelastic loss angle is not cancelled by a proper choice of the diameter like in silica. For this reason the choice of the wire diameter can determine just the wire strength and the frequencies.

2.1 0.3mm

In Virgo the wire diameter was 0.2 mm giving a load stress in the wire of 1.6 GPa.

So, in principle this solution can be adopted, even if the design of the monolithic suspension must be checked to see if it can be adapted for this wire diameter.

In the case of a 0.3mm diameter for AdV the load stress is 1.4 GPa, the first violin is at about 310 Hz and the bouncing mode at 8 Hz

The thermal noise at 10 Hz is foreseen to be $8.06\ 10^{-22}\ 1/Hz^{1/2}$ with the steel wires of 0.3 mm diameter (optimized configuration, i.e. $\phi_{steel}=10^{-4}$, viscous Q of the marionette of 30000). In this case the thermal noise of the upper clamping system is negligible.

For the optimized steel case the horizons are:

BBH Inspiral Range (30-30 MS): 317.82 Mpc

Stochastic Omega: $8.42\ 10^{-8}$

2.2 0.4mm

We also analyze the configuration of 0.4 mm diameter which can be easier to be used to the Advanced Virgo mirrors suspension system, not designed for using steel wires.

In the case of a 0.4mm diameter for AdV the load stress is 0.8 GPa, the first violin is at about 310 Hz and the bouncing mode at 8 Hz

The thermal noise at 10 Hz is foreseen to be $8.06\ 10^{-22}\ 1/Hz^{1/2}$ with the steel wires of 0.3 mm diameter (optimized configuration, i.e. $\phi_{steel}=10^{-4}$, viscous Q of the marionette of 30000). In this case the thermal noise of the upper clamping system is negligible.

For the optimized steel case the horizons are:

BBH Inspiral Range (30-30 MS): 202 Mpc

Stochastic Omega: $2.2\ 10^{-7}$

2.3 0.6mm

In the case of a 0.6mm diameter, the first violin is at about 155 Hz and the bouncing mode at 16 Hz

The thermal noise at 10 Hz is foreseen to be 4.2 10^{-21} $1/Hz^{1/2}$ with the steel wires of 0.6 mm diameter (not optimized configuration, i.e. $\phi_{steel}=10^{-3}$, viscous Q of the marionette of 30000). In this case the thermal noise of the upper clamping system is negligible.

For the optimized steel case the horizons are:

BBH Inspiral Range (30-30 MS): 82.92 Mpc

Stochastic Omega: 1.44 10^{-6}

3 Silica wires with 0.8mm diameter

Another backup solution can be the use of enforced silica wires having a cylindrical shape and a diameter of 0.8 mm. In this case the suspension is safer and the sensitivity can be preserved.

In this case the sensitivity does not change as the thermal noise depends on the thicker portion of the fiber which keeps the diameter of 0.8mm.

The horizon is again :

BBH Inspiral Range (30-30MS): 1025.50 Mpc

Stochastic Omega: 5.77 10^{-9}

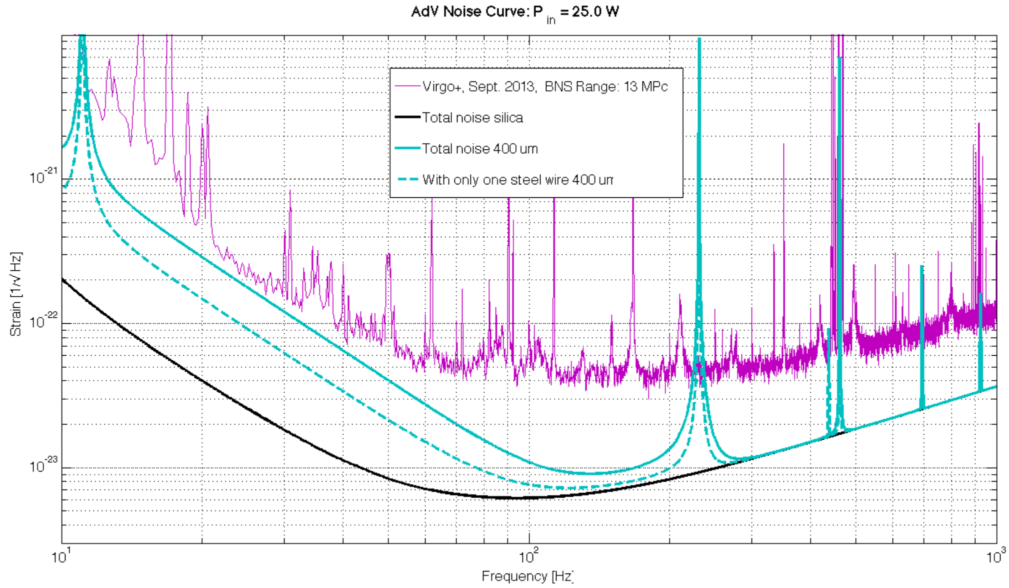
The change is on the lower violin frequency of 220 Hz and the bouncing mode at 13.3 Hz.

