A better cryogenic suspension?

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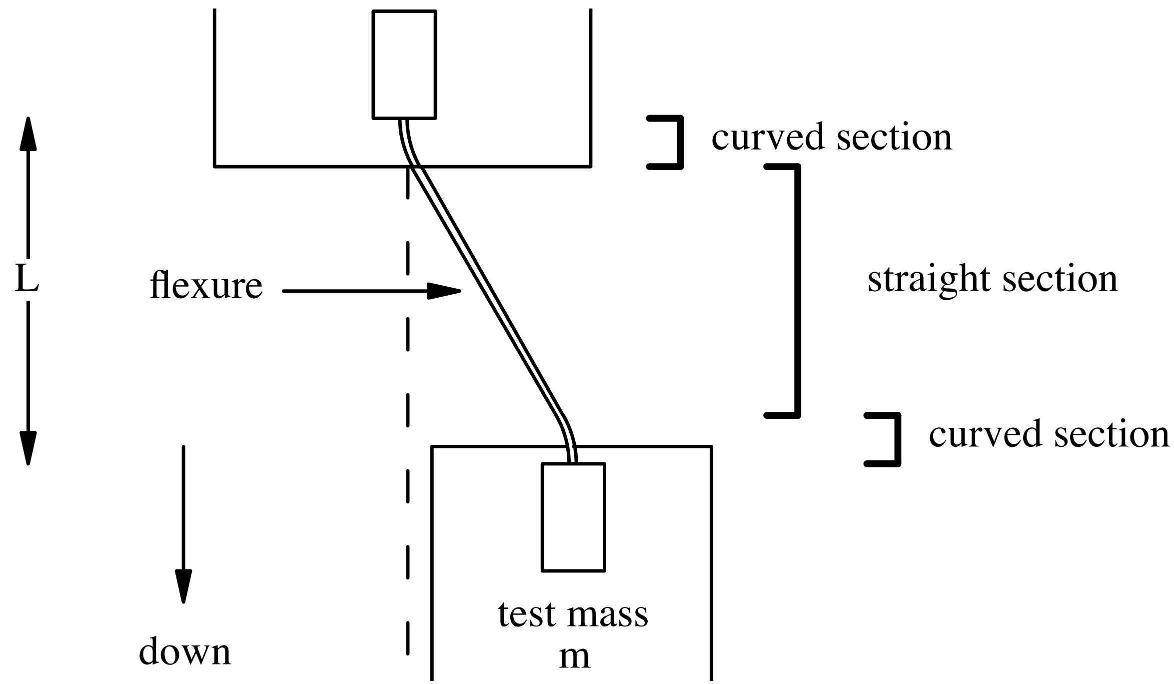
- This is a draft of a proposal to be presented to aLIGO Advanced Interferometer Group in a few days.
- This is first presentation of it anywhere. (you can be first to tell me my mistakes.)
- It is aimed at the new "strawman" competition within LIGO project for ideas for enhanced aLIGO.
- It assumes cryogenic suspensions and silicon mirrors.
- Thought that LCGT might want to consider this idea for bLCGT.

Basic idea

- Use thin suspension fiber ("flexure") at both ends of suspension. This lowers suspension thermal noise.
- Use thick suspension fiber ("strut") in the middle. This lowers thermal resistance of suspension, by large amounts.
- Might call it a "flex-strut".

Calculation of Thermal Suspension Noise - 1



Schematic of a pendulum-like suspension

Calculation of Thermal Suspension Noise - 2

The curved section is has exponential shape, with decay length

$$\Delta = \sqrt{\frac{EI}{mg/N}} \sim 2 - 3\mathrm{mm}$$

Where E = Young's Mod, I = 2nd moment of area, N = # of suspensions,

All noise comes from curved part.

