LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

LIGO-T070155-00-K *Advanced LIGO UK* June 2006

Preliminary Measured and Predicted Frequency Analysis of the Noise Prototype Structures

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This is an internal working note
of the Advanced LIGO Project, prepared by members of the UK team.

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Particle Physics and Astronomy Research Council (PPARC)

http://www.ligo.caltech.edu/

http://www.eng-external.rl.ac.uk/advligo/papers_public/ALUK_Homepage.htm.

1. INTRODUCTION

This document records the status of the frequency analysis performed on the noise prototype structure. A series of frequency tests were done to gain confidence in the structural design presented in the Advanced LIGO ITM/ETM Noise prototype Preliminary Design Review -3 (PDR). For the PDR it was necessary to demonstrate that the proposed design had an experimentally measured fundamental frequency to within 25% of the predicted finite element result (reference LIGO T060088-00-K). Due to the unavailability of some of the structures the tests began with the sleeve and a simplified face plate design, progressing to the sleeve combined with the upper structure.

The experimental results on the sleeve and face plate design were done by the RAL space department on an LDS (Ling Dynamic system) 954LS mk2 electro-dynamic shaker, carrying out low level sine sweeps from 5 – 500 Hertz at 0.5g and 2 octaves per minute. By dwelling on the resonant frequencies the mode shapes were identified with the aid of a strobe.

The experimental results on the upper and sleeve combined structure were done at RAL initially by mounting the structure on steel blocks using accelerometers, power supply and an oscilloscope and tapping with a hammer.

Figures for the discrepancy between the experimental and predicted frequencies are given.

2. PREDICTED AND EXPERIMANTAL RESULTS FOR THE SLEEVE AND FACE PLATE DESIGN.

2.1 FE PREDICTIONS FOR THE SLEEVE DESIGN

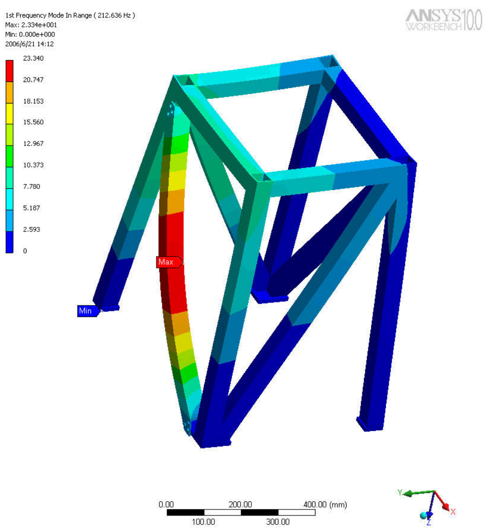

Fig 1. Sleeve structure with removable member first frequency 213Hz

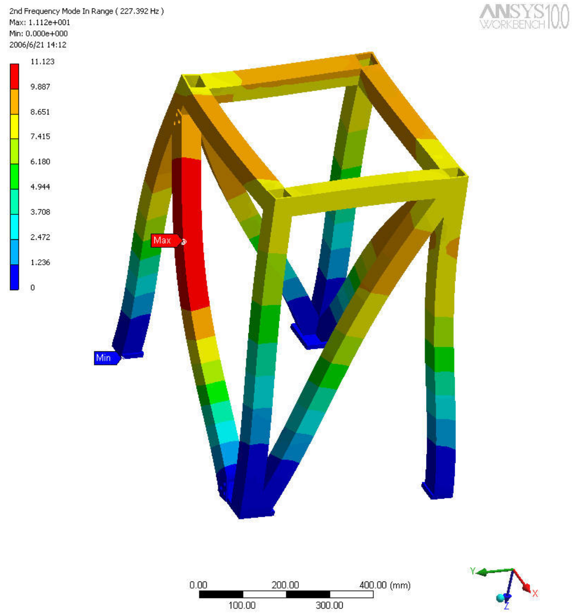

Fig 2. Sleeve structure with removable member second frequency 227Hz

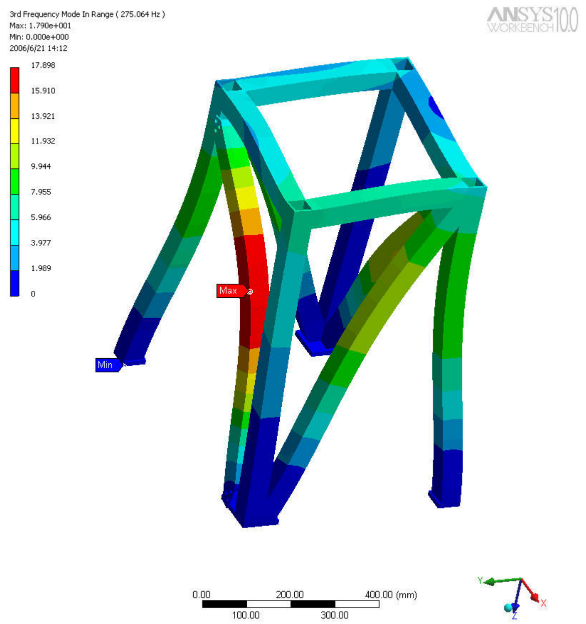

Fig 3. Sleeve structure with removable member third frequency 275Hz

2.2 FE PREDICTIONS FOR THE SLEEVE DESIGN WITH ADDITIONAL MASS

Additional mass is added in the form of two rectangular steel blocks at the interface between the sleeve and the face plate design as shown in figure 6.

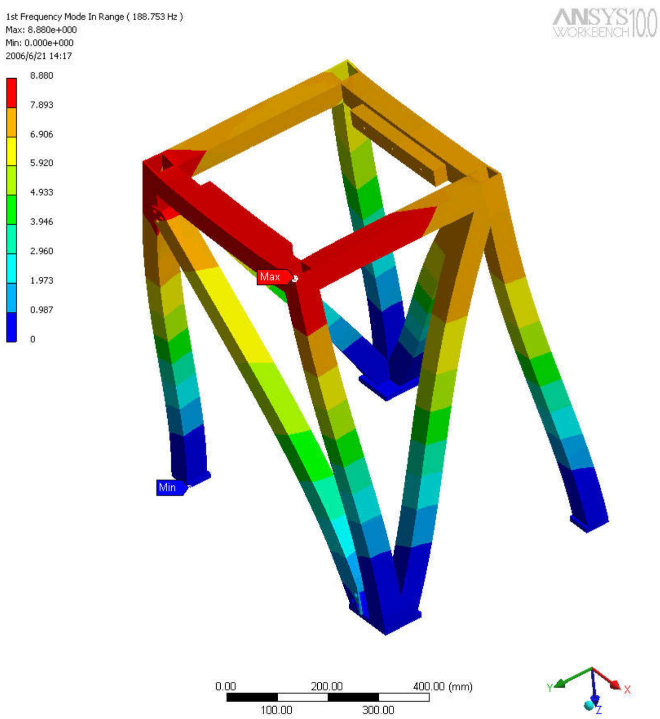

Fig 4. Sleeve structure with removable member and additional mass 5.24kg, first frequency 189Hz

