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LIGO Laboratory / LIGO Scientific Collaboration

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Recent Results and Conclusions from Tests of the UIM Blade Non-Magnetic Damper

Norna A Robertson and Calum Torrie

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1 Introduction

The purpose of this document is to capture results of recent work on testing of a prototype non-magnetic damper for the UIM blades of the quad suspension. We will also discuss the conclusions from our measurements compared to requirements and present the proposed final design for review.

2 Brief Background

As covered in integration issue 976, "ECR to implement a viscoelastic, tuned mass damper on the UIM blade springs", we have been tasked with looking into the design of a non-magnetic damper to damp the internal modes of the lowest blades in the quadruple pendulums, i.e. the blades at the upper intermediate mass (UIM), D060237. These dampers would replace the eddy current dampers originally included in the design, which were removed when they showed unacceptably high coupling to ambient magnetic field fluctuations. The damping is required to reduce the peak height from the first internal mode of the blade at around 110 Hz so that the peak does not compromise the sensitivity of the detector.

For clarification, firstly we note that our design is not in fact a "tuned" mass damper as in the title of the above ECR. It is fairly broadband – it damps both the first and second internal modes of the blade. A better description would be "dynamic absorber". Secondly we note that the ECR system has been subsumed into the FRS system with new numbering. This issue can now be found at fault report 5108.

3 Required Performance

We repeat here the required performance as presented in T1500185 "Notes on Design of Non-Magnetic Damper for UIM Blades" (section 2).

Calculations of the expected peak heights of the first internal mode of the quad blades due to seismic and thermal excitation were presented firstly in T050046, and updated in T1300595. It was shown in T1300595, table 2 page 6, that residual motion from seismic excitation at those peaks was at least a factor of 9 below the target sensitivity at the appropriate frequency, where the target sensitivity was taken from the Systems document T010075. This essentially meets the requirement that technical noise sources should lie a factor of 10 below the desired sensitivity. Residual noise from thermally excited motion is larger than for seismically excited motion and does not meet the technical noise requirements. For the UIM blades (which have the least isolation between blade and test mass) the thermal noise per test mass was estimated by using three different approaches in T1300595, with resulting peak motion at the test mass at the resonant frequency of ~ 114 Hz of between 2.3 and 5.7 x 10^{-21} m/√Hz (see table in section 2.4.2 of T1300595). For further consideration we will take the larger estimate of 5.7 x 10^{-21} m/√Hz to be conservative. These estimates assumed a quality factor for the blade material of 1 x 10^4.

The actual Q of several of the blades has been measured in situ – see LLO alog 16740. The values range from 3.00 x 10^4 to 5.14 x 10^4 at a frequency of ~ 112 Hz, with an average Q of 4.1 x 10^4. Given that the peak amplitude spectral density of thermal noise is proportional to √Q (from eqn 5 in T1300595) this means that the resulting motion at the peak will be higher than the numbers quoted above by on average √(4.1). Hence the peak motion is estimated to be 1.2 x 10^{-20} m/√Hz. This value should be compared with target sensitivity per test mass of 5 x 10^{-21} m/√Hz (see T1300595 table 2 page 6). Clearly the peak would lie above the sensitivity curve and therefore requires to be damped.

The amount of damping should be such as to take the peak height to one tenth of the target sensitivity, i.e. to a level of 5×10^{-22} m/√Hz. Given that the peak is proportional to √Q the requirement is such that Qdamped/Qundamped = $(5 \times 10^{-22} / 1.2 \times 10^{-20})^2$, where Qundamped = 4.1×10^4.

Thus Qdamped = 71.

We have found it challenging to reliably achieve this much damping with our prototype design, given limitations on space and size, and thus sought advice from Peter Fritschel as the Systems Scientist. He checked the above calculation. He further added "Given the conservativeness in some of the steps (thermal noise peak motion; 10x below ultimate noise floor) I think if you get the Q <= 300 that would be acceptable."

Thus we have recently been aiming to achieve a design which reliably gives us a damped Q for the blade of Q < 300. We now believe we have achieved this goal, and present below the design and results.

4 Design of UIM Blade damper

The original concept for a non-magnetic blade damper D1400298-v1 was based on dampers used for the beamsplitter structure side panels (D1101299), where the damper is a dumbbell like assembly with viton used as the spring and damper material. As discussed more fully in T1500185, our initial findings with this damper led us to revise the design to change the orientation of the dumbbell to vertical. We also carried out extensive tests looking at position of damper along the blade, mass of damper and amount of viton included.