Calculation of Thermal Suspension Noise - 3

- elastic spring constant -> $k_e + i k_e \phi_m$
- where

$$k_e = \frac{N}{L^2}\sqrt{\frac{EImg}{N}}$$

Calculation of Thermal Suspension Noise - 4

- Then suspension thermal noise is

$$S_x(\omega) = \frac{4k_bT}{m^2}\frac{(k_e\phi_m)/\omega}{(\omega_0^2-\omega^2)^2+\frac{(k_e\phi_m)^2}{m^2}}$$

where $$\omega_0^2 = \frac{g}{L}$$

Figure of Merit

- Figure of merit for noise is

$$\frac{Tk_e\phi_m}{m^2} = \frac{T}{\sqrt{m}}\sqrt{\frac{Eg^3}{12}}\frac{\phi_m}{\sigma L^2\sqrt{rN}}$$

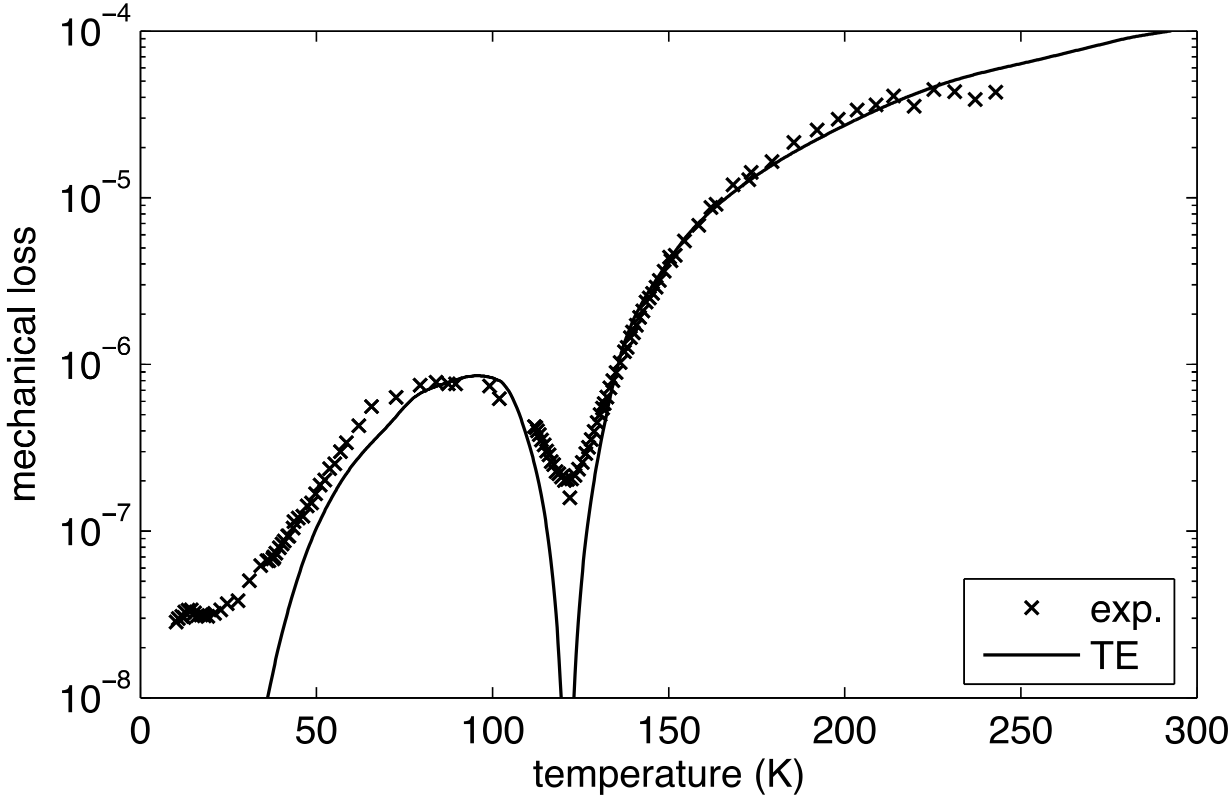
- Where σ = static stress and

  r = width/thickness of flexure

Strawman design

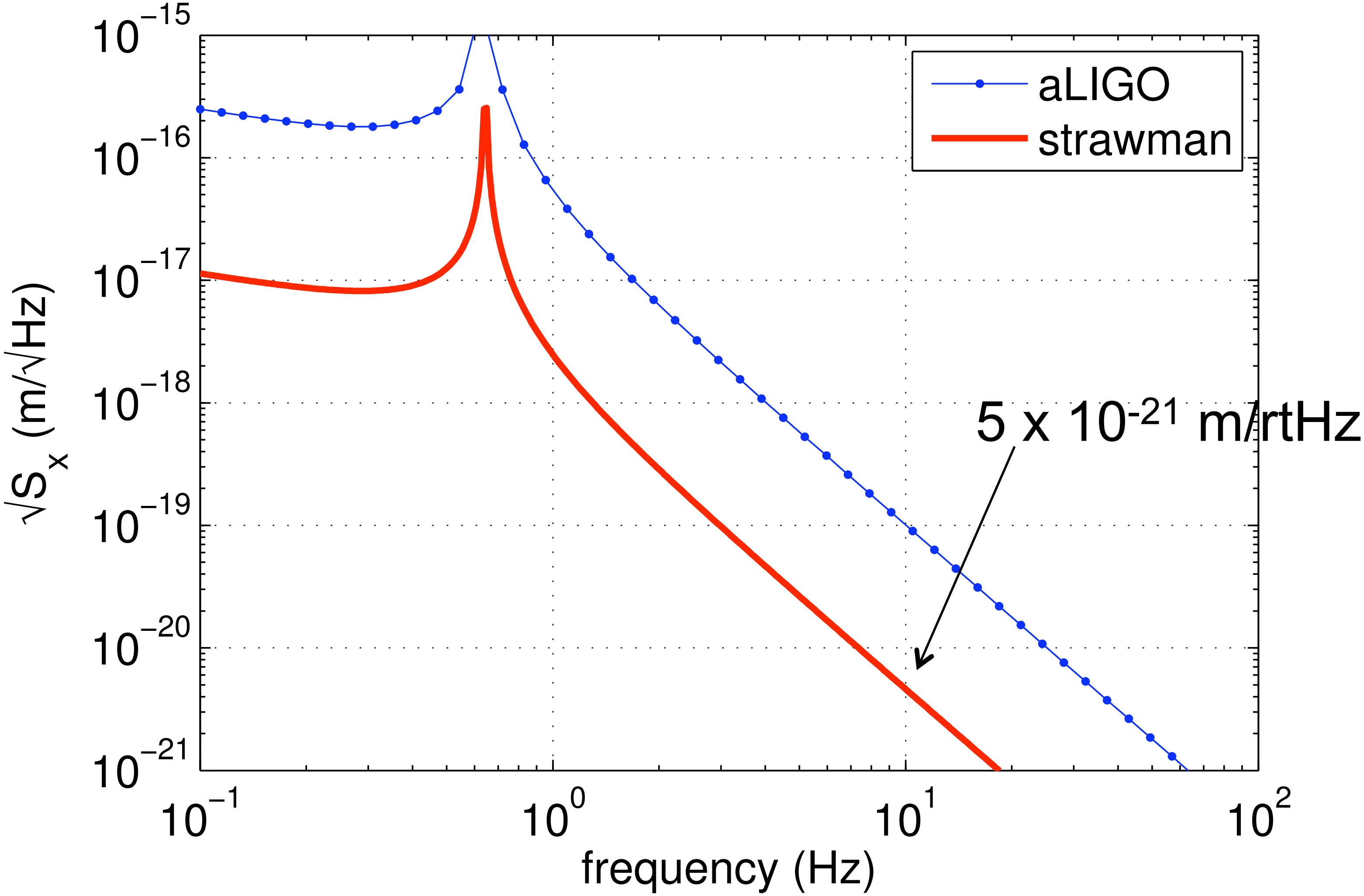
- material = silicon
- Mirror Mass = 205 kg (40 cm dia X 70 cm)
- L = 0.60 m
- T = 25 K, N = 4
- Flexure: 0.50 mm X 2.0 mm
- Stress = 0.5 Gpa (?)
- ϕ_m = 4 x 10^{-8} !