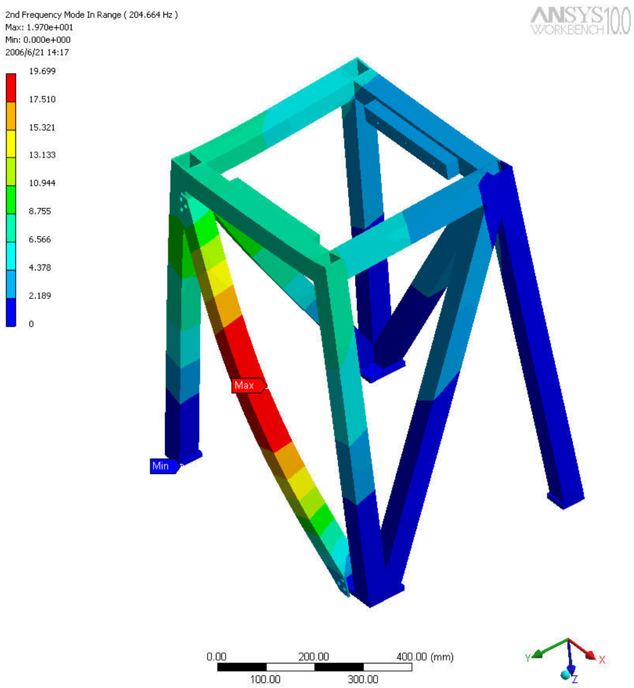

Fig 5. Sleeve structure with removable member and additional mass 5.24kg, second frequency 205Hz

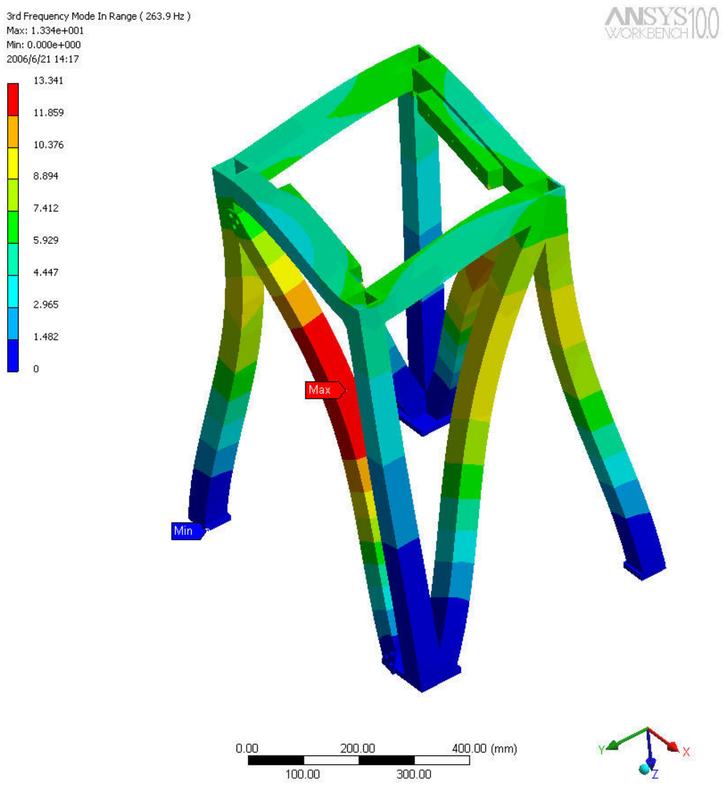

Fig 6. Sleeve structure with removable member and additional mass 5.24kg, third frequency 264Hz

2.3 FE PREDICTIONS FOR THE SLEEVE DESIGN WITH THE ADDITION OF THE FACE PLATE DESIGN.

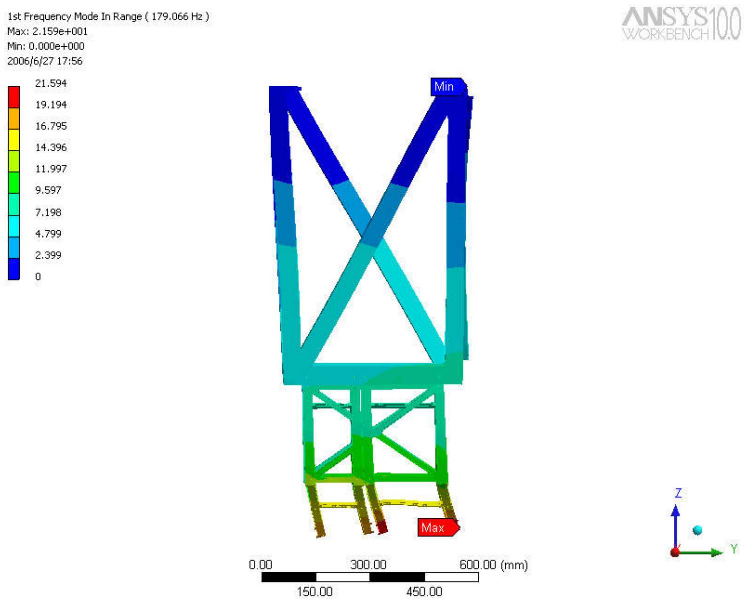

Fig 7. Sleeve structure with removable member and face plate design, first frequency 179Hz

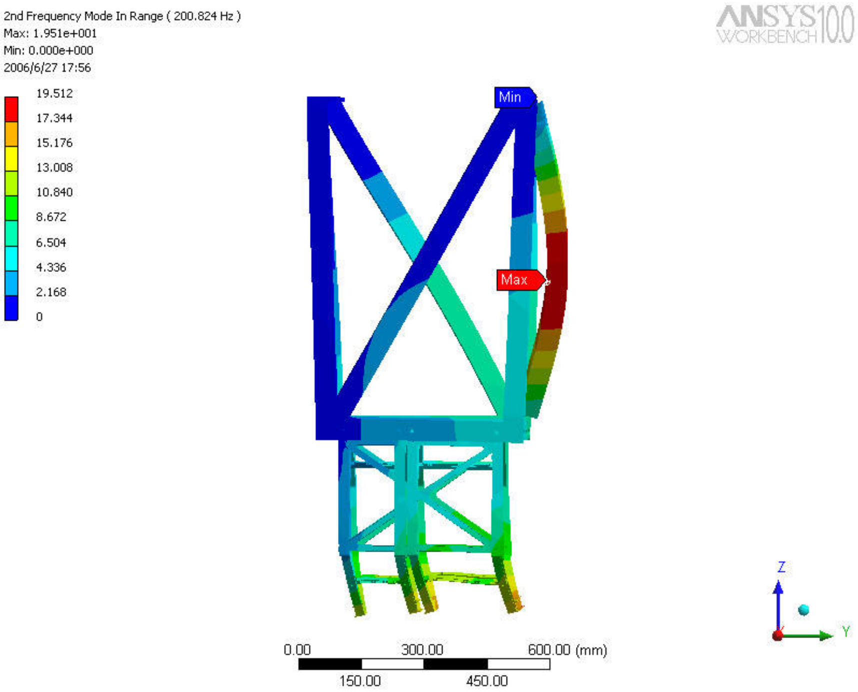

Fig 8. Sleeve structure with removable member and face plate design, second frequency 200Hz

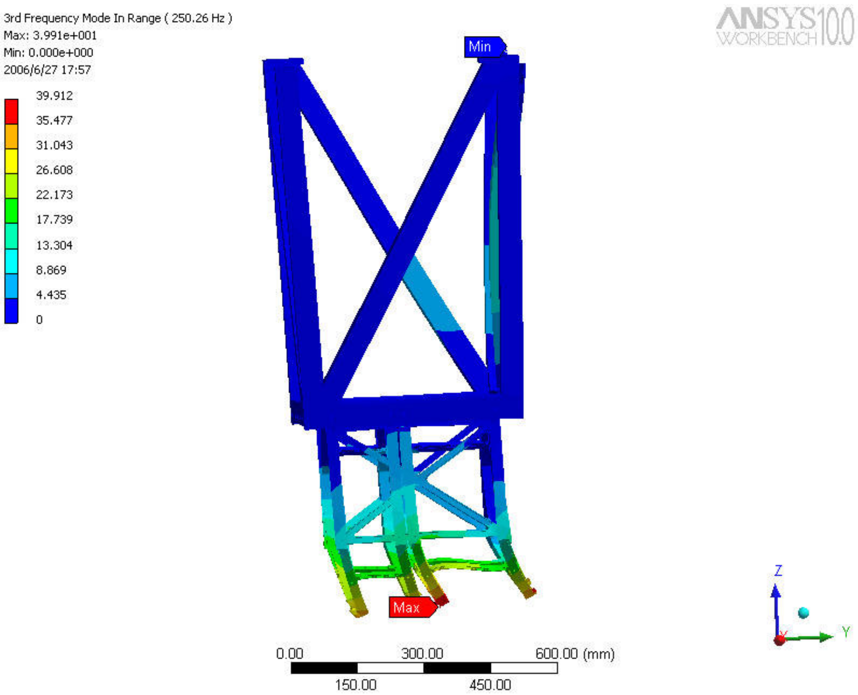

Fig 9. Sleeve structure with removable member and face plate design, third frequency 250Hz

Note: There are 3 tall peaks in the 200 to 300 range. Looked at the mode shape for 209Hz, this had the two face plates that support the reaction chain wagging the other two face plates that support the main chain remained stationary.