Testing results up to June of 2015 are described in T1500186, and limitations and conclusions with respect to mass, size and position are discussed in T1500185. Since that time we have carried out further work and we describe below where we are now with the design.

The current design of the blade damper can be seen at D1400298, shown in figure 1. The basic concept has not changed but some details have.

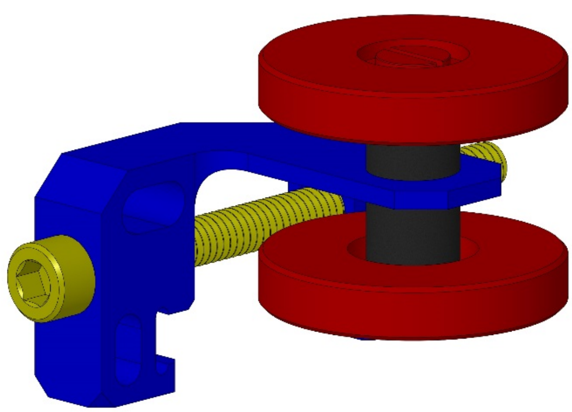


Figure 1. Current design of UIM blade damper

Firstly we have right-handed and left-handed versions of the damper so that the clamp holding the damper to the blade can be tightened from the "open" side of the main chain of the quad for both blades in that chain. This means that both clamps can be attached without requiring any separation or disassembly of the two chains of the quad for access. See figure 2.

Secondly we are using washers (variable in number as needed) to get the correct amount of compression on the viton to achieve the necessary amount of damping. It should be noted that during assembly, the two threaded fasteners which join the ends of the dumbbell together (items 7 and 10 in D1400298-v7) are "bottomed out" and thus the amount of compression of the viton is entirely adjusted by the thickness of the stack-up of washers. One of our findings has been that over-compression reduces the damping. Another finding has been that the manufacture of the viton pieces to the correct length has been challenging, such that the pieces we have in hand at present are somewhat variable in length. Thus we are testing and tuning each damper individually to achieve the required damping.

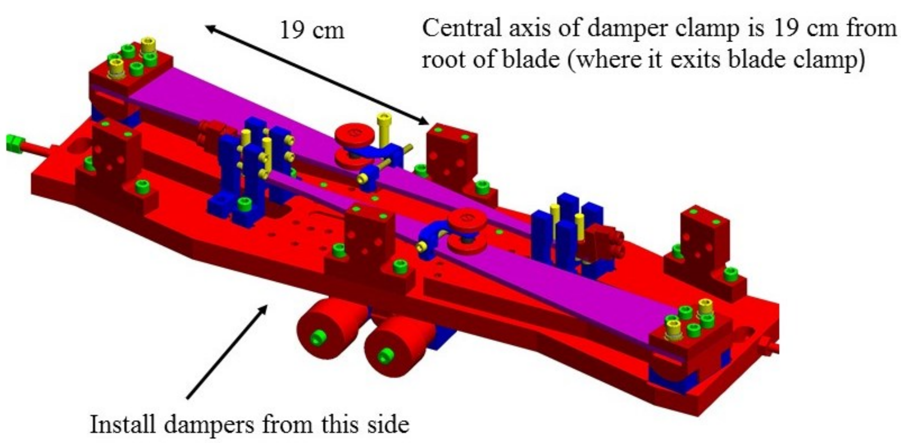


Figure 2. Diagram showing positions of dampers on UIM mass. (Upper plate of mass removed for clarity).

Thirdly, as discussed in T1500185, we have chosen to keep the damper mass at ~ 50 g for each unit, thus adding 100 g in total to the quad main chain. This lowers the test mass by ~ 0.5 mm if not allowed for. However it turns out that the quads at both LLO and LHO currently all have two Cu pieces, which formed part of the original eddy current damping units, still attached to the UIM. Their individual mass is also ~ 50 g. Thus by removing them and adding the new dampers, the total mass will remain approximately the same and no further adjustment in height should be required.

