Advanced LIGO Noise Requirements for ETM/ITM Suspensions: Auxiliary Degrees of Freedom.

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1. Introduction

The Advanced LIGO test mass suspension design requirements are set out in T010007-02. The main thermal and seismic noise requirements (longitudinal and vertical directions) are discussed in the conceptual design document T010103-05. This note addresses the design requirements not covered in the conceptual design document – namely pitch, yaw and transverse seismic noise and transverse thermal noise. The transfer functions are taken from the set of MATLAB files on Mark Barton's website for the current noise prototype model of the ETM/ITM suspensions, which can be found at

http://www.ligo.caltech.edu/~mbarton/SUSmodels/matlab/20060517quadnoise.zip

2. Results

We have used the simple active GEO control for damping, which gives decay times ~ 10 secs. This will give conservative numbers for isolation, since in science mode the decay times will be longer (less damping – see conclusions section). All gain boxes in the pende model were set at 1 except vertical, set at 0.3, and transverse set at 2.

All requirements are taken from T010007-02. We make the assumption that the active isolation platform has a residual pitch and yaw noise of 2 x 10^-13 rad/rt Hz at 10 Hz, and residual longitudinal and transverse noise of 2 x 10^-13 m/rt Hz at 10 Hz. These assumptions are returned to in the conclusions section.

2.1 Yaw Seismic Noise.

This has requirement 1 x 10^-17 rad/rt Hz at 10 Hz.

Yaw to yaw transfer function at 10 Hz: 7.4 x 10^-7.
Thus residual yaw noise is 1.5 x 10^-19 rad/rt Hz, well within the noise requirement (by factor of ~ 60).

2.2 Pitch Seismic Noise.

This has requirement 1 x 10^-17 rad/rt Hz at 10 Hz.

Pitch to pitch transfer function at 10 Hz: 7.1 x 10^-8.

Thus residual pitch noise from pitch input is 1.4 x 10^-20 rad/rt Hz, well within the noise requirement.

We note that longitudinal to pitch transfer function also gives a significant pitch motion. In fact for the current design this dominates.

Longitudinal to pitch transfer function at 10 Hz = 1.0 x 10^-7.
Thus residual pitch noise from longitudinal input is 2 x 10^-20 rad/rt Hz, well within the noise requirement (by factor of ~ 500).

2.3 Transverse Seismic Noise.

This has a requirement of 1 x 10^-17 m/rt Hz at 10 Hz.

Transverse transfer function at 10 Hz: 9.4 x 10^-7
Thus residual transverse noise is 1.9 x 10^-19 m/rt Hz, well within the requirement (by factor of ~ 50).

2.4 Transverse Thermal Noise.

This has a requirement of 1x 10^-17 m/rt Hz at 10 Hz.

Dilution factor by which the pendulum phi is reduced from the material phi is proportional to the inverse of the square root of the cross-section moment of inertia of the ribbon or fibre. For a ribbon the cross-section moment of inertia is equal to (w*t^3)/12 where w is the width and t is the thickness. In the ribbon design t is 10 times smaller than w in the longitudinal direction. Thus in the transverse direction t (transverse) is ten times bigger than w (transverse). Thus the cross-section moment of inertia for the transverse direction is 100 times larger than in the longitudinal. Hence the dilution factor is 10 times smaller for transverse.

The thermal noise level off resonance is proportional to the square root of the pendulum phi. Thus the thermal noise in transverse direction is ~ 3 times larger than in the longitudinal direction. Since the longitudinal thermal noise meets the 10^-19m/rt Hz target at 10 Hz, the transverse thermal noise is at most 3 x 10^-19 m/rt Hz, well within the requirement (by factor of ~ 30).

3. Conclusions

3.1 Seismic noise

We see that for all the degrees of freedom discussed above, the estimated residual noise is well below the requirements, by factors of 50 or more. Thus even if the seismic platform noise level is higher than the assumed values by a factor of a few, there is plenty of isolation in hand from the suspension system. We have also checked that if eddy current damping at a level equivalent to b = 27kg/s eddy current damping is used instead of active damping in pitch and yaw with the lever arms in the current model (pitch = 6 cm and yaw = 15 cm) the transfer function values are smaller than the active control values, yaw by factor ~1.7 and pitch by factor ~ 2.6. In practice we expect to use eddy current damping at this level combined with active control more steeply rolled off so that the coupling at 10 Hz due to the active control will be less than that due to eddy current damping. Thus the active damping model as presented above is a safe conservative estimate. Note that there are no plans to use eddy current damping in the transverse direction (some modest amount will come from eddy current damping applied in other directions).

3.2 Transverse Seismic Noise.

We see that there is a large margin of safety in meeting the requirement for this term.