Sources of technical noise in the quad suspensions

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1 Background

The Cavity optics suspension DRD, T010007-03, section 4.2, required that no "technical" noise source may contribute more than 10% of the total allowable noise. This document has been prepared for Noise Prototype PDR #3 and lists the known possible sources of technical noise and shows that in each case the contribution meets the DRD requirement. We have not attempted to sort the sources into any particular sequence.

2 Technical noise sources

2.1 Local control coupling

This potential noise source comprises coupling of noise from the local control sensors into motion of the test mass. As was shown in E040108 "Recommendation of a design for the OSEM sensors", and summarised in G040216 "OSEM sensor recommendation: requirements and decision process", the arrangement of sensors and eddy-current damping we will use, meets the noise requirements. This was covered in the OSEM review (noise prototype PDR#1), but the reference is included here for completeness.

2.2 Eddy current dampers

T050109 "Note on application of eddy current damping regarding noise requirements ETM/ITM/BS and FM suspensions" showed that, in the worst case, there would be a minor infringement of the noise requirements by the eddy current dampers. We are only a factor of three below the sub-system noise requirement at 10Hz and only come down to the full factor of ten at 11.5 Hz. Since that document was written we have agreed to reduce the strength of the magnets by about 20% (change to higher bakeout temperature). We will check the actual damping on the noise prototype and if necessary, adjust it. This can only be planned once the full results from the control prototype are available.

2.3 Noise from magnets mounted on the top mass

Following the reasoning in T050105-00 "Advanced LIGO ITM/ETM SUS Magnets at Top Mass", we decided that it would be acceptable from a noise point of view to mount eddy-current damper magnets on the top mass. They, and the OSEM magnets, will be mounted in pairs to reduce the distant dipole moment.

2.4 Noise from magnets mounted on the UI mass and the penultimate mass

The requirement in T050271-00 "Considerations regarding magnet strengths for the Advanced LIGO test mass quadruple suspensions" to increase the force in the OSEMs at the UIM and PM led to concerns that using stronger magnets could result in noise being coupled into the mass from stray magnetic fields. This was discussed in T060001-00 “Increased strength Advanced LIGO ITM/ETM suspension PM and UIM Actuators” which concluded with recommendations for the magnet sizes which we have followed. We have chosen, conservatively, to use matched pairs of magnets with a small (30mm) spacing centre to centre.

2.5 Violin modes

T050108-00 showed that violin mode damping would be required. We are including provision for violin mode damping in the noise prototype design, although the mechanism for doing the damping is still under development.

2.6 OSEM driver noise

The requirements for noise in the electronics have been derived (see Jay Heefner’s document T060067 “AdL Quad Suspension UK Coil Driver Design Requirements”) to meet the technical noise limit and Birmingham’s designs will meet those requirements.

2.7 Creep

Creep is a discontinuous phenomenon at the microscopic scale. The concern is that discrete creep events may cause noise, especially in highly-stressed components. There are four highly-stressed parts in which this may be a problem: the blades, the wires, the blade clamps and the wire clamps.

2.7.1 The blades

We have chosen to use maraging steel, which has a good pedigree and has been demonstrated not to suffer from creep, provided it is correctly treated. In particular we will use a creep-relaxation heat treatment step. See T040108-03 “Blade, wire and clamp process specification” for details of the processing we will use and of the rationale. See T040083-01 “Comments on blade references from VIRGO” for more on the conclusions in the literature on which we based our decisions.

2.7.2 The wires

Any creep-induced noise effects in the wires will be isolated from the test mass by the monolithic silica final stage.

2.7.3 The blade clamps

In order to get a clean breakoff at the blade root (see “creak” below) we have chosen to make the edges of the clamps sharp. This will involve high stresses in the clamps, and so in order to avoid creep we will use maraging steel jaws at the UIM and a creep-relaxation heat treatment in the loaded state. See T040108-03 “Blade, wire and clamp process specification” section 5.

2.7.4 The wires and wire clamps

As with the wires, the test mass will be isolated form the effects of creep in the wire clamps. However, we are considering whether a creep-relaxation heat treatment step would be feasible and useful for the wires. The most critical wire break-off occurs at the penultimate mass where we have chosen to use a prism over which the wires pass. This is the same style of break-off used on initial LIGO at the test masses, and so we know that their noise performance at 100Hz was acceptable for initial LIGO. We extend this as best we can to the performance of the noise prototype as follows:

Assume that the creep events are short, so make a relatively flat force noise spectrum, up to some limit which is the same in initial LIGO and Advanced LIGO (because we manage to scale the design in the correct way not to make anything worse, presumably). Assume that the greater suspended mass brings no penalty (bigger events) or benefit (less reaction to events). There do not seem to be too many events in LIGO at the level of about, very roughly, 1e-19m/rtHz at 150 Hz.

