Comparing the modal frequency results of a finite element analysis with physical tests on a suspended noise prototype structure – 1
T070147-00-K

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Introduction

During physical testing of LIGO structures, modal frequencies have been seen below the first predicted frequency as calculated by finite element analysis (FEA). The purpose of this work is to go some way in proving that these lower frequencies are not attributed to the structure and that they are more likely to do with the clamping method, or that the structure is not, as assumed, clamped to something that is infinitely stiff.

In order to get a clear picture of the modal frequencies of the LIGO structures physical tests have been carried out on unconstrained structures. The structures are suspended by a sling in a way that does not limit the motion of the mode shapes, accelerometers are placed in positions that will identify the mode shapes predicted by the finite element analysis. The results from the physical tests are then compared to a finite element analysis of the same unconstrained structure; the first modal frequency measured from the physical tests is compared to the seventh modal frequency of the finite element analysis.

In this report the upper and sleeve structure are considered to see whether their behaviour can be predicted by FEA, similar reports exist for the beam splitter structure, T070148 and T070149.

Modal frequencies from the finite element analysis

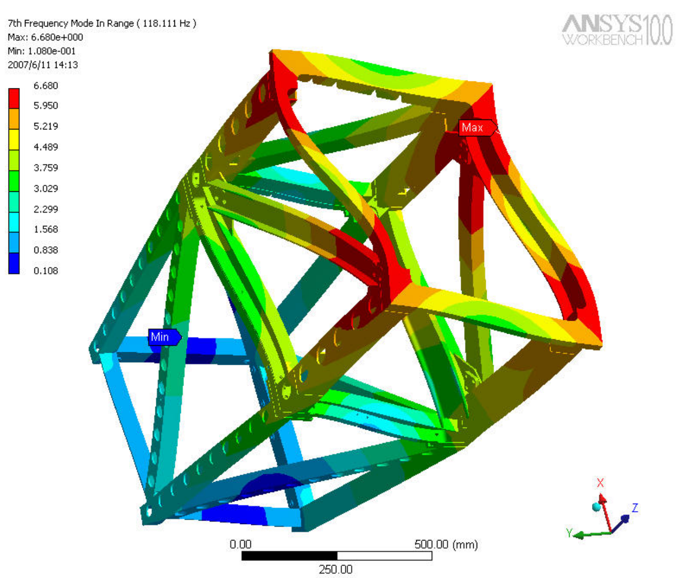

Fig 1. The 7th mode from the FEA gives the unconstrained mode at 118Hz.

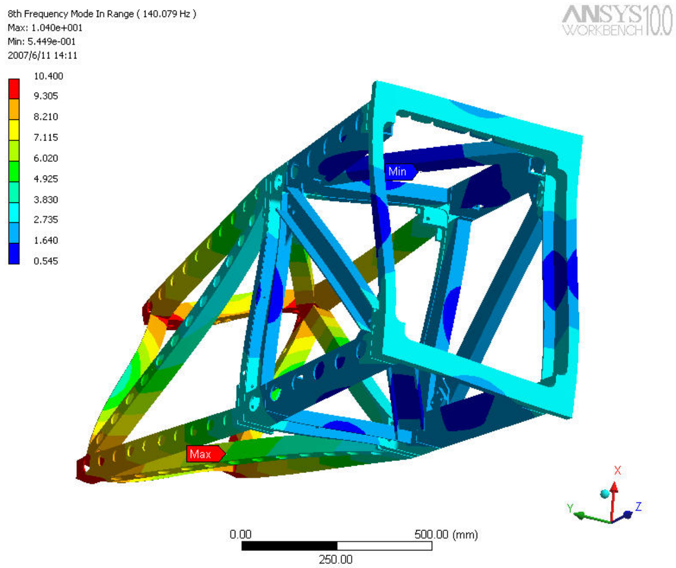

Fig 2. The 8th mode from the FEA gives the unconstrained mode at 140Hz.

Physical tests of the structure

The structure is suspended form the sleeve so not to constrain the 7th mode shape.

Fig 3. The upper and sleeve structure suspended at the sleeve end by a sling.

Fig 4. An accelerometer is positioned on the front face of the upper structure in the bottom right corner, as shown in the photograph, this represents channel one.