5 Position of the dampers along the blade, and number of dampers.

Previously, as discussed in T1500185, we had chosen a position of 16 cm from the root of the blade. After tests on the spare production quad assembled at LLO, we have ascertained that to avoid possible fouling on the "Z-tip" adjuster which lies under the blade, the best position for the damper is with its clamp positioned 19 cm from the root of the blade, as indicated in figure 2. This position still works for damping both the first internal mode at around 110 Hz and the second internal mode at around 320 Hz, as can be seen in the results section.

We will add dampers to the main chain only, thus two dampers per quad. The reaction chain can have significantly more motion than the main chain since it only affects the test mass motion through coupling. See for example T060043, where the allowed residual motion at the reaction mass is shown to be of order 10^4 times the residual motion of the test mass, whereas the actual isolation properties of the reaction chain are very similar to the main chain. Thus dampers are not required for the reaction chain.

6 Measurements and Results

We estimate the expected Q using the damper by taking measurements of the Q of the internal resonance of a UIM blade set up in air in the lab at Caltech, with and without the damper attached. An accelerometer is used as sensor and hammer as exciter, with the Bruel and Kjaer modal analysis system. See figure 3 for pictures of the setup. The total mechanical loss, Φ_{total}, is equal to the sum of the losses from each contributing factor, which for the blade without damper are the loss from the blade material, loss from its method of attachment and the presence of the accelerometer, and loss from the damping of the blade due to air. The losses, Φ, sum together, so that we have

Φ_{total} (undamped) = $\Phi_{material} + \Phi_{attach} + \Phi_{air}$.

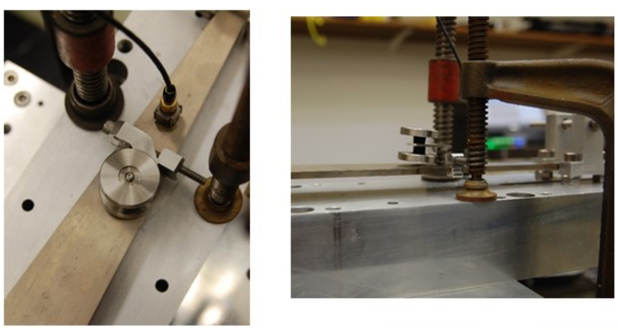
Similarly when we attach the damper with its associated loss Φ_{damper} we have

Φ_{total} (damped) = $\Phi_{material} + \Phi_{attach} + \Phi_{air} + \Phi_{damper}$

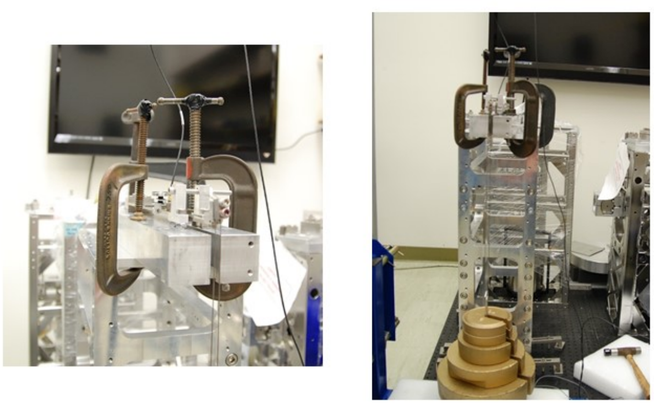
Thus $\Phi_{damper} = \Phi_{total}$ (damped) - Φ_{total} (undamped)

Also on resonance Q is given by $1/\Phi$

Hence $Q_{damper} = 1/\ \Phi_{damper} = [1/Q_{total}\text{ (damped)} - 1/Q_{total}\text{ (undamped)}]^{-1}$



Top view (left) and side view (right) of damper attached to blade. The accelerometer can be seen in the left image.



Pictures of overall set-up showing method of loading blade to its nominal flat position.

Figure 3. Measurement set-up in the lab at Caltech.

Examples of data are shown in figures 4 and 5. Figure 4 shows data from a prototype and includes the first and second internal modes of the blade. We see both modes are damped. Figure 5 shows data for one of the production units at the first internal mode.

