Cold damping of fused silica suspension violin modes

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Motivation

High Q $\geq 10^8$ of violin modes of the fused silica suspension may result in:

a) instability of the interferometer length control servo,

b) inconvenience associated with the long ring-down time.

S. Goβler et. Al.,Class. Quantum. Grav. ***21*** *(2004) S 923.*

High Q of internal modes and high light power in interferometer **may result in:** the parametric instability due to the interaction of mechanical and optical modes.

V.B. Braginsky, S.E. Strigin and S.P. Vyatchanin, Phys. Lett. A, ***305****, (2002) 111-124.*

Frequency selective damping and cold damping can be used to reduce these effects

Damping of suspension violin modes

First step: damping of the fused silica fiber suspension violin modes with small increasing of thermal noise in the detector band

A number of schemes has been suggested:

S.D. Killbourn, K.D. Skeldon, D.I. Robertson, H. Ward, Active damping of suspensions wire violin modes in gravitational wave detectors, Phys.Lett A 261 (1999) 240-246

S. Goβler et. al.,Damping and tuning of the fibre violin modes in monolithic silica suspension, Class. Quantum. Grav. ***21*** *(2004) S 923*

We propose another version of damping of violin modes which is frequency selective and can be made cold

Controllable damping of mechanical oscillators

These schemes of controllable cold damping appears to have promise:

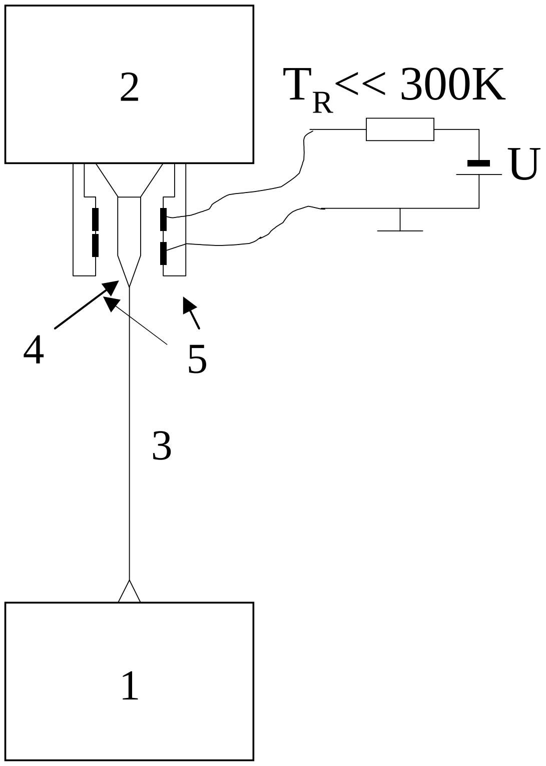
Schemes based on a coupling of mechanical oscillator with electrical* or optical** subsystem which has a small noise temperature.

**H. Hirakava, S. Hiramatsu, Y. Ogawa, Phys. Lett. A 63 (1977) 199.*

*** B. Braginsky and S. P. Vyatchanin, Low Quantum Noise Tranquilizer, Phys. Lett. A, 293, 228-232 (2002).*

Optomechanical systems allowed to obtain a more deep cooling than electromechanical ones but they are more complex in the implementation because of a smallness of forces exerted by photons.

Schematic of violin modes cold damping in fused silica suspension



1 – intermediate mass

2 – main mass

3 – fiber or ribbon

4 – pin (fused silica plate 4×1×0.2 cm^3 used in order to weld the fiber or ribbon to the “ear” on the intermediate mass)

5 – plates with electrodes (are glued to the intermediate mass)

