Notes on adding an o-ring to the outer barrel of the TNI test mass

Dennis Coyne
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At the recent "ring-damper/embedded test-mass" teleconference, Sept. 9, 2005, the suggestion was made to try adding a damping ring (e.g. an o-ring) to the barrel of the Thermal Noise Interferometer (TNI) test mass. In principle a ring-damper can be used to damp internal modes and thereby avoid parametric instabilities due to overlap of optical cavity modes and acoustic modes. However, we wish to avoid significantly increasing sensed thermal noise.

TNI test mass parameters and laser beam diameter[1] are:

- 4" diameter
- 4" thick
- 1/8" bevel on both edges
- 1 meter radius of curvature on front surface
- 1/2 minute wedge on back (flat) surface
- 160 micron Gaussian beam wait, w0
- 4.26 micron thick high reflectance (HR) coating

An axisymmetric finite element model[2] of the TNI test mass (not including the small back surface wedge angle) was used to determine contributions to the overall thermal noise due to the inhomogeneous loss associated with the coatings and the addition of a damping ring. The strain energy distribution is associated with a static Gaussian pressure distribution with the same profile as the laser beam used for interferometric readout, per Levin[3].

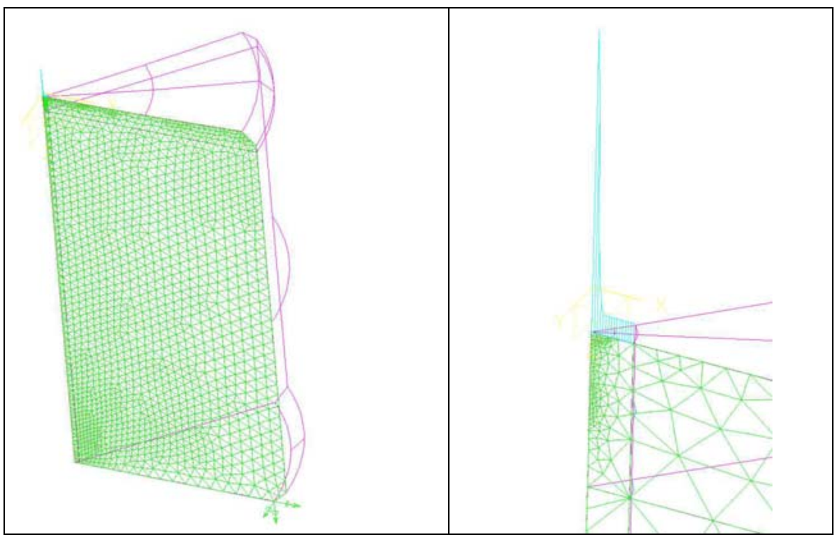

Figure 1: Axisymmetric Finite Element Mesh and Gaussian Pressure Distribution

[1] E. Black et. al., "Direct observation of broadband coating thermal noise in a suspended interferometer", Physics Letters A, 328 (2004); LIGO-P030065-03

[2] D. Coyne, "Thermal Noise Calculation with Inhomogeneous Loss using the Finite Element Method", [incomplete], 11 Jul 2002, LIGO-T020070-01

[3] Y. Levin, Phys. Rev. D, 57, 659 (1998)

N.B.: Converged mesh is actually finer.