2.4 THE EXPERIMENTAL SET UP

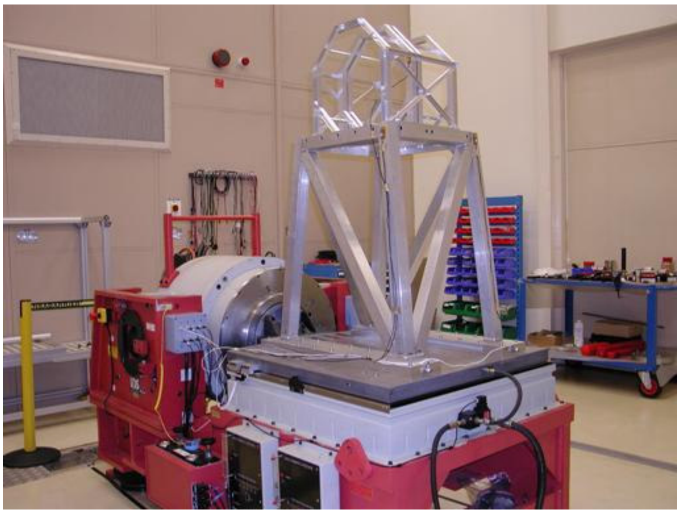

Fig 10. The LDS electro-dynamic shaker with sleeve and face plate design. (x axis test configuration)

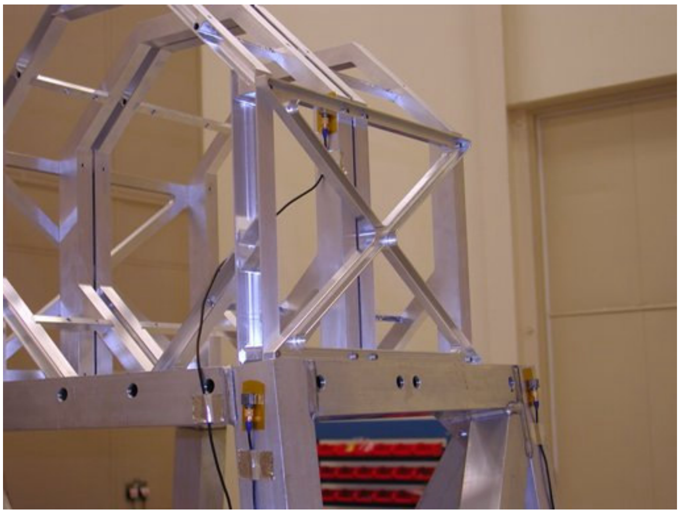

Fig 11. Three accelerometers positioned on the structure.

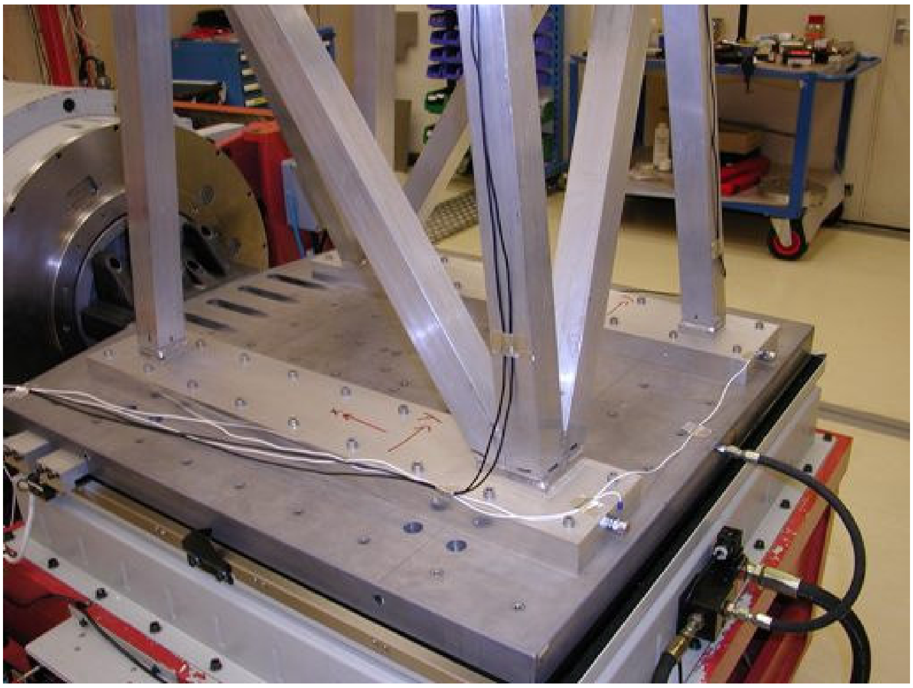

Fig 12. Sleeve structure mounted to shaker table via 40mm plate.

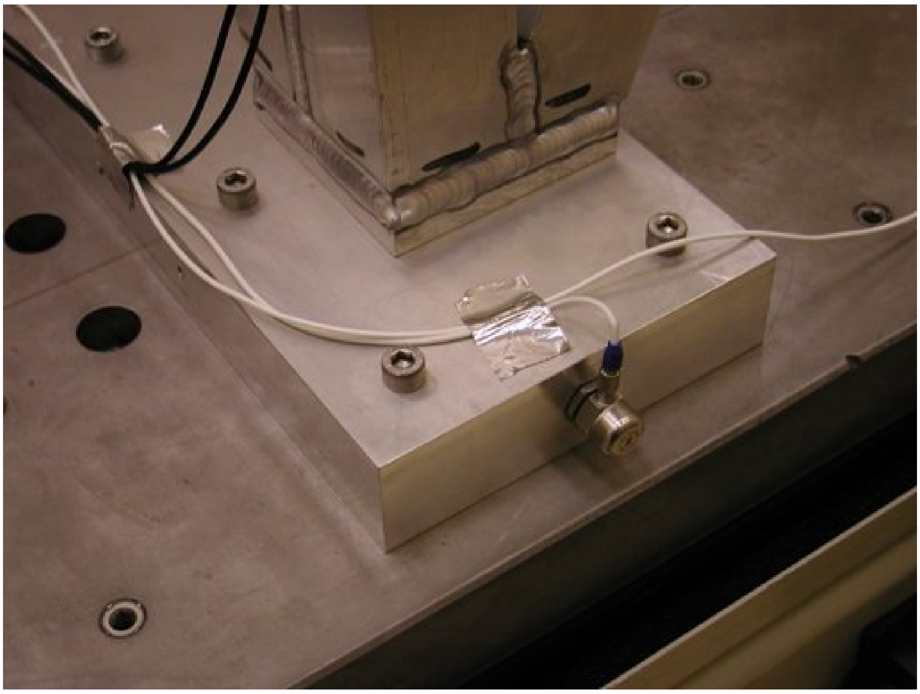

Fig 13. Control accelerometer.