Coupling of violin modes with bending mode of the pin

The effect of loss in the pin δQ^{-1}_{pin} on the violin mode damping δQ_{v}

can be estimated from the simple model* (if $\omega_{v} \leq 0.5\omega_{pin}$) :

$$\delta Q_{viol}^{-1} \approx \frac{2T_{viol}}{l m_{pin} \omega_{pin}^{2}} \delta Q_{pin}^{-1}$$

$$\delta Q^{-1}_{v} \approx 10^{-2}\, \delta Q^{-1}_{pin}$$

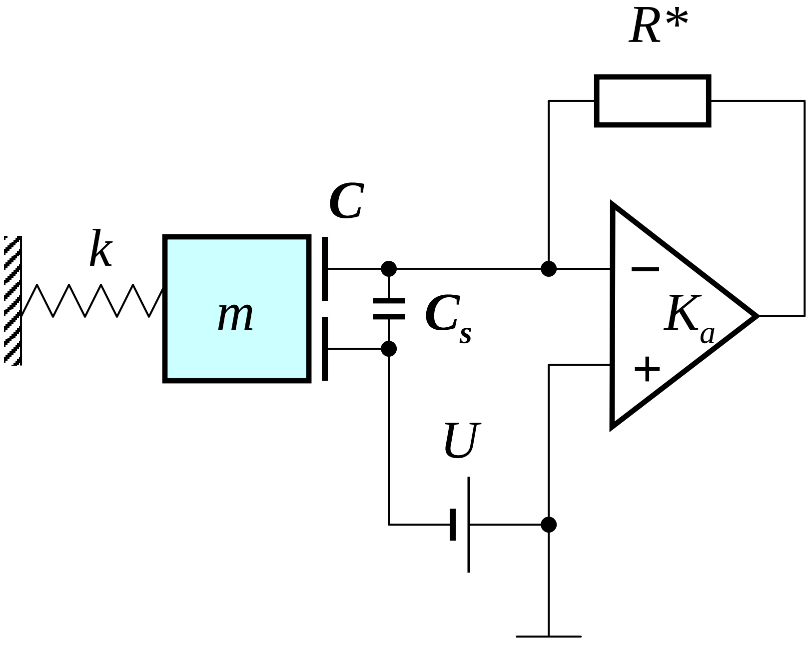
* More detailed calculations were carried out by Phil Willems

Phys. Lett. A 300 (2002) 162

Coupling of the pin bending mode with electrical circuit

Introduced damping:

$$\delta Q^{-1}_{pin.damp} = \frac{U^2 C}{m_{pin}\omega^2_{pin} d^2} \frac{\omega RC}{1+(\omega RC)^2} \frac{C}{C + C_{stray}}$$



For:

$U = 300$ V, $C = 4$ pF, gap $d = 100$ μm

eff. mass $m_{pin} = 0.5$ g, $\omega_{pin} = 2\pi 10^3$ Hz

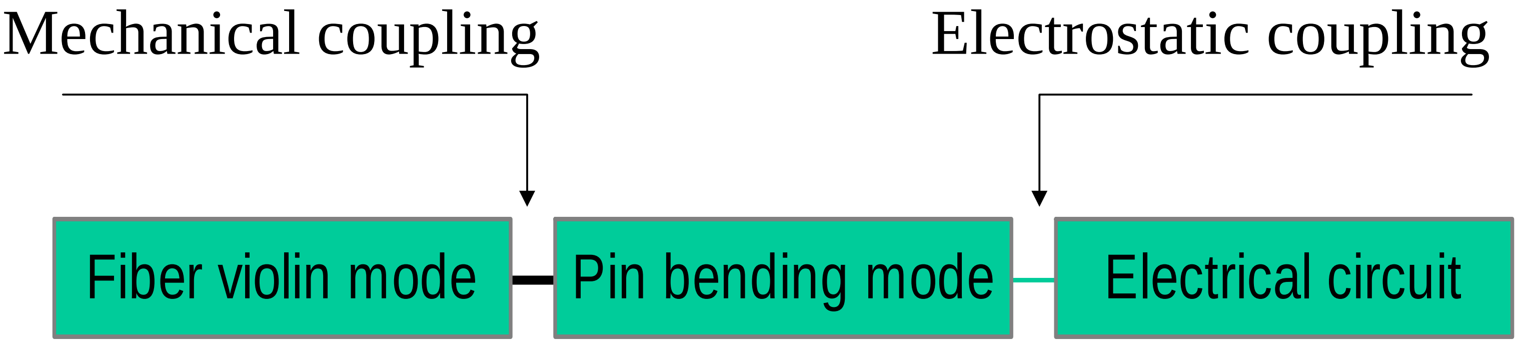
$R = R^*/(1+K_a) = 1/(\omega C)$; $C_s \approx C$