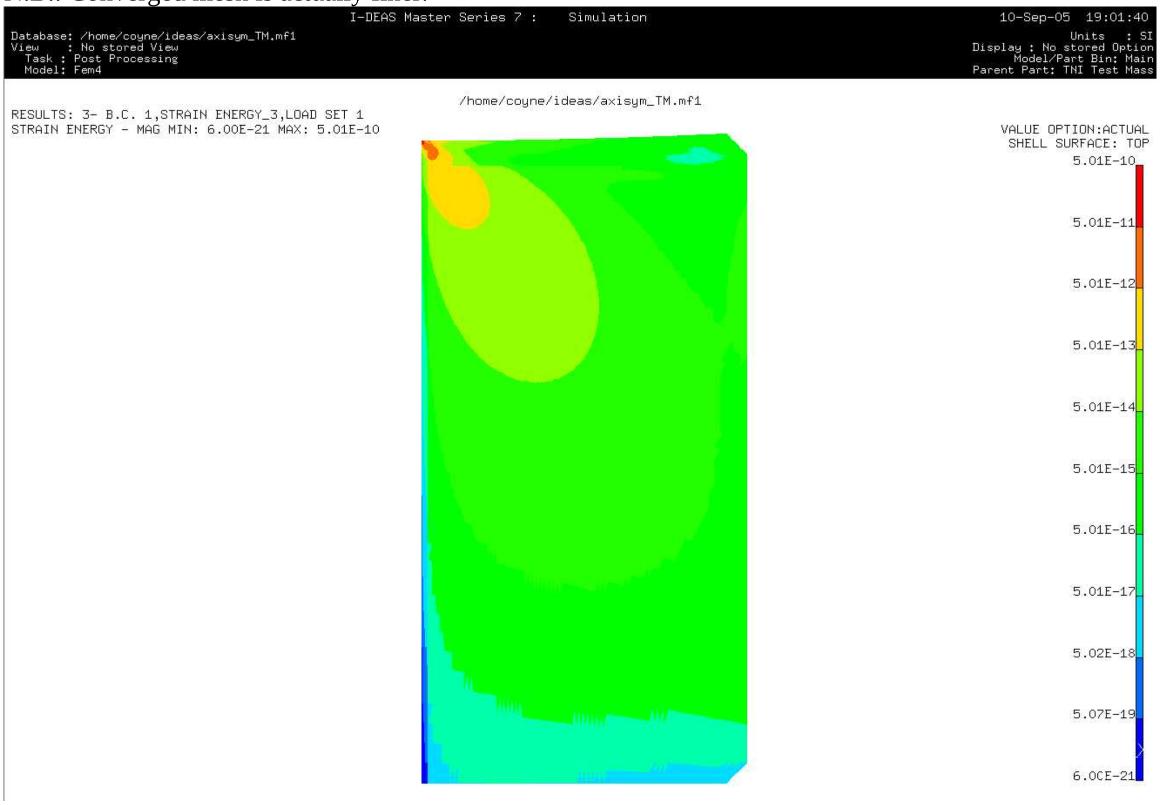

Figure 2: Strain Energy Contours

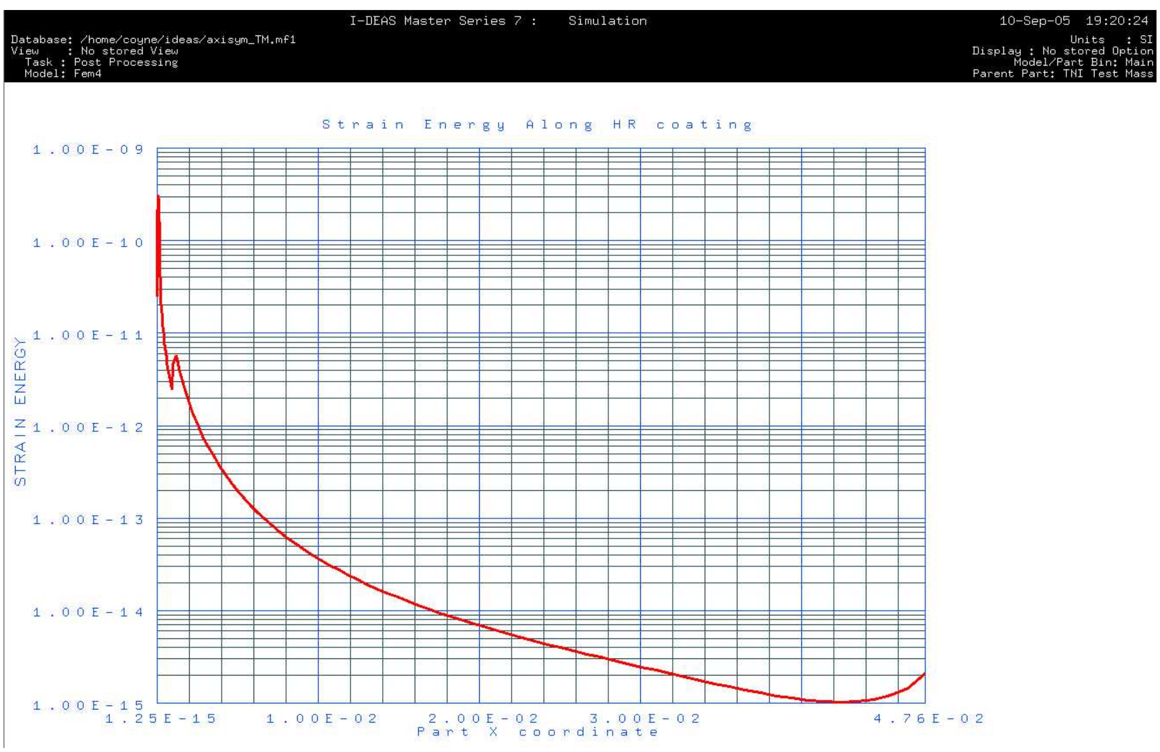

Figure 3: Strain energy variation across the front face (HR coating)

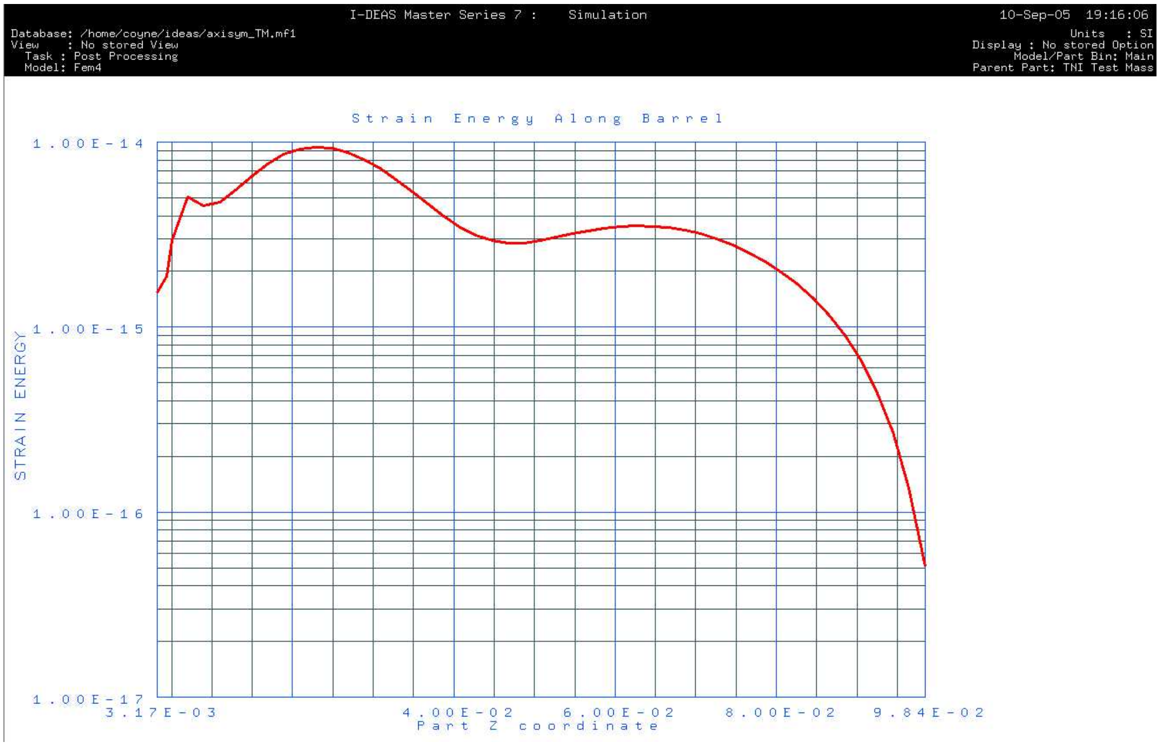

Figure 4: Strain energy variation across the barrel

As indicated in Figure 5, thermal noise is dominated by the HR coating, for representative loss factors (see legend of Figure 5 for loss factors used in the calculation). If an o-ring is added to the barrel, with an interfacial length of 5 mm and comprised of a very high loss material ($\varphi \approx 1$), then it may be possible to measure the thermal noise increase with the TNI interferometer. However, the loss factor may not need to be this high to effect sufficient test mass internal mode damping; The effect of the o-ring damper on internal modes needs to be calculated (pending).