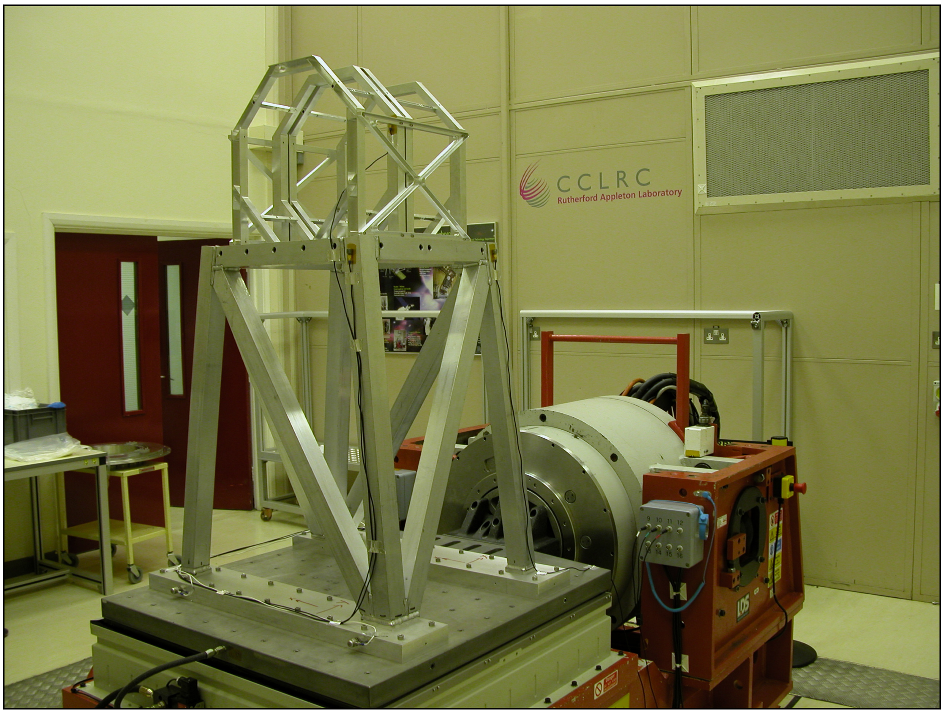

Fig 14. Sleeve and face plate design (y axis test configuration).

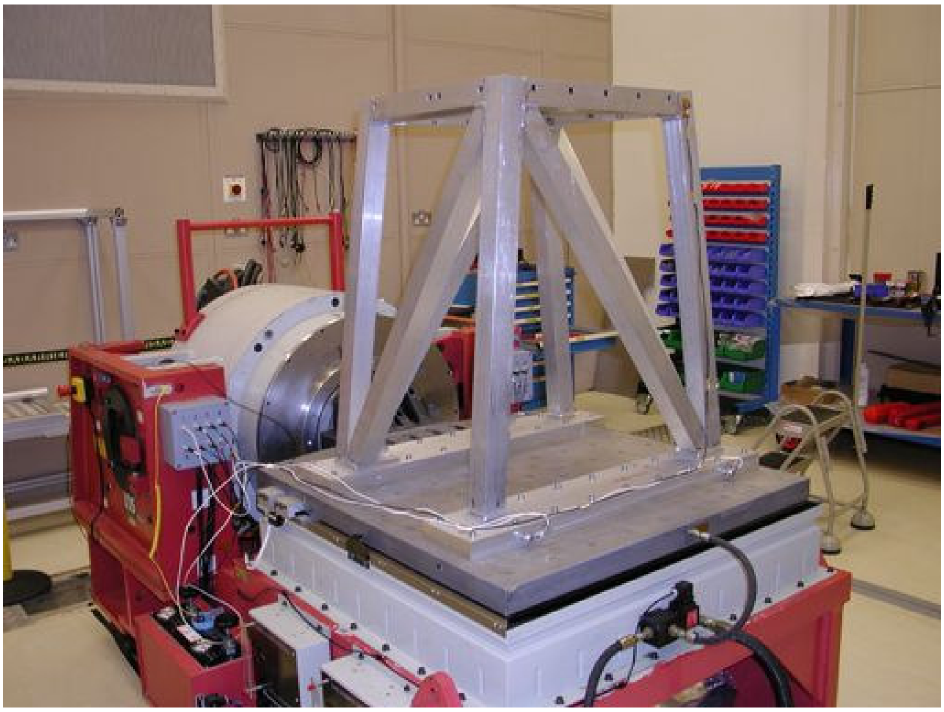

Fig 15. Sleeve structure only (y axis test configuration).

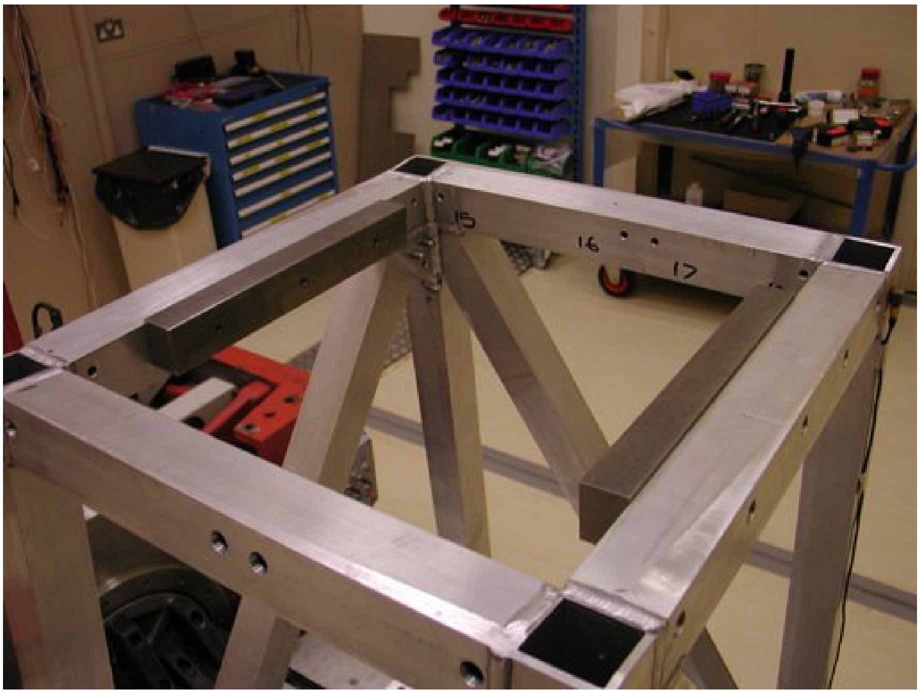

Fig 16. Sleeve structure with additional mass 5.2kg.