Fig 5. An accelerometer is positioned on the front face of the sleeve in the top right corner, as shown in the photograph, this represents channel two.

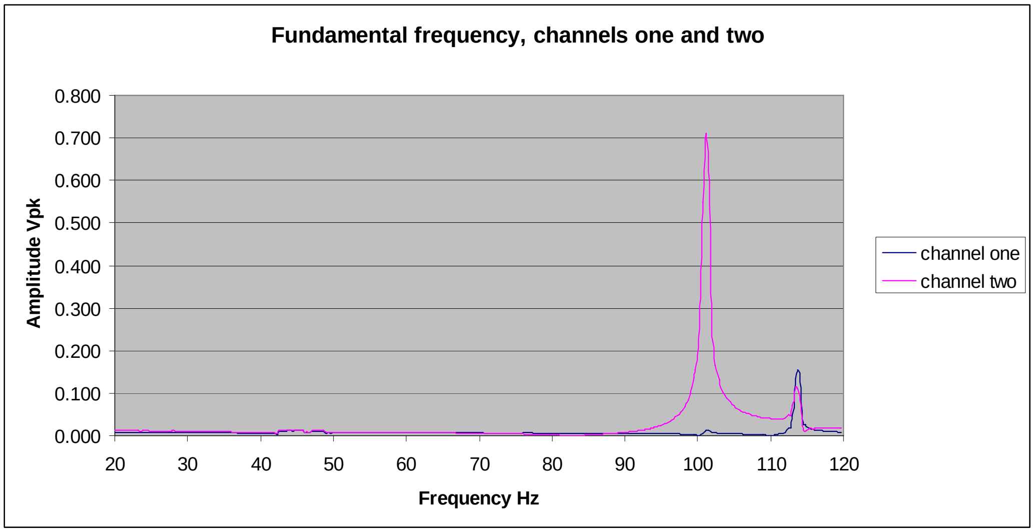

Fig 6. Modal frequencies from the upper and sleeve structure set up as in figures 3-5.

Channel two shows a frequency peak at 101Hz with an amplitude of 700 mVpk while channel one only shows an indication of the same peak with an amplitude of 12 mVpk. This indicates that the majority of the movement at this frequency is in the sleeve structure, pointing the mode shape to be that of the 8th mode from the FEA.

Channel one shows a frequency peak at 114Hz with an amplitude of 156 mVpk while channel two shows the same peak at 114 mVpk, this indicates that the more of the movement at this frequency is in the upper structure, pointing the mode shape to be that of the 7th mode from the FEA.

The mode shapes seem to have switched position in the real tests, with the 8th modal frequency coming in 30% lower than predicted by the FEA, suggesting that the sleeve structure is not as stiff as the FE model. This might be explained by the weld configurations in the sleeve not working to best effect for the given mode shape.

If the second peak measured at a frequency of 114Hz represents the 7th mode from the FEA predicted at a frequency of 118Hz then there is a very good comparison between the FEA and the real tests. This is to be expected if you consider that the part of the upper structure governing the mode shape is a ring machined from solid which is very well represented by the FE model.

Validating the 7th modal frequency

To prove that the second peak at 114Hz in figure 6 is the 7th modal frequency from the FEA shown in figure 1, a beam was clamped across the corners of the upper structure. If the assumption is correct the frequency at 114Hz should increase.

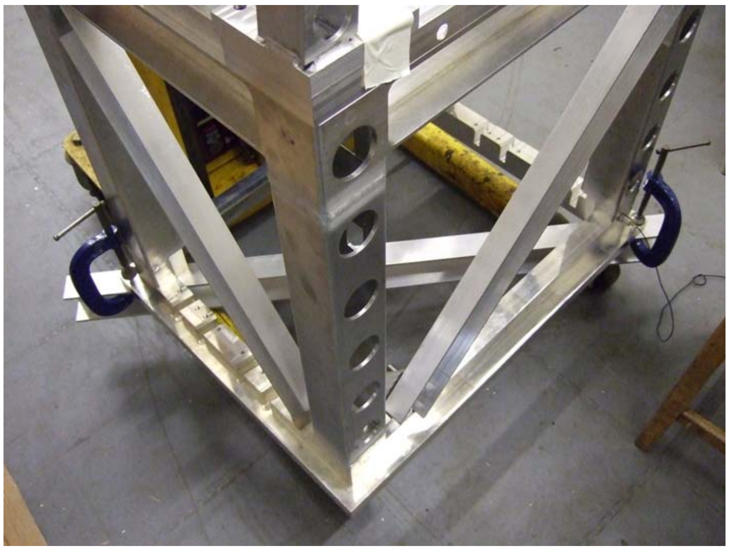

Fig 7. Channel section clamped across the corners of the upper structure.

