OMC Structure Frequencies –Results and Interpretation

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New conclusions section added (section 6) 28 Aug 2007

LIGO DCC #: T070207-00-R

1. Introduction

A series of measurements have been made to measure the first few resonances of the support structure for the OMC to test whether the structure meets the requirement of no resonances below 150 Hz.

These measurements were made using a loudspeaker style driver with amplifier to drive the structure, and a B and K accelerometer type 4378 and SR560 amplifier for sensing, using a swept sine signal from the SR785 spectrum analyzer to measure a frequency response over a frequency band of 70 Hz to 400 Hz. We did a check that there were no resonances below 70 Hz. See figure 1 for a typical early setup.

Figure 1: set-up for first set of measurements. Note that the scissors table under the driver was replaced by heavy steel blocks in later measurements.

2 First measurements

The first measurements were made on 13th April 2007. For an unloaded structure a persistent small feature around 138 Hz was seen in both longitudinal and transverse directions with first main peaks much higher (around 211 and 195 Hz respectively). Note that the longitudinal direction is that perpendicular to the long axis of the structure. We also looked at loading the structure with non-suspended mass and as expected the main peaks moved downwards, as did the 138 Hz feature.

3 Second measurements – tightened and increased number of dog clamps

The second set of measurements was made on 16th April. It was found that the 6 large clamps (2 each on long sides, one each on short sides) holding the structure to the milling machine bed were not as tight as they could be. The two on long sides were moved to be closer to the corners and tightened and two new ones added so that there were now three on each long side and one on each end. The effect of adding and tightening clamps was to remove the 138 Hz feature. The results from these series of measurements are presented in Vuk Mandic's report "test_support.pdf" April 18, 2007 on the OMC wiki. A brief summary is given here.

3.1 Driving and sensing transverse, no added mass, first peak at ~ 180 Hz, with other peaks at ~ 290 and 390 Hz.

3.2 Driving and sensing longitudinal with no added mass, first (smaller) peak at ~165 Hz, and next at ~222 Hz. 165 Hz peak larger when looking at middle of top bar compared to close to driving point on leg half way up. When sensing vertical at middle of top bar 165 Hz was strong and there was very small bump around 131 Hz.

3.3 Driving and sensing longitudinal with added mass (tablecloth, blade supports and additional mass of 6 steel cylinders, total 9 lbs = 4.1 kg)
Observed features at ~ 148 and 207 Hz plus at higher frequencies.
When moved sensor from middle of top bar to close to driving point similar results
(~ 146 and ~ 204 Hz).

3.4 Driving and sensing transverse with added mass as above. Large feature at ~ 153 Hz and further peaks around 260 Hz and above.

Figure 2 shows what the structure with its added mass for these measurements.

Figure 2 Structure with added mass = 4.1 kg (9 lb)

3.5 Conclusions

We concluded the following from these measurements. Firstly without added mass the first two peaks appear to be at ~165 (long) and ~180 Hz. When we loaded the structure those resonances went down to 148 and 153 Hz. Thus we are very close to meeting the requirement of no resonances below 150 Hz. However the added mass was not quite as much as will be used in practice (blade assemblies are likely to add ~ 1kg). Also it is of interest for us to understand how well the leg plates used to stiffen the weld joints are working for future applications. So we decided to take another series of measurements.

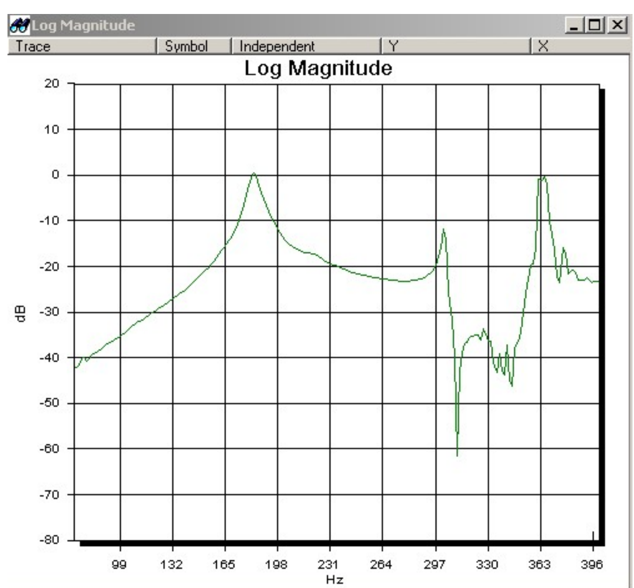
4 Measurements to investigate effect of leg plates – no added mass