2.4 EXPERIMENTAL RESULTS

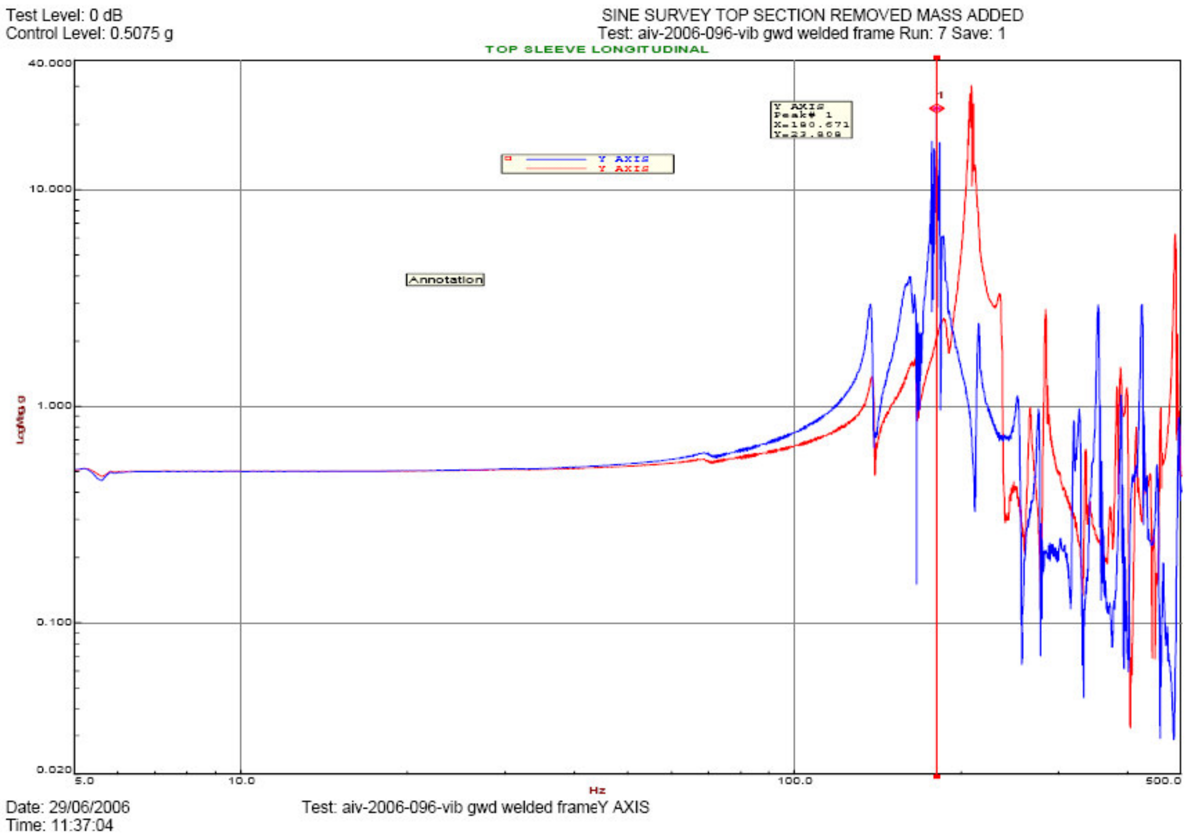

Figure 17. This plot shows two sine sweeps overlaid on top of each other, the blue line shows the peaks for the Sleeve structure with additional mass and the red line shows the peaks for the structure without additional mass as shown in figures 16 and 9 respectively.

The first red and blue peaks are coincident showing the ever present 138Hz, existing independently of the structure configuration i.e. additional mass, this mode shape was unable to be seen by the strobe possibly due to the low amplitude.

The second blue peak shows the sleeve design with the additional 5.2Kg mass at 180Hz. The first mode from the FE prediction is at 189Hz, assuming the 180Hz corresponds to the 189Hz then the discrepancy is 5%.

The second red peak shows the sleeve design at 208Hz. The first mode from the FE prediction is at 213Hz, assuming the 208Hz corresponds to the 213Hz then the discrepancy is 2%.

Neither the 180Hz nor 208Hz could be seen by the strobe as it was impossible to dwell at resonance because the control system for the dynamic table kept cutting out.

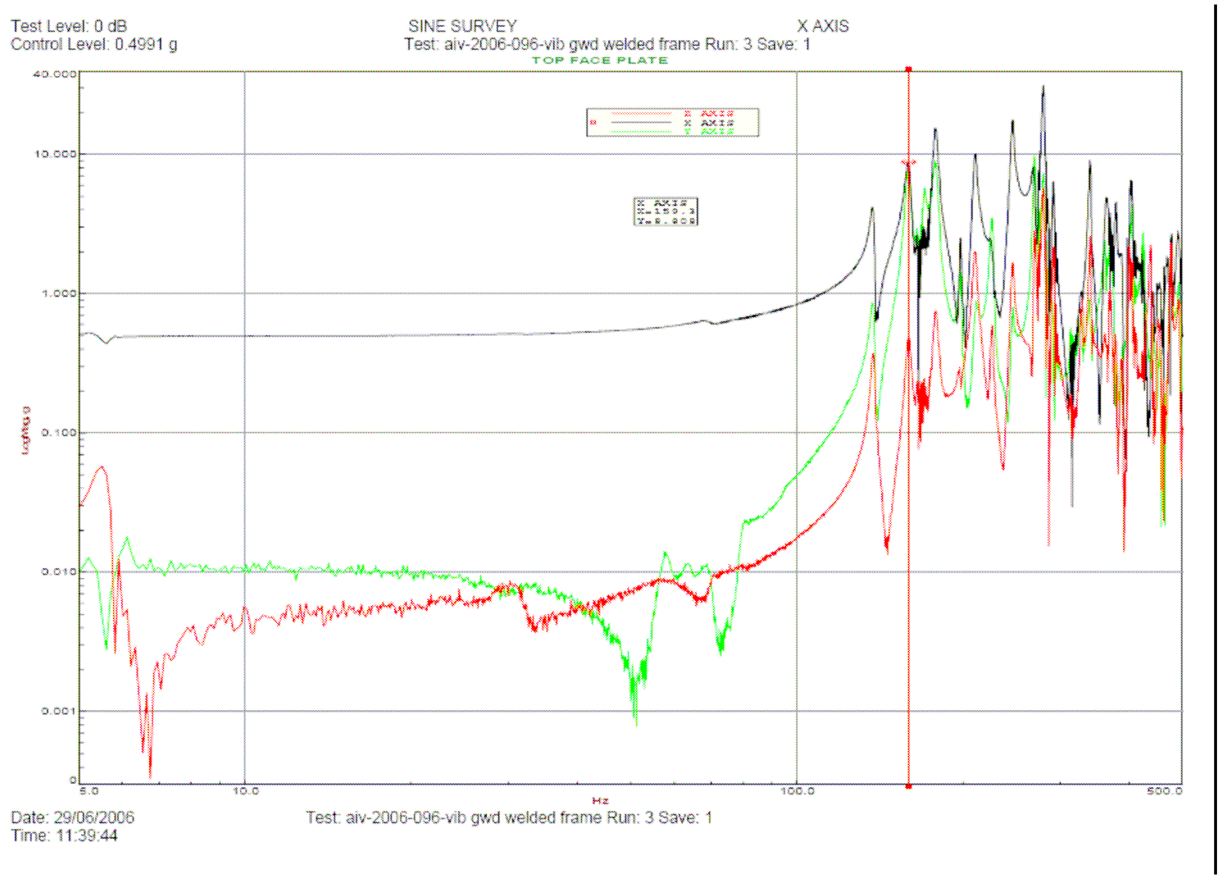

Figure18. This plot shows a sine sweep of the sleeve and face plate design as shown in figure 1.

The first peak is the ever present 138Hz, existing independently of the structure configuration i.e. additional mass, this mode shape was unable to be seen by the strobe possibly due to the low amplitude.

The second peak on the plot is at 159Hz; its mode shape was identified by the strobe. The first mode predicted by FE is at 179Hz and has the same mode shape as the observed 159Hz. Assuming the predicted and measured modes are one in the same the discrepancy between the two is 12%.

The third peak on the plot is at 179Hz; again the mode shape was identified by the strobe. The second mode predicted by FE is at 200Hz and has the same mode shape as the observed 179Hz. Assuming the predicted and measured modes are one in the same the discrepancy between the two is 10.5%.