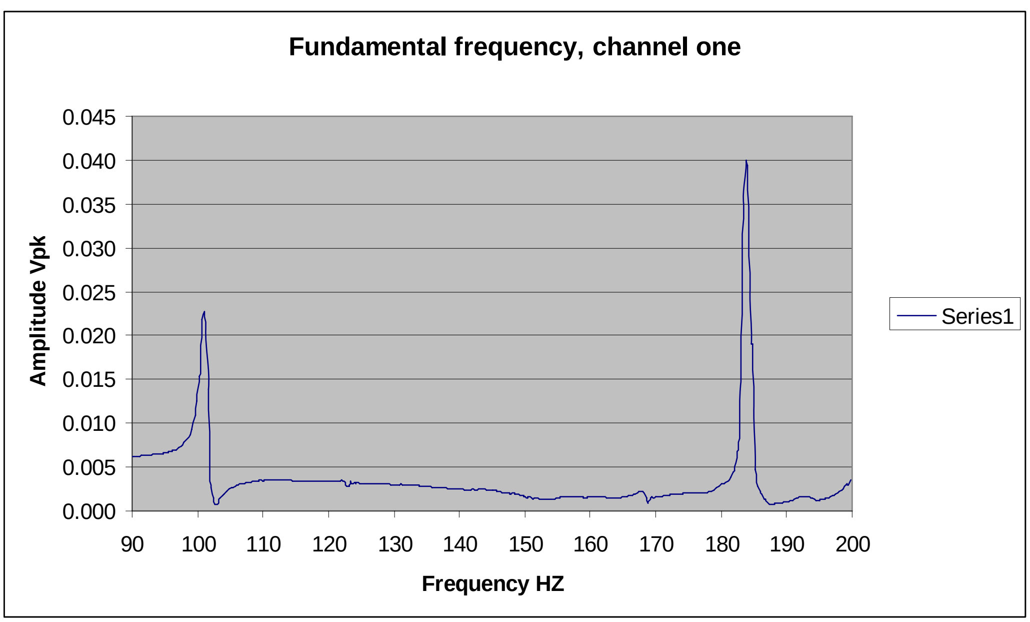

Fig 8. Modal frequencies from the upper and sleeve structure set up as figure 7.