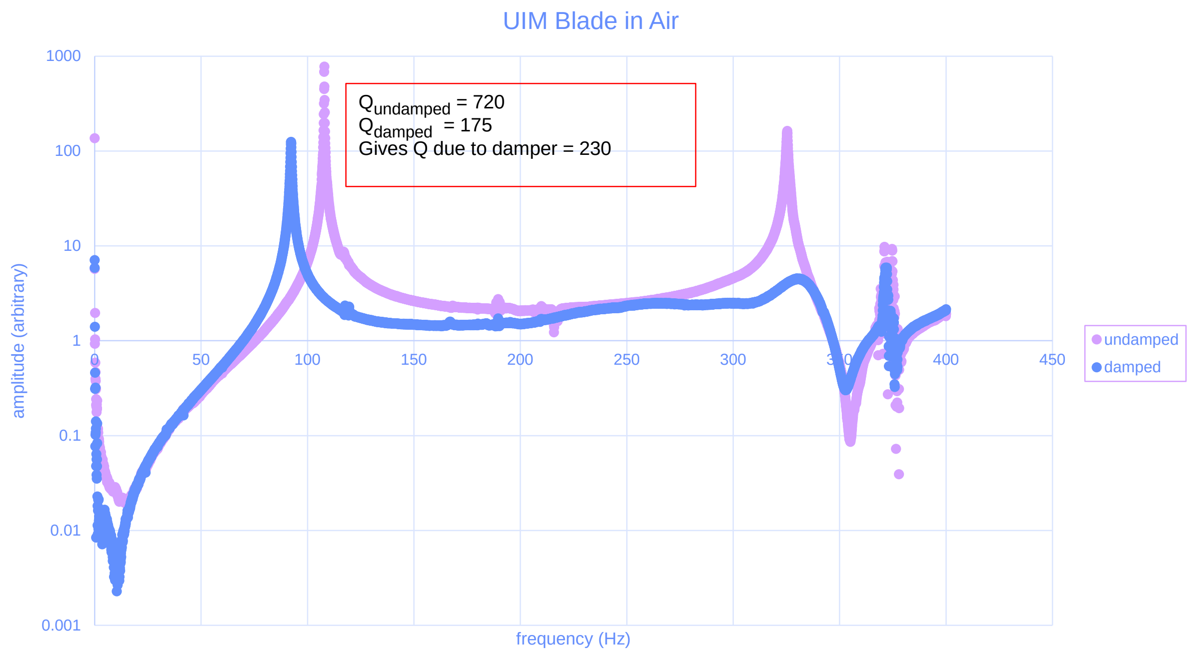


Figure 4. Example of data taken in air, showing the first two internal modes.

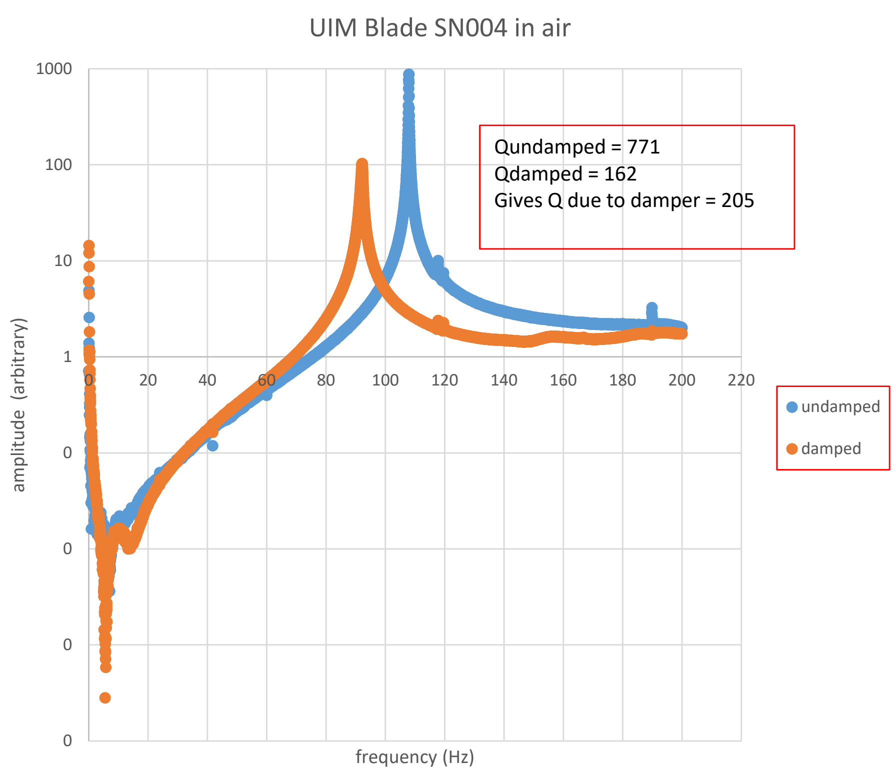


Figure 5. Example of data for one of the production units at the first internal mode.