Table 1. Frequency summary table

Structure	Predicted frequency Hz	Measured experimental frequency Hz	Discrepancy %
Sleeve design	213	208	2
Sleeve design with additional 5.2kg Mass	189	180	5
Sleeve and face plate design	179	159	12

2. 5 CONCLUSIONS

Results between measured and FE predicted modes are to within 12% which seems reasonable.

The first mode is at 138Hz but not as predicted by the FEA. This mode is a local mode not affected by additional mass, could be the clamping fixtures or bolted cross brace.

We should not become over confident in our ability to model the full structure accurately based on the 12% discrepancy demonstrated here. The faceplate section is not very stiff compared to the stiff sleeve structure so the stiffness of the bolted connections between the two doesn't influence the results (lowest modes involve large movements of the least stiff elements i.e. faceplates and localised modes of the bolted cross-brace).

We may see a larger discrepancy when testing the sleeve structure bolted to the upper structure, here we will have two stiff structures mounted end to end with a bolted interface, the stiffness of the bolted interface will have a greater influence on the overall stiffness of the combined structure result.

3. PREDICTED AND EXPERIMENTAL RESULTS FOR THE COMBINED STRUCTURE

3.1 FE PREDICTIONS FOR THE UPPER STRUCTURE

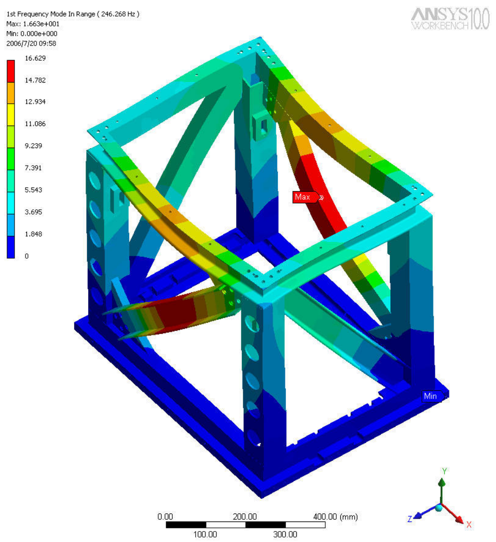

Fig 19. Mode shape has the frame wagging in longitudinal direction, exasperated by the panting of the two removable cross braces, frequency 246Hz.

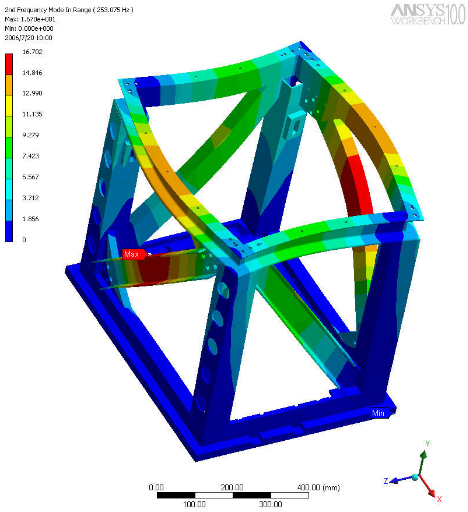

Fig 20. Mode shape has longitudinal then traverse faces panting about the vertical axis of the box section. The box section remains vertical but twists as a result of the panting, frequency 253Hz.

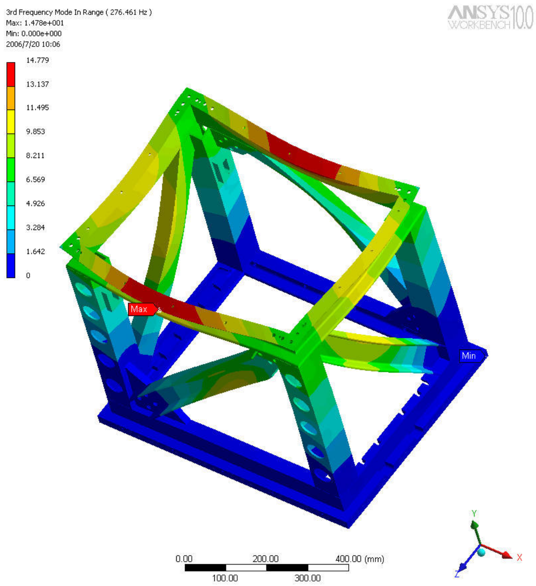

Fig 21. Mode shape has the frame wagging in the traverse direction, frequency 276Hz.

3.2 FE PREDICTIONS FOR THE UPPER AND SLEEVE STRUCTURE

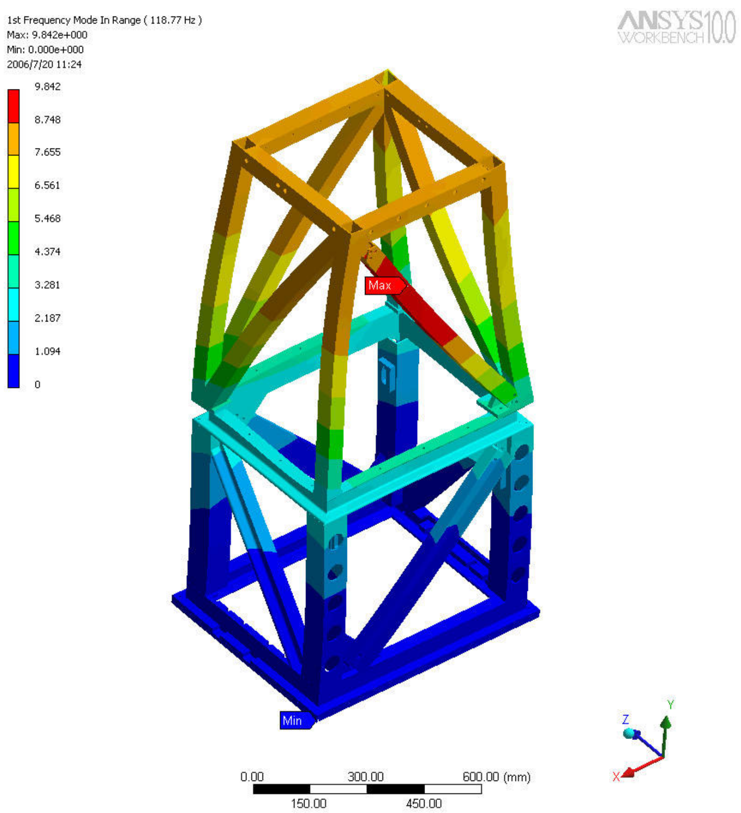

Fig 22. Mode shape has the removable cross brace panting, frequency 119Hz.

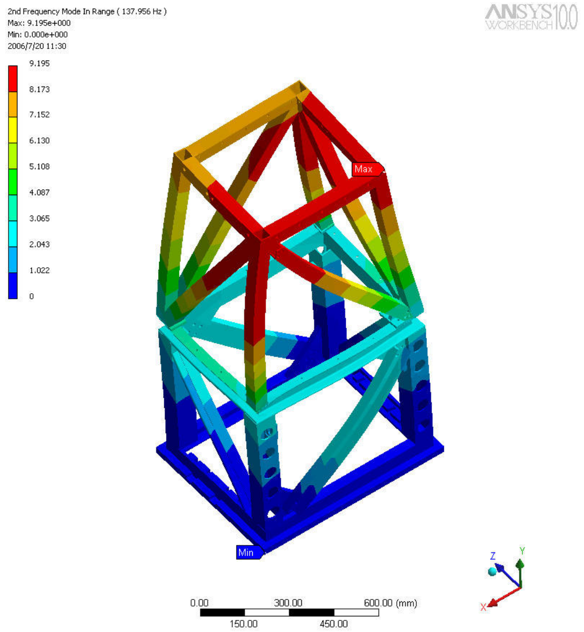

Fig 23. Mode shape has the structure wagging in both longitudinal and traverse directions, frequency 138Hz.

