LSC Six-Month Progress Report

LIGO-M010139-00-M

Organization Iowa State University Eddy-Current Subgroup (ECSG)

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Attachment B - Isolation/Suspension/Thermal Noise

Participation Norio Nakagawa - 50%

Thermal Noise Formulas

Developed a general Green's function method for computing intrinsic thermal phase noises, applicable to a single-bounce mirror, Fabry-Perot resonator, and optical delay lines. Explicitly estimated the noise for each case using the half-space mirror model, and has shown that there exist cases where delay-line optics can be quieter than Fabry-Perot. The result has been submitted for publication.

Phase noise of a Mirror with Lossy Surface Layer
The primary output this period has to do with thermal noise estimation for coated mirrors.

To be explicit, we worked on an analytical model of a half-infinite mirror with a coating layer. We first assumed that the layer material has excess loss compared to the substrate, while the layer and the substrate share a uniform elastic property (i.e. identical Young's modulus and Poisson ratio). Specifically, we have computed the noise increase due to the coating up to the first order of the ratio between the coating thickness and the beam spot size. We have found that, for a thin lossy coating layer, the excess noise scales as the ratio of the coating loss to the substrate loss and as the ratio of the coating thickness to the laser beam spot size. As an example, for a silica substrate with a loss function of 3x10-8, the coating loss must be less than 3x10-5 for a 6 cm spot size and a 7 mm thick coating to avoid increase of the spectral density of displacement noise by more than 10%.

The result has been written into a preprint (N. Nakagawa, A. M. Gretarsson, E.K. Gustafson, and M. M. Fejer, "Thermal noise in half infinite mirrors with non-uniform loss: a slab of excess loss in a half infinite mirror."), which has been cleared by the LSC Review Committee and submitted for publication.

Second, the same coating result has been generalized to include the case where the layer and substrate materials have dissimilar elastic properties. The result has revealed that the first correction term to the noise with respect to the (coating thickness)/(beam size) ratio actually consists of three components; one arising from compressional strain of the coating, the second from the bending strain the substrate (primarily), and the third due to the spread of the beam force profile after the penetration through the coating. The paper is in preparation.

Numerical Thermal Noise Calculation

In addition to the coating noise estimation, we continued to develop the Green's-function-based noise computation for mirrors of finite transverse dimension. The software for computing elastic Green's function based on the boundary element method has been developed. The status of the code is that it is up and running, and undergoing test and validation phase against test mesh.

Analytical Expressions

As for analytical modeling, we started to work on a stretched membrane model in order to gain insight for transverse-dimension effects and particularly for subtracting rigid body motions. The 2D Green's function has been obtained, where the subtraction of the linear acceleration is straightforward. We are still working on the free disk problem, where accelerated rotation can be an issue, for which appropriate subtraction scheme needs to be found.