Measurements were made on 19th April, morning and afternoon. These measurements are summarised in the EXCEL spreadsheet "summary_19april07.xls"

The morning measurements involved investigating the structure with no added mass. Data was taken for longitudinal and transverse directions with all plates, only bottom plates, only top plates and with no plates. We consider the first resonance in each case

4.1. Longitudinal
All plates: 166 Hz
Bottom plates only: 171 Hz (see figure 3a)
Top plates only: 125 Hz
No plates: 124 Hz.

4.2 Transverse
All plates: 183 Hz
Bottom plates only: 183 Hz (see figure 3b)
Top plates only: 138 Hz
No plates: 133 Hz



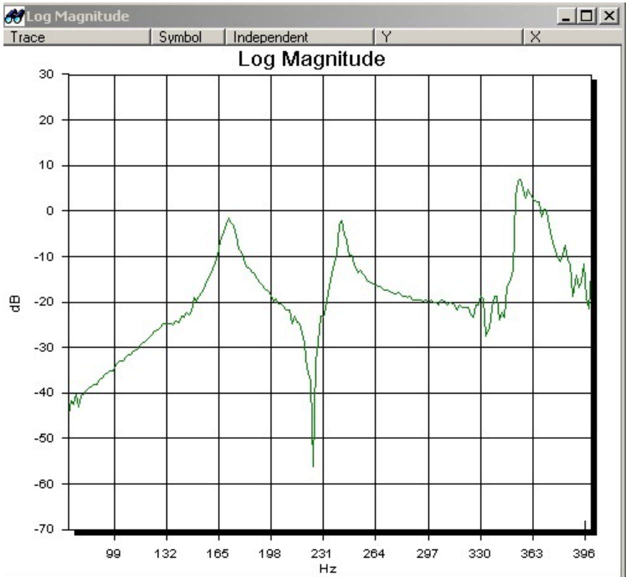


Figure 3a (left) Bottom leg plates only. Longitudinal direction. No added mass
Figure 3b (right) Bottom leg plates only. Transverse direction. No added mass

4.3 Conclusion

We see that the bottom plates are doing all the work, and that they considerably stiffen the structure by 40 to 50 Hz. The top plates may provide some stiffening but they also add mass and the net effect on the first resonances in this set of measurements is essentially zero. Similar effects on the higher modes can also be seen (see EXCEL file – the case of “no plates” and “bottom plates only” are similar.) There is evidence that we didn’t tighten the plates well when we replaced them – repeat measurements with all plates were lower than the original measurements by up to 10 Hz.

5 Measurements to investigate effect of leg plates – with added mass

The previous measurements demonstrated that the top leg plates were not adding anything useful to the structure when no added mass is present. However that may not be the case when we add mass, so we took a further set of measurements – see EXCEL file for details. We looked at cases with top and bottom plates and with bottom plates only. Two different set-ups of added mass were investigated, firstly with added mass as in figure 2 and 3.3 and 3.4 above (tablecloth, blade supports and additional mass of 6 steel cylinders, total 9 lbs = 4.1 kg), and secondly with 2 additional Al plates (each 2.0 lb) resting on the blade supports, held in place with beeswax, minus 4 cylinders previously attached there (hence tablecloth, blade supports, 2 cylinders and 2 Al plates, total mass 5.5 kg). Note that the second mass is probably more than we will have in practice. We note the first frequencies for each case below.

