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Ear bond area limit for ETM/ITM optics from consideration of thermal noise

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1 Introduction

The analysis underpinning this document was performed by E. Elliffe at Glasgow in 2004/05. Full details of the analysis and the results obtained will be provided in a paper which is currently in preparation for publication in *Classical and Quantum Gravity*[1].

2 Analysis approach

Finite element calculations were made for prediction of the thermal noise in the test masses of Advanced LIGO associated with the silicate bonds used for silica ear attachment. The analyses were based on the thermal noise analysis technique developed by Levin[2] and experimental measurements of bond thickness, elastic energy storage and losses[3] [4]. Upper limits were placed on the thermal noise contribution from the bonds as a function of bond area. This provided constraints on the size of the bonds from consideration of the introduction of 'technical noise' to the test mass[5].

A comparison was made of the thermal noise contribution at 10 Hz, 40 Hz and 100 Hz of two and four[6] 81 nm thick sodium silicate bonds on the sides of a 40 kg Advanced LIGO silica test mass as a function of bond area with a normalized gaussian pressure of 55 mm radius[7] incident on the front face of the test mass.

The maximum bond areas were evaluated for the thermal noise contribution to be ≤ 10% of the overall intrinsic thermal noise level of the interferometer as specified in the Advanced LIGO Systems Design document[5].

3 Results

3.1 Limit to bond area

From the analysis the limit to the total bond area on each Advanced LIGO optic was determined to be 7.1cm^2. This is dictated by the requirement at 100 Hz where, from the Advanced LIGO Systems Design document[5], the thermal noise for one test mass is 8.0×10^{-21} m/√Hz. This sets the (technical noise) limit of 8.0×10^{-22} m/√Hz for the total bond noise per test mass.

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[1] Elliffe, Hough, Rowan & Cagnoli, *"Characterisation of the thermal noise contribution of hydroxide catalysis bonds on 40 kg silica and sapphire test masses in the Advanced LIGO gravitational wave detector"* (in preparation for publication in *Class. Quantum Grav.*)

[2] Levin Y., *Physics Review D* **57** 659 (1998)

[3] Sneddon P. et. al., *Class. Quantum Grav,* **20** 5025-37 (2003)

[4] Elliffe E. et. al., *Class. Quantum Grav,* **22**, 1-11 (2005)

[5] T010075-00-D, "*Advanced LIGO Systems Design*", Fritschel et. al..

[6] When four bonds were modelled the bond pairs on each flat were separated by 30 mm as per proposed ribbon spacing for Advanced LIGO monolithic suspension design.

[7] Radius value quoted for 1/*e* amplitude of beam.

3.2 Resulting stress levels

From the analysis, the limit to the total bond area on each Advanced LIGO test mass is 7.1cm^2. The Advanced LIGO test masses are ~ 40 kg each, producing an average stress level of ~0.55 MPa on the bonds. The measured breaking stress of sodium silicate bonds (1:6) is typically much larger than this (in range 4.8 MPa to 6.3 MPa)[8].

4 Conclusions

Simple scaling up from the bonds used in GEO 600 based on the increase of the test masses from 10 kg to 40 kg would require a total bond area per test mass of 24 cm^2 to maintain the same level of average stress on the bonds.

The analysis described has shown that the total bond area on each test mass is limited to 7.1cm^2 by consideration of the thermal noise associated with the bonds. However, this is acceptable since the resulting average stress level on the bonds when the test masses are suspended will be several factors lower (at least x 8) than the typical measured breaking stress for these types of sodium silicate bonds (1:6).

[8] Private communication. Data measured at Caltech by H. Armandula in 2001 on unbaked sodium silicate bonds.