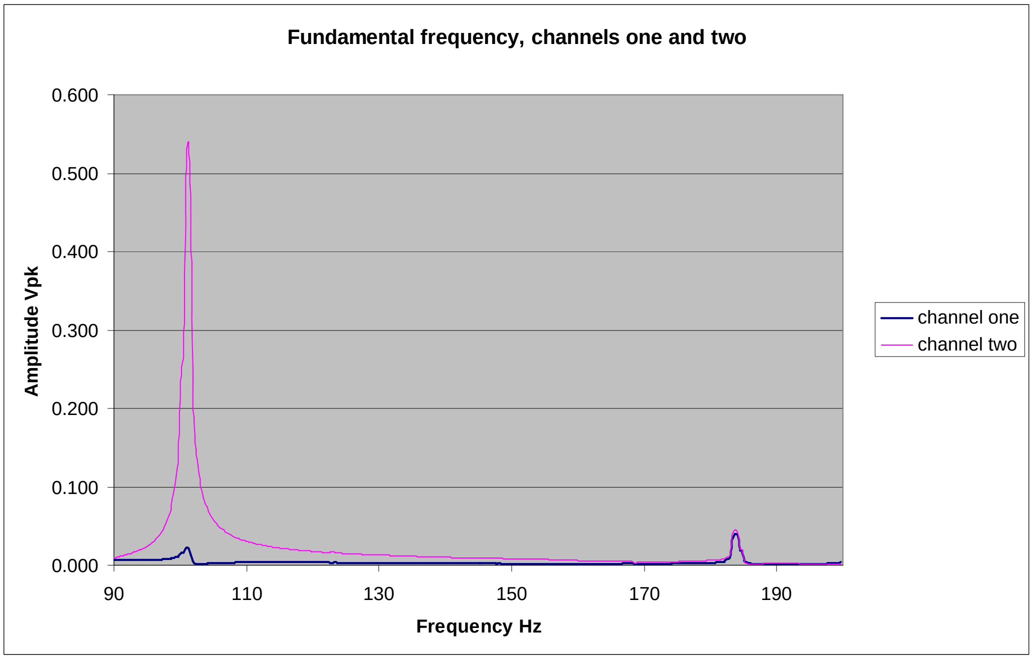

Figure 9. Modal frequencies from the upper and sleeve structure set up as figure 7.

Both channels indicate that the modal frequency at 101Hz has not moved and that the modal frequency at 114Hz has moved up to 183Hz, confirming that the 114Hz is that of the 7th modal frequency shown in figure 1.

Validating the 8th modal frequency

To prove that the first peak at 101Hz in figure 6 is the 8th modal frequency from the FEA shown in figure 2, a beam was clamped across the corners of the sleeve structure. If the assumption is correct the frequency at 101Hz should increase.

Fig 10. The upper and sleeve structure suspended at the upper structure end by a sling.

Fig 11. An accelerometer is positioned on the upper structure in the top left corner and on the sleeve structure in the bottom left corner as shown in the photograph, these represent channels one and two respectively.

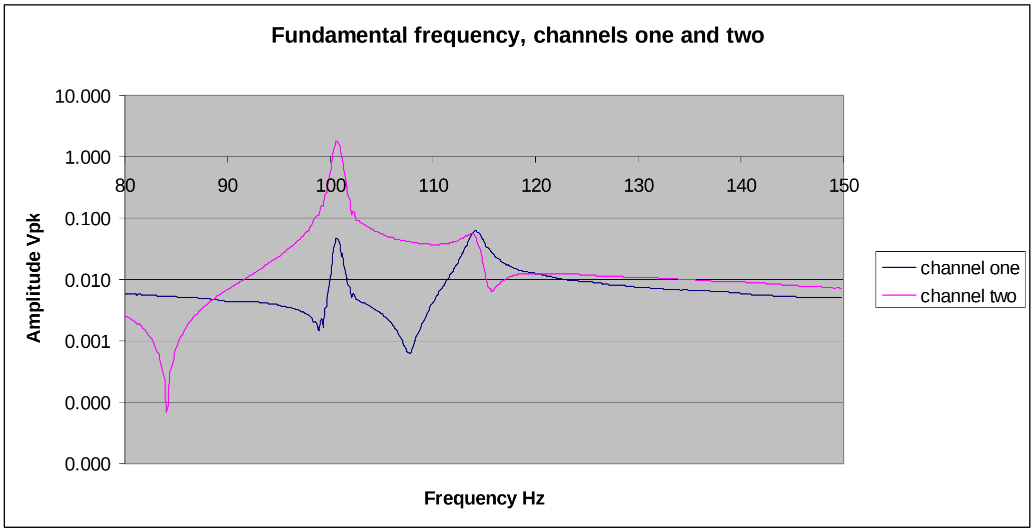

Fig 12. Modal frequencies from the upper and sleeve structure set up as in figure 10.

From figure 12, channel one shows the sleeve mode at 101Hz at 0.042Vpk and the upper structure mode at 114Hz at 0.059Vpk, channel two shows the sleeve mode at 101Hz at 1.62Vpk and the upper structure mode at 114Hz at 0.054Vpk.

Adding the stiffener to the sleeve structure

Fig 13. A square bar clamped across the corners of the sleeve structure.