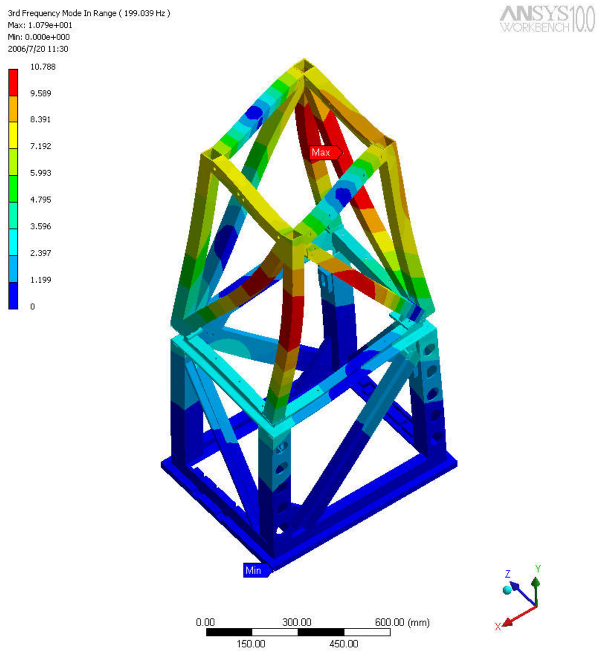

Fig 24. Mode shape has the structure squeezing in and out, frequency 199Hz.

3.3 FE PREDICTIONS OF THE UPPER AND SLEEVE STRUCTURE WITH ADDITIONAL MASS.

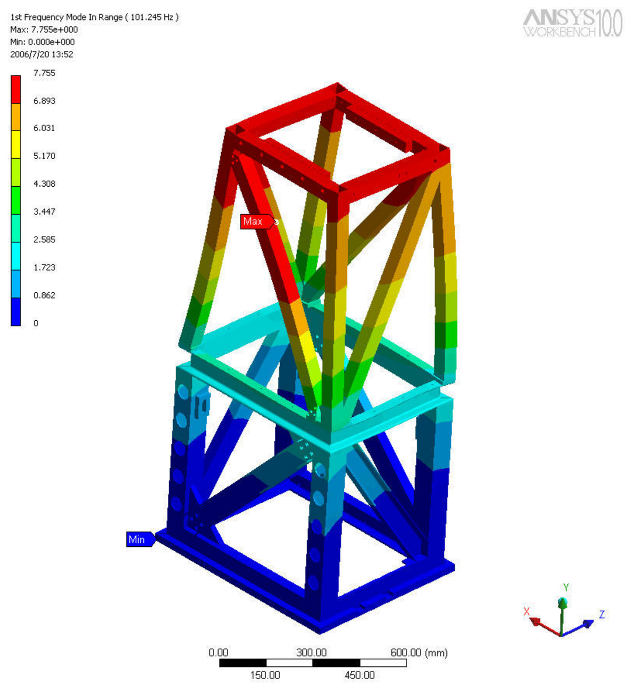

Fig 25. Mode shape has the structure wagging in the longitudinal direction, frequency 101Hz.

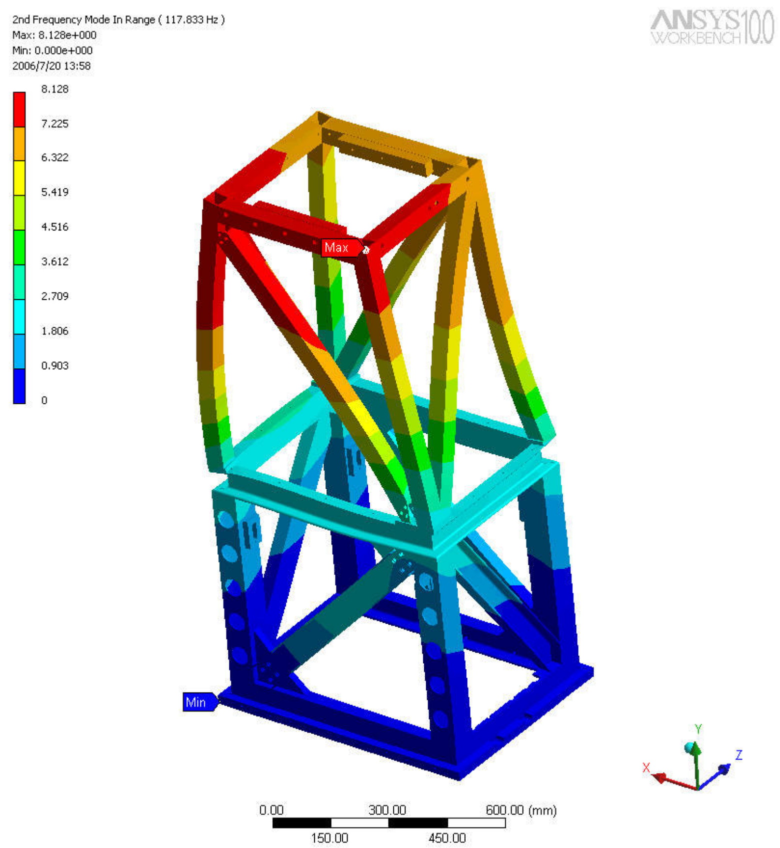

Fig 26. Mode shape has the structure wagging in the traverse direction, frequency 118Hz.

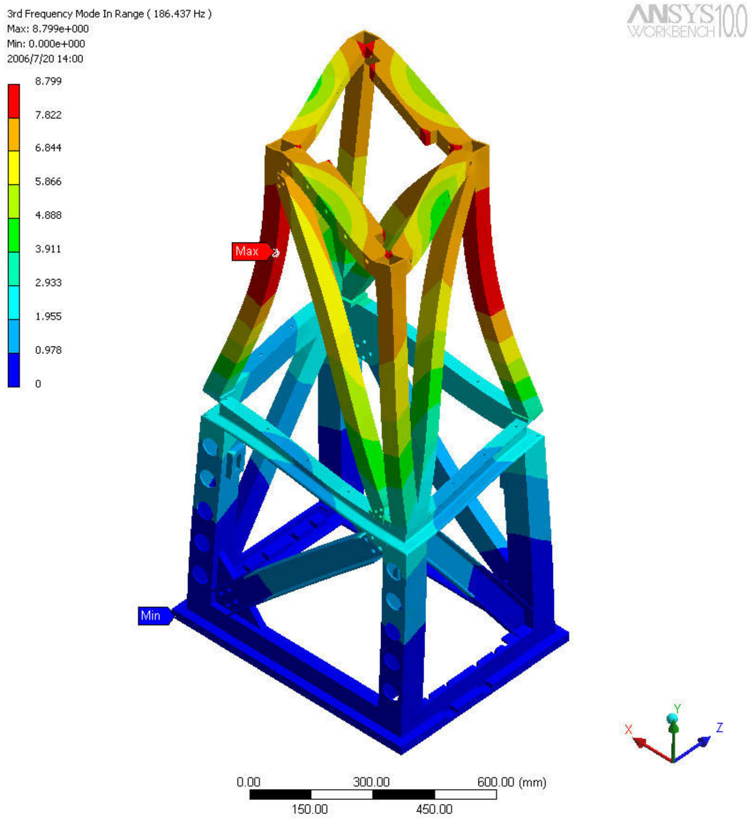

Fig 27. Mode shape has the structure squeezing in and out, frequency 186Hz

EXPERIMENTAL RESULTS

Figure 28. Upper structure dog-clamped to four steel blocks.

We used an accelerometer with it's own power supply, bashed the structure, put the signal response through an oscilloscope got a sine wave took the period and did 1/t to get the frequency, compared that to the Fourier transform. Bash test plots can be found in Appendix 2.

