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LIGO Laboratory / LIGO Scientific Collaboration

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Note on Transmissibility at the Internal Mode Peaks of the Beamsplitter Blades

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1 Introduction

The purpose of this document is to record the calculations which show that the transmissibility at the peaks of the internal modes of the Advanced LIGO beamsplitter suspension is low enough that those modes do not require to be damped.

Comparison can be made to T050046-01-R where similar calculations are done for the test mass suspension blades.

2 Transmissibility and peak noise of beamsplitter blades due to seismic excitation

Justin Greenhalgh has done FEA analysis on the BS blades, see T060295-00-K. Using data from this document, page 7, the transmissibility peaks at the first internal modes of the top and bottom blades are 0.056 and 0.14 at frequencies of 143 Hz and 294 Hz respectively, calculated assuming a quality factor for maraging steel of 10^4. Following T050046, these values are combined with an assumed input noise level and transmissibility of the final stage of the suspension to estimate the residual seismic noise at the first internal modes of the blades. This is then compared with requirements. See the table below.

1	2	3	4	5	6	7	8	9
Blade	freq of mode	peak height	transmissibility	X-coupling factor	platform residual	long. noise	target	factor below
	(Hz)	(transmissibility	of final stage	(vert. to long.)	vert. noise	at test mass	noise level*	target
		of blade stages)	(fo/fm)^2		(m/rtHz)	(m/rtHz)	(m/rtHz)	
top	143	5.60E-02	6.93E-03	1.00E-03	3.00E-14	1.16E-20	2.00E-19	17
bottom	294	1.40E-01	1.64E-03	1.00E-03	3.00E-14	6.88E-21	2.00E-19	29

* taken from Evans and Fritschel, T080192-01, fig 2

To calculate the total vertical transmissibility from the top of the suspension to the test mass, the values in column 3 are multiplied by those in column 4, the vertical transmissibility of the final stage on its wire suspension, where fo= 11.9 Hz for a mass of 14.175 kg on 4 wires each 125 micron radius, and fm is the appropriate frequency of the internal mode. Note that fo is the uncoupled vertical frequency of the final stage. The longitudinal noise at the test mass (column 7) is calculated by multiplying the entries in columns 3, 4, 5 and 6, where the residual noise level on the seismic platform (column 6) is taken from the Seismic Design Requirements Document (E990303-03-D). The target noise level per test mass (column 8) is taken from T080192-01.

We conclude that the peaks are well below the noise requirement. Further it should be noted that the noise requirement as set in T080192-01 includes a safety factor of at least 10 below the Adv. LIGO sensitivity curve.

3. Thermal Excitation of Peaks

We also check the thermal noise peaks. We follow the method given in T050046-01-R. The most important blades for thermal noise considerations are the lower set, nearest to the test mass, since noise associated with the blades further up the chain is better isolated at the test mass. A lower BS blade is approximately triangular with dimensions length 0.14 m, width 2.58x 10^{-2} m and thickness 1.6 mm, giving mass ~ 23 g. Thus using

$$x_{rms}^2 = \left(\frac{kT}{m\omega^2} \right)$$

and noting that the bandwidth is given by fm/Q where fm = 294 Hz and Q = 10^4, we find the amplitude spectral density, x_{th}, by dividing x_{rms} by the root of the bandwidth, to obtain

$$x_{th} = 1.3 \text{ x } 10^{-12} \text{ m}/\sqrt{\text{Hz}}.$$

The resulting displacement at the test mass is given multiplying by the vertical transmissibility of that stage* (the transmissibility treating the blade as a rigid body), the vertical transmissibility of the final stage and the cross-coupling factor between vertical and horizontal, giving

$$x_{\text{from one blade}} = 1.3 \text{ x } 10^{-12} \text{ x } 3\text{x}10^{-3} \text{ x } (11.9/294)^2 \text{ x } 10^{-3} = 6.4 \text{ x } 10^{-21} \text{ m}/\sqrt{\text{Hz}}.$$

(* estimated from blade transmissibility curve on page 7 of T060295-00-K)

We should multiply by 2 to take account of the four blades at the lowest stage, giving

$$x_{\text{test mass}} = 1.3 \text{ x } 10^{-20} \text{ m}/\sqrt{\text{Hz}} \text{ at 294 Hz}.$$

This is more than a factor of 10 below the target noise level (as given in column 8 above).

4. Conclusion

There is no need to damp the internal modes of the blades in the beamsplitter/folding mirror suspensions.