Advanced LIGO: Note on application of eddy current damping regarding noise requirements ETM/ITM/BS and FM suspensions LIGO-T050109-00-K

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1 Introduction and references

This note presents a reconsideration of the application of eddy current damping motivated by a comment from N.A. Robertson. The information is hard to find in other documents are there are clear (if relatively minor) performance implications.

Generic requirements for the suspensions are given in T010007-03. This note affects the application of eddy current damping, including hybrid damping. It therefore affects the following documents: T010103 (with which this partly overlaps), T040110 – and other aspects of the OSEM review, and T050093-00 on hybrid damping.

ECD: Eddy current damping.

Noise from ECD units

The thermal noise force from the eddy current damping is given by

$$\tilde{f} = \sqrt{4kTb}\,\mathrm{N}/\sqrt{\mathrm{Hz}},$$

where k is Boltzmann's constant, T the system temperature and b the damping strength.

The transfer function from force noise to longitudinal optic motion is given by the latest MATLAB models (Ref: N.A. Robertson), for the significant degrees of freedom at 10 Hz as

- ITM/ETM longitudinal: -209 dB
- ITM/ETM vertical:-210 dB (including -60 dB cross-coupling)
- BS/FM longitudinal:-182 dB
- BS/FM vertical:-167 dB (allowing -60 dB cross-coupling).

These are all preliminary results and are rounded to 1 dB.

In the case of the ETM/ITM, the noise couples almost equally through the two paths and the fall-off is with the 8th power of frequency – unless the bounce mode is above 10 Hz in which case the situation becomes quite complex. The maximum amount of damping allowed to meet the technical requirement for TM displacement noise is around 4 kg/s, in each of vertical and horizontal. This is too small to be useful. The canonical 27 kg/s applied to both longitudinal and vertical, would produce noise only about only about 10 dB below the detector noise floor, compared to the requirement of 20dB for a technical noise source – and so would increase that noise floor by about 1 dB at 10 Hz. The noise requirement would be met at and above about 11.5 Hz.

In the case of the BS/FM suspensions the noise couples dominantly through the vertical path, the fall-off above 10 Hz is with the 6th power of frequency. The maximum amount of damping allowed to meet the requirement for BS/FM displacement noise is very large. The canonical 27 kg/s on vertical, would produce noise about 34 dB below the detector noise floor and is acceptable.

2 Performance of hybrid damping with less ECD

With 14 kg/s in vertical, direction performance appears to be generally acceptable. The most significant difference is that it is less simple to optimise pitch damping, if pitch is damped with vertical dampers. Otherwise it is possible to meet all goals.

With 14 kg/s on longitudinal, performance is clearly poorer than with 27 kg/s. The gain margin of the active part is much reduced and settling performance is worse (both comments apply to emergency/acquisition mode). It may be possible to achieve adequate performance, but there is definitely more risk of failure to meet goals than with 27 kg/s. Yaw is similarly affected unless the dampers can be placed near the extreme ends of the mass.

If less than 27 kg/s were to be used for longitudinal/yaw it would probably be necessary to use weaker magnets than we had planned to retain a symmetrical arrangement of dampers. This is because a cluster of 4 magnets is ideal with respect to radiated field and that 3 or 4 clusters are needed to achieve the damping of one translation and two angular degrees of freedom on at least one face of the mass. With the same size of copper pieces, half length magnets should give just over half of the damping (about 0.9 kg/s/magnet or 3.6 kg/s per cluster of 4). By having magnet blocks with either 5 mm or 10 mm long magnets available (and designed for compatibility), it should be possible to decide on the final amount of damping at the noise-prototype stage.

3 Conclusions, cautions and recommendations

There is no problem with the application of ECD to the BS/FM suspensions.

No useful level of ECD can be applied to the ETM/ITM suspensions (as currently designed) while meeting all displacement noise requirements. It has been assumed that the predicted, less than 1 dB, degradation in performance between 10 Hz and 11.5 Hz is acceptable. This can be justified provided

- the situation is reviewed if the bounce mode exceeds 10 Hz
- it is understood that the predicted noise level is quite firm unless there is a deliberate design change (there is essentially no risk of the noise being unexpectedly large).

The recommendation is therefore to proceed with hybrid damping as currently planned but to consider whether a modest decrease in damping is tolerable to make the noise-penalty even smaller, as initially explored in the preceding section.