We have tested all the dampers (SN001 - 004) which have so far been assembled for use at LLO on the ITMs. The in-air measurements give values of Q due to the damper in air of 219, 169, 115, 205 (with estimated errors around +/- 5%.)

We have recently recognized that the damper loss we measure in air will be affected by the presence of air on the damper. We have thus tested a damper attached to a UIM blade on our test quad under vacuum to see how much of an effect this is. For the same damper we have found Qdamper (in air) = 191 and Qdamper in vacuum = 242. This implies that the extra loss due to air on the damper is approximately 1.1×10^{-3}. With a target Qdamper in vacuum of <=300, we want to see a Qdamper in air given by Qdamper in air = $(1/300 + 1.1 \times 10^{-3})^{-1} \approx 225$.

Thus in fact our target becomes a measurement of Qdamper in air <=225, for a Qdamper in vacuum of <=300. Our recent results are still in line with these targets.

Finally we note for completeness that when such dampers are attached to a UIM blade on a real quad in vacuum, the resulting Q_{total} comes from the sum of loss due to the damper (i.e. 1/Q due to damper) and the loss of the blade at its resonance, whose Qs have been measured to be ~ (3 to 5) x 10^4 (LLO alog 16740). However since the blade loss is so much less than the damper loss, the resulting loss is essentially that due to the damper loss alone. Hence the above targets remain.

7 Conclusions

We believe we now have a robust design and testing procedure to check that the UIM blade dampers achieve a Q of <= 300 in vacuum. All dampers will be tested and tuned to meet this target before being shipped to the observatories for installation.

8 Appendix: Update on Review Points and Further Measurements

Several points were raised at the review of the damper design held on 6th April. These are summarized in the review report L1600062. We address the four actions here. In addition we have amended text in the body of this document to address comments/observations 1), 2) and 7) from L1600062.

8.1 Assembly temperature

As stated in L1600062, a concern was raised about possible variation in damping performance as a function of temperature. To address this, all production units, starting with the measurements of the cleaned and baked first four units (SN001-004 inclusive), are being/will be tested in a lab at approximately the same temperature as the appropriate LVEA/VEA environments at the observatories. LLO have recently changed their working temperature to be 68 deg F in the LVEA and VEAs. Thus we are carrying out measurements at this temperature (to within ~1 deg F) for all LLO units (SN001-004 for the ITMs and SN006-009 for the ETMs). The LHO units (still to be assembled at time of writing) will be tested at their appropriate temperature(s).

8.2 Venting

To avoid trapped volumes, SN001-SN004 have had grooves added to the bracket where the viton damper parts sit (see L1600062). Subsequent units will have a vented buttonhead screw, as described in L1600062.

8.3 Change of position of accelerometer

As stated in L1600062, we are now carrying out testing with the accelerometer mounted close to the root of the blade (~ 1 cm away from the edge of the blade clamp). This has given us two benefits. Firstly the Q of the "undamped" blade is significantly higher than the values we were seeing with the accelerometer near the tip. Secondly the variability in Qs is much reduced. We do keep checking how well the accelerometer is adhering and also checking that the "dressing" of its cable is good (not touching anything, not taut etc). We check the undamped Q value for every set of damped measurements of a particular unit, so that we can keep an eye on any drifts in the undamped Q.

8.4 Installation procedure

E1600011 will be updated as required with fuller details.

8.5 Further Measurements

The values for the Qs reported for SN001-004 in section 6 above predated the move of the accelerometer to being close to the blade root. This they suffered from the variabilty we had been seeing which we attribute to the varying effect of the damping due to the accelerometer. They were also taken before the units were cleaned and baked. We have subsequently remeasured these units after they were disassembled for clean and bake and reassembled, and after the accelerometer position was changed, and at a common temperature of 68 deg F. The results are more consistent and more tightly clustered, with Qs in the range 114 to 136. These results are well within the target value required. Full details of results are given at E1600083. That document will be updated as further units are assembled and tested.