Loss of 130 μm thick Si flexures



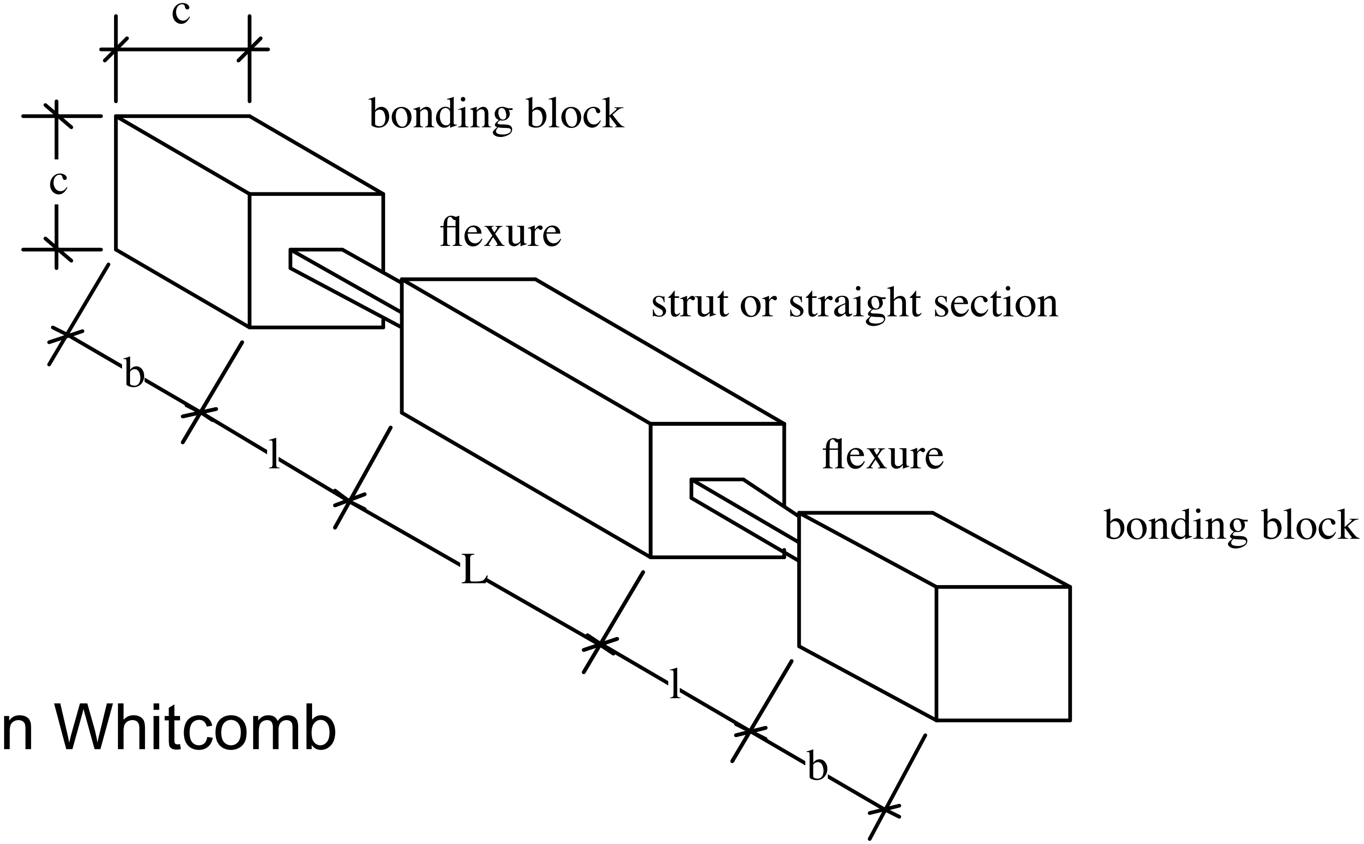
R. Nawrodt et al., "Investigation of mechanical losses of thin silicon flexures at low temperatures, arXiv:1003.2893v1, 2010.