$$\delta Q^{-1}_{pin.damp} \approx 10^{-4}$$

$$T_R = \frac{T}{1+K_a} + \frac{1}{4k_B R} \frac{(1+K_a)^2 S_{Ua} + R^2 S_{Ia}}{1+K_a}$$

$$T_R \approx 1.5 \text{ K}$$

Coupled systems



Mechanical coupling

Electrostatic coupling

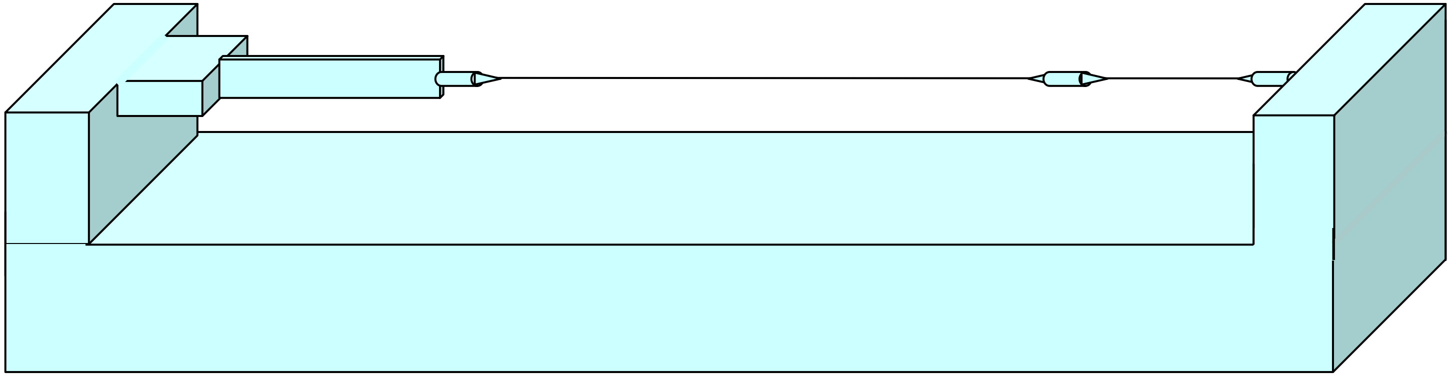
Fiber violin mode

Pin bending mode

Electrical circuit

Resonance frequency	$\omega_\nu + \delta\omega_\nu$ $(\delta\omega_\nu / \omega_\nu) << 1$	$\omega_{pin} + \delta\omega_{pin}$ $(\delta\omega_{pin} / \omega_{pin}) << 1$	Aperiodic
Damping	$Q_\nu^{-1} + \delta Q_\nu^{-1}$ $(\delta Q_\nu^{-1} / Q_\nu^{-1}) = g_m >> 1$	$Q_{pin}^{-1} + \delta Q_{pin}^{-1}$ $(\delta Q_{pin}^{-1} / Q_{pin}^{-1}) = g_e >> 1$	$Q_e^{-1} < 1$
Noise temperature	$T_\nu \approx \frac{T_0}{g_m} + T_{pin}$	$T_{pin} \approx \frac{T_0}{g_e} + T_R$	T_R

Prototype of all fused silica suspension with the additional pin designed to investigate the damping of violin modes



Main task is to exclude additional losses which are not associated with electrical damping

Conductive coating of the pin or comb capacitive electrode?

Above calculation of electrostatic damping was carried out in the case when the pin has a conductive coating. According the estimations additional dissipation associated with thin (<500 nm) metal coating can be made small.

Nevertheless, it is convenient to work without coating of the pin using comb capacitive electrode. It takes reduction of the separation gap between pin and electrodes. In this case effects associated with electrical charging of the pin should be considered.

Summary, Issues

- In the schemes of cold damping the main task is: not to “kill” the high mechanical Q of the fused silica suspension by installation of additional elements which are used in order to create the controllable damping.

- The relatively high level of thermal noise of violin modes allows direct measurement of the noise. This gives the possibility to test various “underwater rocks” which can heat the damped mode.