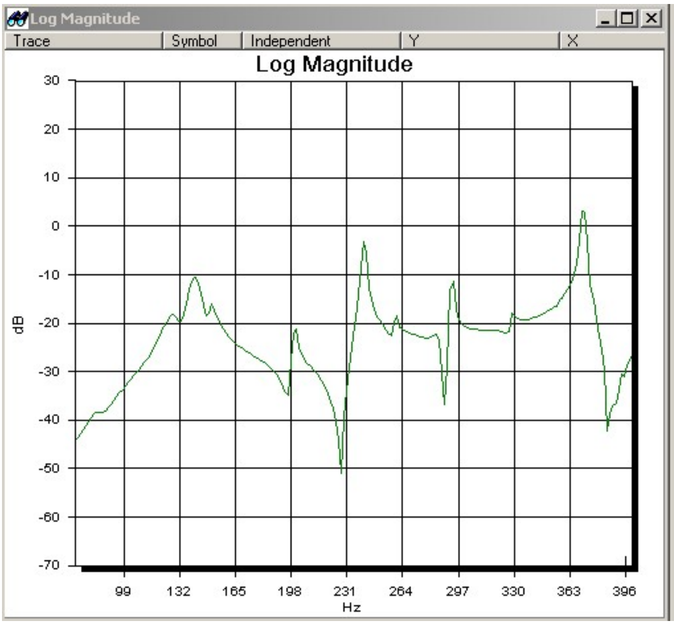
5.1 Longitudinal

All plates, no extra mass: 160 Hz
All plates, extra mass 4.1 kg: ~141 Hz (middle of three peaks) (figure 4a)
All plates, extra mass 5.5 kg: ~136 Hz (middle of three peaks) (figure 4b)
Bottom plates only, extra mass 4.1 kg: ~ 143 Hz (middle of three peaks) (figure 5a)
Bottom plates only, extra mass 5.5 kg: ~138 Hz (middle of three peaks) (figure 5b)

5.2 Transverse

All plates, no extra mass: 174 Hz
All plates, extra mass 4.1 kg: 150 Hz
Bottom plates only, extra mass 4.1 kg: 151 Hz (figure 6a)
Bottom plates only, extra mass 5.5 kg: 141 Hz (figure6b)

We note a small feature at 132 Hz has appeared in the longitudinal and it is more marked when extra mass is added (could this be the same feature seen when clamping to the table was not optimum?). In general the longitudinal results were rather messy when mass was added, with the first peak actually split into three peaks – see figures 4 a) and b) below with all leg plates and figures 5 a) and b) with bottom leg plates only. With 4.1 kg added mass we see small features below and above the first prominent resonance. With 5.5 kg added mass using beeswax to hold the two extra masses a triple peak effect is more obvious. The 132 Hz feature is part of this effect, and also the beeswax was probably not stiff enough so that we are seeing movement of the added plates coupling to the structure resonances. Beeswax was used for expedience. If repeating such measurements we should clamp or bolt all the mass added.