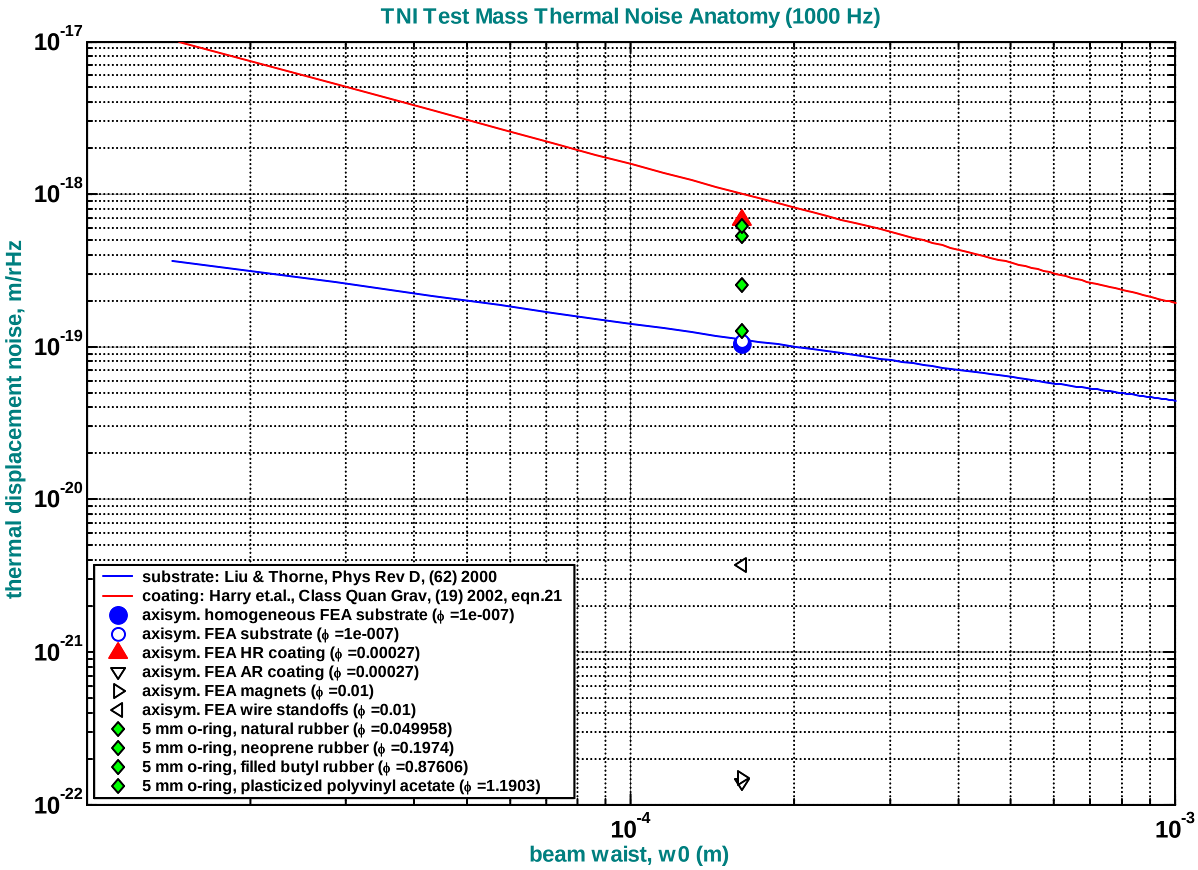

Figure 5: Predicted TNI test mass thermal noise

FEA predicted substrate strain energy (thermal noise) agrees well with Liu & Thorne's formulation. FEA predicted HR coating strain energy (thermal noise) is close, but somewhat less than Harry et. al.'s formulation. This may be due to lack of convergence in the finite element model. (TBD)

Values for the loss factors[4] for some possible o-ring damper materials (see legend) are for 1 kHz excitation at room temperature.

[4] J. Snowdon, Vibration and Shock in Damped Mechanical Systems, John Wiley & Sons, 1968.