Result



10^−15
10^−16
10^−17
10^−18
10^−19
10^−20
10^−21
√S_x (m/√Hz)
aLIGO
strawman
5 x 10^-21 m/rtHz
10^−1
10^0
10^1
10^2
frequency (Hz)

Loss is at ends, so can make middle a “strut”, with no change in noise



Idea from Stan Whitcomb

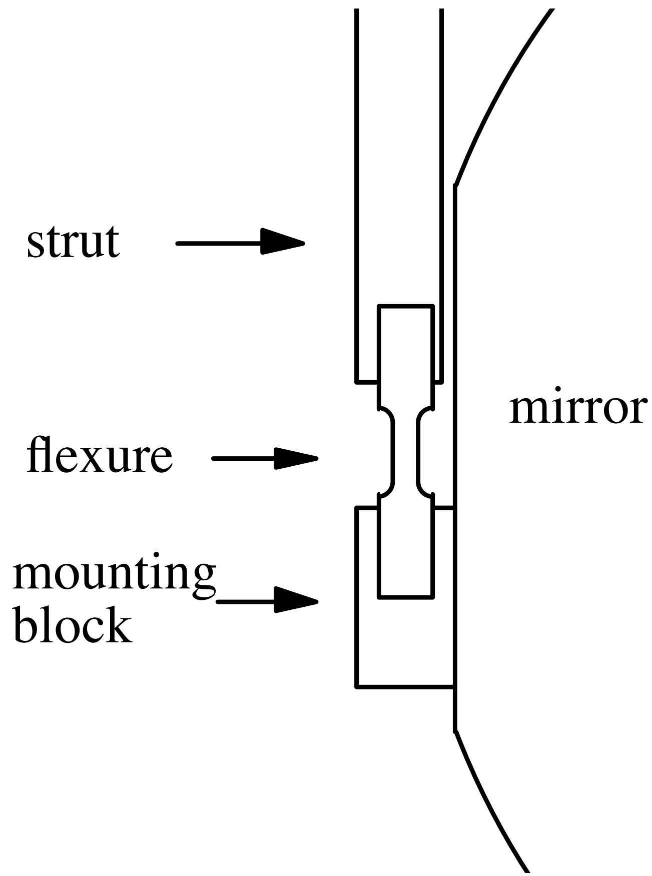
This increases heat extraction

$$\dot{Q} = N \frac{-\int_{T_1}^{T_2} \kappa(T) dT}{\int_0^{L+2l} A^{-1}(s) ds} \simeq N \frac{-\kappa(\bar{T})(T_2 - T_1)}{2\frac{l}{wt} + \frac{L}{c^2}}$$

- T1 = 30 K, T2 = 20 K, κ ~ 5000 W/mK
- Strut dimension = c = 6 mm X 6 mm
- -> Qdot = 6.0 Watts !!
- -> Arm power ~ Qdot/coating absorption

$$P = \frac{6.0 \text{ W}}{0.5 \times 10^{-6}} = 12 \times 10^6 \text{ W} \quad !$$

Fabrication -1



Fabrication-2

- Bond from pieces: mating surfaces flat, ground and polished.

- Possible bonding method: metallize mating surfaces, compress and heat.

Open questions

- Does strut cause too much noise at higher frequencies? Does it affect inspiral range? [Calculation in progress].
- What about vertical suspension noise? (have an idea, no calculations yet)