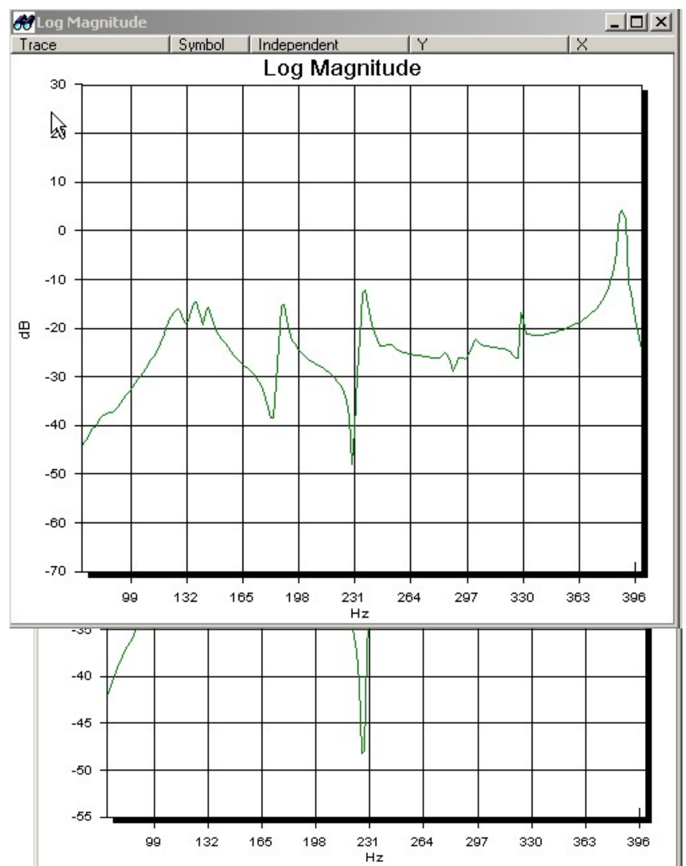


Figure 4a (left) leg plates top and bottom. Longitudinal direction. 4.1 kg added mass
Figure 4b (right) leg plates top and bottom. Longitudinal direction. 5.5 kg added mass

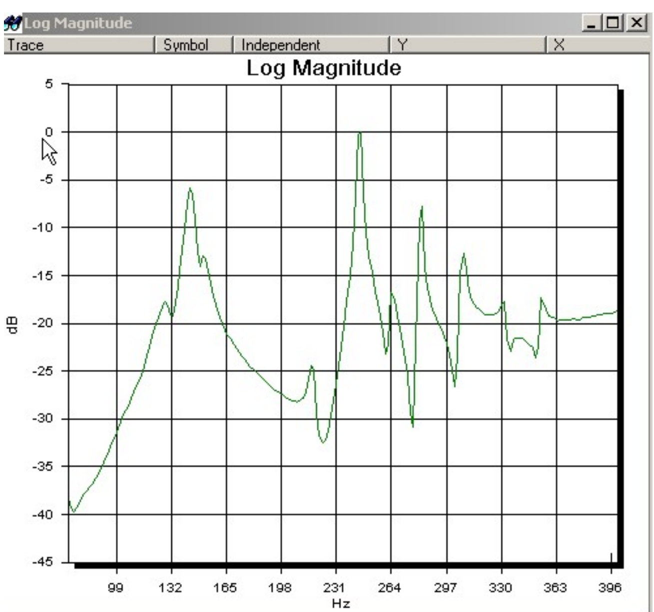


Figure 5a (left) bottom plates only. Longitudinal direction. 4.1 kg added mass
Figure 5b (right) bottom plates only. Longitudinal direction. 5.5 kg added mass

The transverse traces were cleaner, see figure 6.