Unless the creep events lead to nearly perfectly vertical motion, the dominant coupling to the interferometer will be longitudinal (as the vertical is rejected by >1000 times). But let us consider both cases:-

a) mainly longitudinal events

Here Advanced LIGO benefits by the extra suspension stage, so over 100 times isolation at 10 Hz (i.e. the extra isolation, ignoring the $1/f^2$ common to both cases to convert the force noise of the creep event to displacement).

It seems very unlikely that this type of event would show up at a rate very large compared to the rate of 150 Hz events in initial LIGO. We would have to make the 10 Hz behaviour at least 10 times worse in displacement terms than 100 Hz performance in initial LIGO to have the creep events show up above even the technical noise requirement in advanced LIGO.

b) mainly vertical events

Here Advanced LIGO has no isolation around 10 Hz, but good isolation by 100 Hz. We can't make a very strong statement about this type of event, as if they are just hidden in initial LIGO they could still be too large/frequent in Advanced LIGO, if only well below 100 Hz.

Although it seems that the motion should be mainly vertical, we find it hard to believe that the creep leads to 99.9% pure vertical motion (which it would have to do if we were not to see the longitudinal component already in initial LIGO). If the events are only 99% vertical, we can say that longitudinal dominates and case b) becomes less important.

2.8 Creak

By “creak” we mean the frequency up-conversion that might occur when surfaces slide or come into and out of contact. The blade and wire clamps are potential sources of creak. We have not made any measurements of creak but we note that the test mass will be isolated from the effects of creak by the penultimate mass and the ribbons. Arguments extrapolating from initial LIGO are similar to those above. We propose to minimise the effects by

- Using sharp break-off corners on the blade and wire clamps
- Using maraging-steel jaws on the blade clamp at the UIM

- Avoiding undoing the blade clamps once they have completed the anti-creep heat treatment

2.9 Noise in ear bonds

This was covered in the ribbon, ear and welding PDR #2 but is included here for completeness. T050216-00-K “Ear Bond Area Limit for ETM/ITM Optics from consideration of Thermal Noise” showed the relevant detail.

2.10 OSEM parasitic ECD

There is a potential for the magnets associated with the global control OSEMs to be coupled to the bodies of the OSEMs by eddy-current effects. This could allow noise in the reaction chain to reach the main chain. In T050102-00 “Eddy current damping in OSEM bodies, clamps and penultimate masses of Advanced LIGO ITM/ETM suspensions” it is shown that this effect could not be ruled out as insignificant on the basis of simple calculations at the level of the penultimate mass. For that reason we will use LIGO-style OSEMs, which have non-metal bodies, in these locations.

2.11 Blade resonances

In T050046-01 “Seismic and Thermal Noise Peaks from Blade Internal Modes in an ETM/ITM Quadruple Pendulum.” it is shown that, with reasonable assumptions about the Q factor of the blades, internal resonances in the blades could cause an infringement of the 10% noise requirement in a very narrow frequency band around 100 Hz. We have followed the outcome of that note by allowing for eddy-current damping of the lowest blades in the chain and by taking care to ensure that the blades at the various different levels have natural frequencies sufficiently separated to avoid coincident peaks. The blade natural frequencies for the noise prototype are approximately (T010103-05 “Advanced LIGO Suspension System Conceptual Design” page 39):

Top blades (in the top stage near the seismic table) 70 Hz
Middle blades (in the top masses) 98 Hz
Bottom blades (in the UI masses) 115 Hz

2.12 Clamp mass

The mass of the wire clamp should in principle be kept small in order to avoid invalidating the assumption (of zero mass) made in the transmissibility calculations. However, T040024-00 “Initial exploration of transmissibility by FEA of blades.” showed (in section 6.4) that a wire clamp of up to 100g mass has negligible effect on transmissibility of a typical blade, and T050046-01 “Seismic and Thermal Noise Peaks from Blade Internal Modes in an ETM/ITM Quadruple Pendulum.” included the effect of 10g wire clamps (from T040061-01 “Transmissibility of a revised set of blades”), when checking for the combined effect of the three blades on transmissibility performance. The clamps we will use have masses up to around 60 g.

3 Conclusion

None of the technical noise sources identified here, when taken individually, is expected to contribute more than 10% of the relevant noise limit with the possible exception of the eddy-current dampers which can be easily fixed once better data become available.