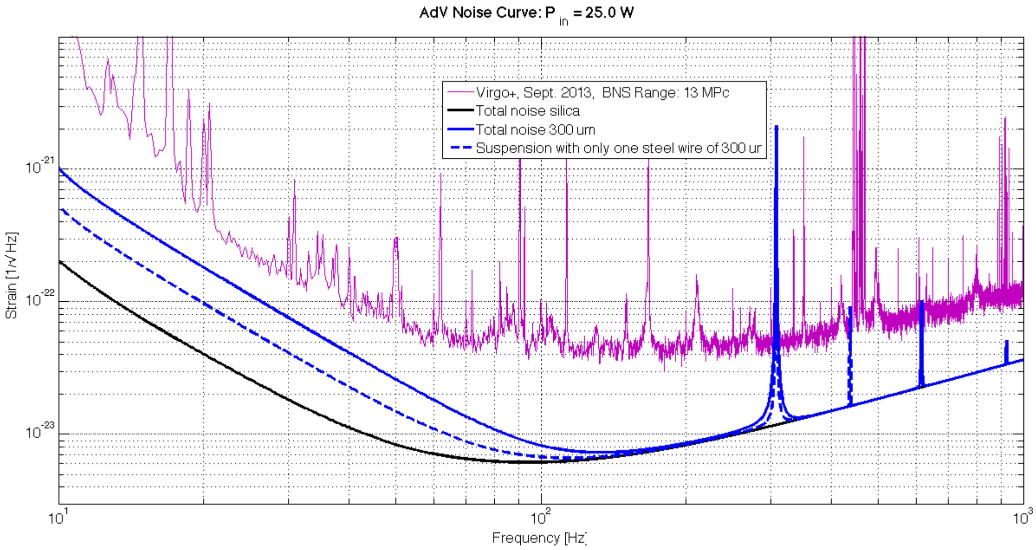
We notice that although the bouncing mode is greater, the pitch mode, important for the control activity, should remain similar to the optimized silica solution as it depend on the bending zone of the wire which is still 0.8mm.

Only one mirror suspended with steel wire

	Silica opt	***Steel 400 μm***	Steel 300 μm
Violin (Hz)	**440**	***231***	307
Bouncing	**8.0**	***11.1***	8.3
BNS Horizon (Mpc)	**109.9**	***65***	80
BBH Horizon (Mpc)	**1023**	***379***	548
Stochastic	**5.7 10^{-9}**	***2.1 10^{-7}***	2.8 10^{-8}

In this case two types of violin modes are present in the bandwidth.


AdV Noise Curve: P in = 25.0 W
Virgo+, Sept. 2013, BNS Range: 13 MPc
Total noise silica
Total noise 400 um
With only one steel wire 400 um
Strain [1/√Hz]
Frequency [Hz]


AdV Noise Curve: P in = 25.0 W
Virgo+, Sept. 2013, BNS Range: 13 MPc
Total noise silica
Total noise 300 um
Suspension with only one steel wire of 300 um
Strain [1/√Hz]
Frequency [Hz]

Evaluation with the new gwinc version

	Silica opt	*Steel 400 μm (φ=10-4) (φ=10-3)*	Steel 300 μm (φ=10-4) (φ=10-3)
Violin (Hz)	**440**	***231***	307
Bouncing	**8.0**	***11.1***	8.3
BNS Horizon (Mpc)	**105.5**	***54 (46)***	69(59)
BBH Horizon (Mpc)	**979**	***279(195)***	419(274)

The differences between the gwinc previously used are:

- Coating Brownian Noise based on experimental measurements performed at LMA by M. Granata (see (VIR-0204A-15) note).
- The gravity gradient noise is based on the on site measurements of the ground seismic noise performed by Irene Fiori.

The steel wired payloads are supposed to be two and the losses are 10^{-3} or 10^{-4}.

The wire diameter is 400 μm.