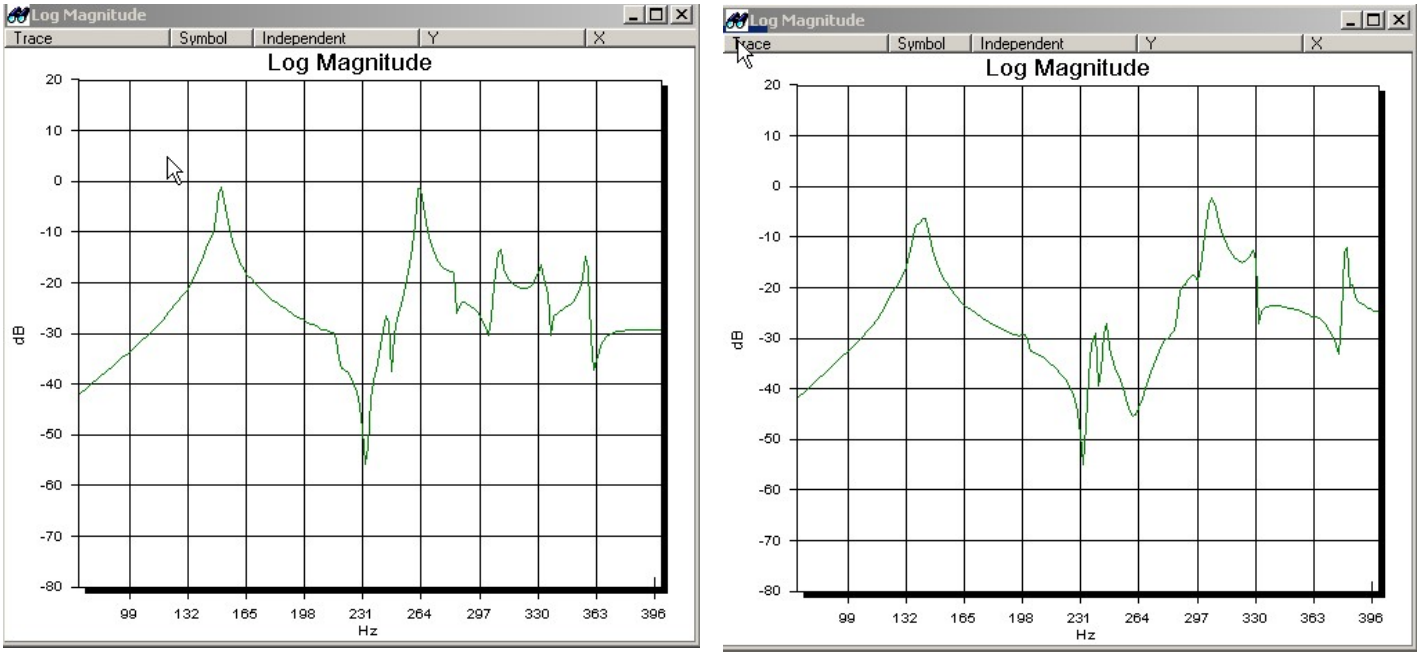


Figure 6a (left) bottom plates only. Transverse direction. 4.1 kg added mass
Figure 6b (right) bottom plates only. Transverse direction. 5.5 kg added mass

5.3 Conclusions

Firstly the top leg plates are not doing anything useful to stiffen the first two resonances. We note that each of the leg plates weighs 0.68 kg. Thus with four of them the added mass is 2.7 kg, which is not insubstantial compared to the total non-suspended mass which we expect to use (between 4 and 5 kg). Secondly we note that the initial conditions (no extra mass) had resonant frequencies less than we have seen before any leg plates were removed, and hence all of these results are likely to be several Hz less than we could achieve with extra care taken in tightening all the bolts (and possibly in the exact positioning if there is some slop?) Thirdly the results show that with added mass of 5.5 kg the lowest frequency (in the longitudinal) was found to be around 136 Hz, taking the middle of the 3 peaks. This is a lower bound on what we should be able to achieve for two reasons: 1) the added mass should be less than 5.5 kg in reality, and 2) the leg plates are not bolted on as well as they can be.

6 Overall Conclusions and Comparison to Requirement

Concentrating on the lowest resonant frequency we observed the following key results:-

i) With no added non-suspended mass, and after tightening and increasing the number of dog clamps attaching the structure to the table: 165 Hz

ii) With added non-suspended mass of 4.1 kg: 148 Hz
iii) With added non-suspended mass of 4.1 kg, after taking off and re-bolting on all leg plates: 141 Hz
iv) With added non-suspended mass of 5.5 kg, after taking off and re-bolting on all leg plates: 136 Hz

We note the difference between results ii) and iii). Clearly we did not reattach the leg plates well (as already noted above). This implies that result iv) is less than it would be if the reattachment was done correctly. We can estimate that we have lost ~7 Hz and thus this frequency should be closer to 143 Hz. We also note that we do not have an exact figure yet for the non-suspended mass for the final configuration. Several reworks are been carried out to the added mass and to the structure itself (different design of “diving board” supporting the top blades, new mounting brackets for electrical wiring etc) and thus a final figure for this is not yet available. We anticipate it will lie between 4.1 and 5.5 kg.

Our requirement was to achieve 150 Hz for the first resonance. From the results to date we expect that actual first resonance to lie between ~143 and ~148 Hz. Thus we are a few hertz below the requirement. Given the difficulties encountered in making an aluminium structure with a design incorporating welds which satisfy our vacuum requirements while still maintaining stiffness (see LIGO DCC # T070205-01) we believe that achieving a result as close as this is commendable, and we trust it will be acceptable for Enhanced LIGO. A longer term solution which could be investigated for Advanced LIGO if necessary is discussed in T070205-01.