LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Q's of LASTI Violin Modes

Gregg Harry, Alastair Heptonstall, Matt Evans, Norna Robertson

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of the LIGO Project.

California Institute of Technology
LIGO Project - MS 18-34
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project – NW 22-295
185 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 1970
Mail Stop S9-02
Richland WA 99352
Phone 509-372-8106
Fax 509-372-8137

LIGO Livingston Observatory
P.O. Box 940
Livingston, LA 70754
Phone 225-686-3100
Fax 225-686-7189

http://www.ligo.caltech.edu/

A monolithic quadruple suspension is in the LASTI vacuum chamber and the quality factors of the fused silica suspension fibers have been measured. We compare these measurements to expectations based on theory to help determine if there is any excess loss affecting the suspension fibers.

The theoretical expectation for violin mode Q's is based on two factors; the theoretical mechanical loss and the dissipation dilution factor. The theoretical mechanical loss of fused silica can be calculated from Penn *et al,* Physics Letters A **352** (2006) 3-6. This paper gives this formula for mechanical loss in silica

$$\phi = C_1 (S/V) + C_2 (f / (1 Hz))^{C3} + C_4 \phi_{thermo}$$

where ϕ is the overall mechanical loss, S is the surface area of the fiber, V is the volume of the fiber, f is the frequency of the oscillation, ϕ_{thermo} is the thermoelastic loss in the fiber, and C_1, C_2, C_3, and C_4 are coefficients that come from fitting mechanical loss data. The Penn paper give values of $C_1 = 12.1\ 10^{-12}$ m, $C_2 = 11.8\ 10^{-12}$, $C_3 = 0.77$, and $C_4 = 0.61$ for Suprasil 2 fused silica. The distinctions between the different types of fused silica are often lost when the silica is drawn into fibers, so the exact type of silica is likely not important. The only other type of silica where these parameters are available, Suprasil 312, has C_1 and C_2 within a factor of 2 of these numbers, C_3 identical, and no value available for C_4.

Using the Suprasil 2 numbers, the geometry factors of the LASTI fibers allow for an estimate of ϕ. S and V depend on where the bending in the violin mode takes place. FEA models (see Cumming *et al,* Classical and Quantum Gravity **26** (2009) 215012 and Mark Barton) indicate that this bending is in the 800 μm diameter section of the fibers. $S/V = 4/d$ for fibers, and thus 5000 1/μm. The frequency of the lowest violin mode is about 500 Hz, well above the 3 Hz thermoelastic peak for an 800 μm silica fiber, so thermoelastic damping is ignored from here on. These parameters all together predict

$$\phi(f_0) = 7.33 X 10^{-8}$$

$$\phi(f_1) = 6.83 X 10^{-8}$$

for the silica fibers at the first two violin modes.

Dissipation dilution for violin modes has been calculated by Gonzalez and Saulson in Journal of the Acoustical Society of America **96** (1994) 207 as

$$r_n = 2\ \delta/l\ (1 + (n\ \pi)^2\ \delta/(2\ l))$$

where r_n is the dissipation dilution factor, δ is $\sqrt{Y I/T}$, where Y is the fiber's Young's modulus, I is its moment of area, and T is the tension, n is the mode number, and l is the fiber length. Using 7.27 10^9 Pa for Y, $\frac{1}{4}\ \pi\ (d/2)^4$ for I, 98 N for T, and 60 cm for l, the dissipation dilution factor for the first two violin modes are

$$r_0 = 1 / 77.2$$

$$r_1 = 1 / 74.8$$

The expect violin mode Qs can then be expressed as

$$Q_n = 1 / (r_n \, \phi(f_n))$$

Using the above values for r and ϕ, the Q's become

$$Q_0 = 1.3 \; 10^9$$

$$Q_1 = 1.0 \; 10^9$$

This theoretical value can be compared to the experimentally value on the LASTI suspension measured to be

$$Q_0 = 5.9 \; 10^8$$

$$Q_0 = 6.1 \; 10^8$$

$$Q_1 = 4.6 \; 10^8$$

as shown in the LASTI ILOG July 31, 2010.

The use of a single thickness for the fiber in both the silica mechanical loss (where it enters through S/V) and the dissipation dilution factor (where it enters through I) is simplistic, the actual fibers have a very large diameter stock region of d = 3000 μm, a thick region of d = 800 μm, and a long thin middle region of d = 400 μm. A true estimate of the mechanical loss and dissipation dilution, and thus the violin mode Q's, requires finite element modeling, which is in progress by Alan Cummings et al.