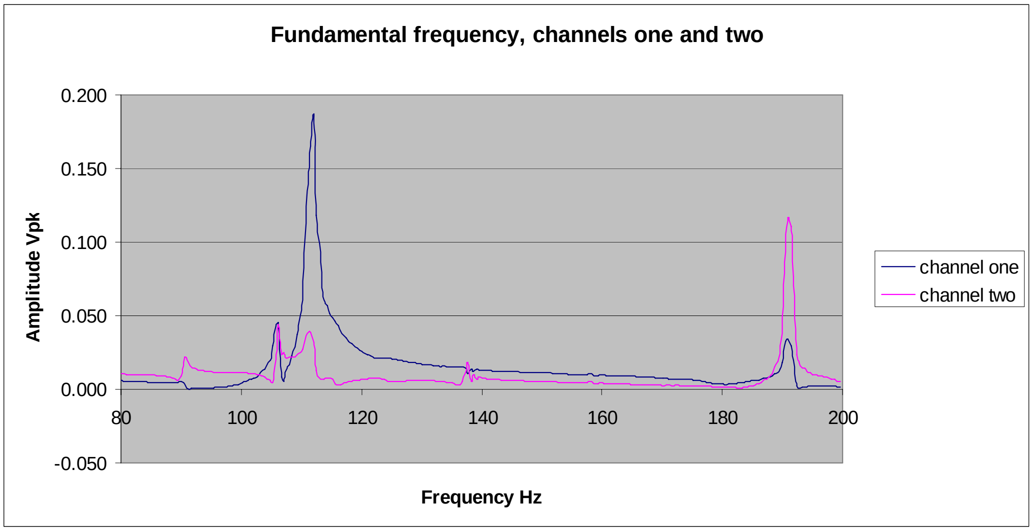

Fig 14. Modal frequencies from the upper and sleeve structure set up as in figure 13.

Both channels indicate that the modal frequency at 114Hz has not moved and that the modal frequency at 101Hz has moved up to 190Hz, confirming that the 101Hz is that of the 8th modal frequency shown in figure 2.

Fig 15. Accelerometer placed mid-span of the square bar

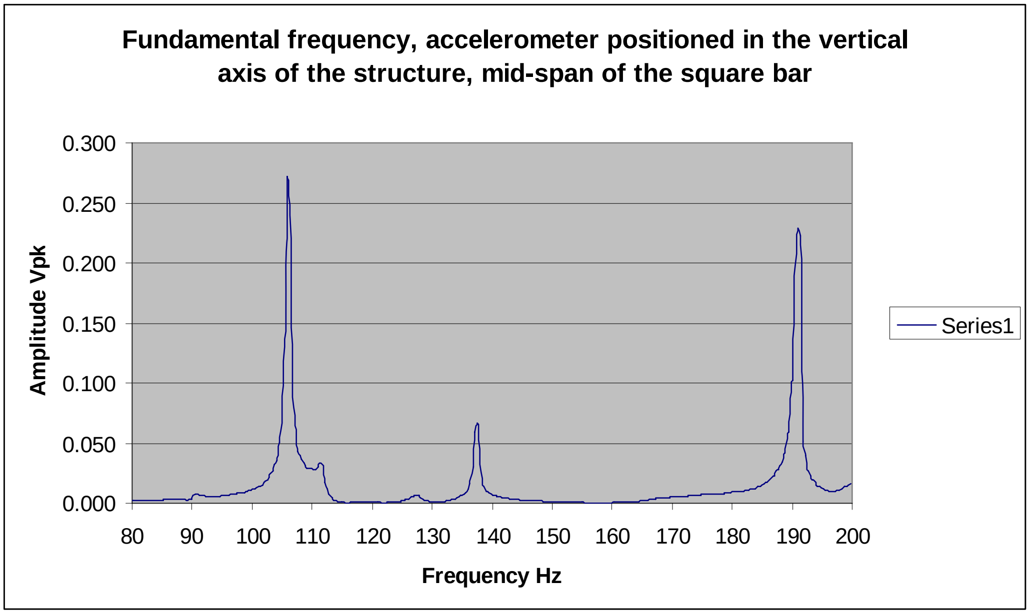

Fig 16. Accelerometer positioned in the vertical axis of the structure, mid-span of the square bar, as shown in figure 15.

The accelerometer when positioned mid-span of the stiffening bar has a peak at 106Hz and 138Hz accounting for the extra peaks seen in figure 14.

Modal frequency	FEA [Hz]	Measured frequency [Hz]	Discrepancy [%]
1st	101	140	28
2nd	114	118	3