Table 2. Bash test results

Structure	Predicted fundamental frequency Hz	Measured fundamental frequency Hz	Discrepancy %
Upper	246	210	15
Upper and sleeve with additional 5.2Kg mass	101	80 - 85	15 - 20

3.3 FE PREDICTIONS OF THE UPPER AND SLEEVE STRUCTURE WITH FACE PLATE DESIGN.

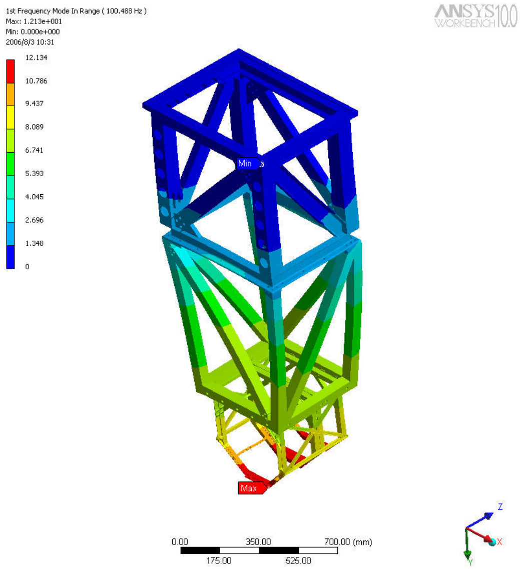

Figure 29.

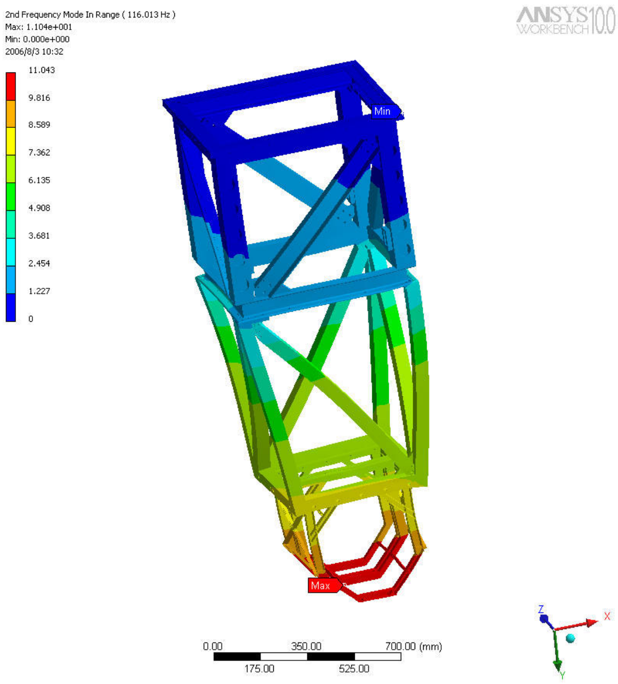

Figure 30.

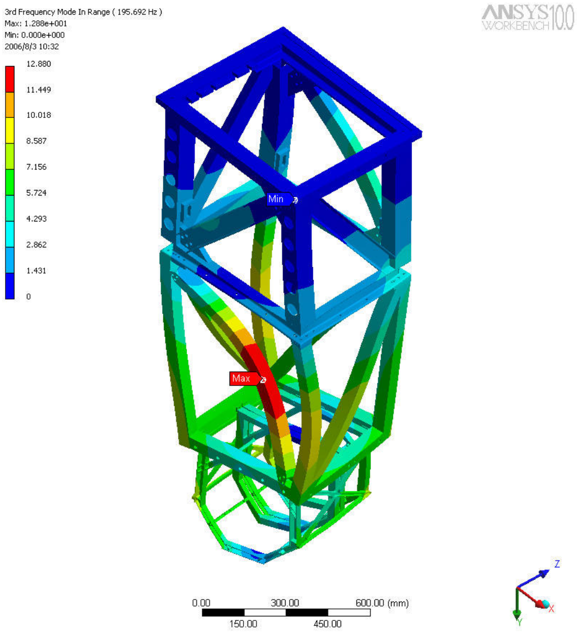
3rd Frequency Mode In Range (195.692 Hz)
Max: 1.288e+001
Min: 0.000e+000
2006/8/3 10:32
12.880
11.449
10.018
8.587
7.156
5.724
4.293
2.862
1.431
0
ANSYS 10.0
WORKBENCH
Min
Max
0.00
300.00
600.00 (mm)
150.00
450.00
Z
X
Y

Figure 31.

APPENDIX 1

ACCELEROMETER CALIBRATION STATUS

Monitoring Accelerometers: -

TRIAXIAL – Endevco 65-10

SERIAL NUMBER	CALIBRATION mV/g	Date	SIGNAL CONDITIONER
10283-X	9.78	07/12/06	Constant Current Source supplied via Controller.
10283-Y	9.62	07/12/06	
10283-Z	10.01	07/12/06	
11260-X	10.33	12/01/06	
11260-Y	10.30	12/01/06	
11260-Z	10.17	12/01/06	
11259-X	10.00	10/01/06	
11259-Y	10.02	10/01/06	
11259-Z	10.28	10/01/06	

1. **Control Accelerometer :** Endevco Type 7254A-10 (10.16 mV/g) Serial No. 11606

Next Calibration due**:** 7 December 2006

2. **Control Accelerometer :** Endevco Type 7254A-10 (10.03 mV/g) Serial No. 11630

Next Calibration due**:** 7 July 2006

Signal Conditioner: Vector II 16C2S S/N 70234

Next Calibration due**:** 12 July 2006

TEST SUMMARY

Testing Dates: 28 and 29 June 2006

Observer: Tim Hayler

Organization: RAL

CHANNEL ALLOCATION:

CONTROL:-

Channel No.	Accelerometer Type/Serial No.	Testing Axis	Mounting Position
1	Endevco 11606	In-axis	Fixture
8	Endevco 11630	In-axis	Fixture

MONITORING:-

Channel No.	Accelerometer Type/Serial No.	Testing Axis	Mounting Position
2	Endevco 10283-X	**Z**	Top Sleeve (Long.)
3	Endevco 10283-Y	**X**	Top Sleeve (Long.)
4	Endevco 10283-Z	**Y**	Top Sleeve (Long.)
5	Endevco 11260-X	**Z**	Top Faceplate
6	Endevco 11260-Y	**X**	Top Faceplate
7	Endevco 11260-Z	**Y**	Top Faceplate
9	Endevco 11259-X	**Z**	Top Sleeve (Traverse)
10	Endevco 11259-Y	**Y**	Top Sleeve (Traverse)
11	Endevco 11259-Z	**X**	Top Sleeve (Traverse)

NOTE

When the top section was removed (Figure 15) the top face plate monitoring accelerometer (ch. 5 - 7) was no longer used.

Additional runs were carried out dwelling at frequencies using the strobe to identify mode shapes.

ACCELEROMETER TEST PLOTS

VIBRATION TESTS in the X-axis

RUN 00003 SINE SURVEY *FIG 10 (5 - 500 Hz 0.5g)* **sleeve and face plate design**

VIBRATION TESTS in the Y-axis

RUN 00004 SINE SURVEY *FIG 14* (5 - 500 Hz 0.5g) **sleeve and face plate design.**

RUN 00006 SINE SURVEY *FIG* 15 (5 - 500 Hz 0.5g) **sleeve with face plate design removed.**

RUN 00007 SINE SURVEY *FIG* 16 (5 - 500 Hz 0.5g) **sleeve with face plate design removed and dummy mass added.**

RUN N/A SINE SURVEY OVERLAY SHOWING RUN 6 AND RUN 7. *FIG 17*

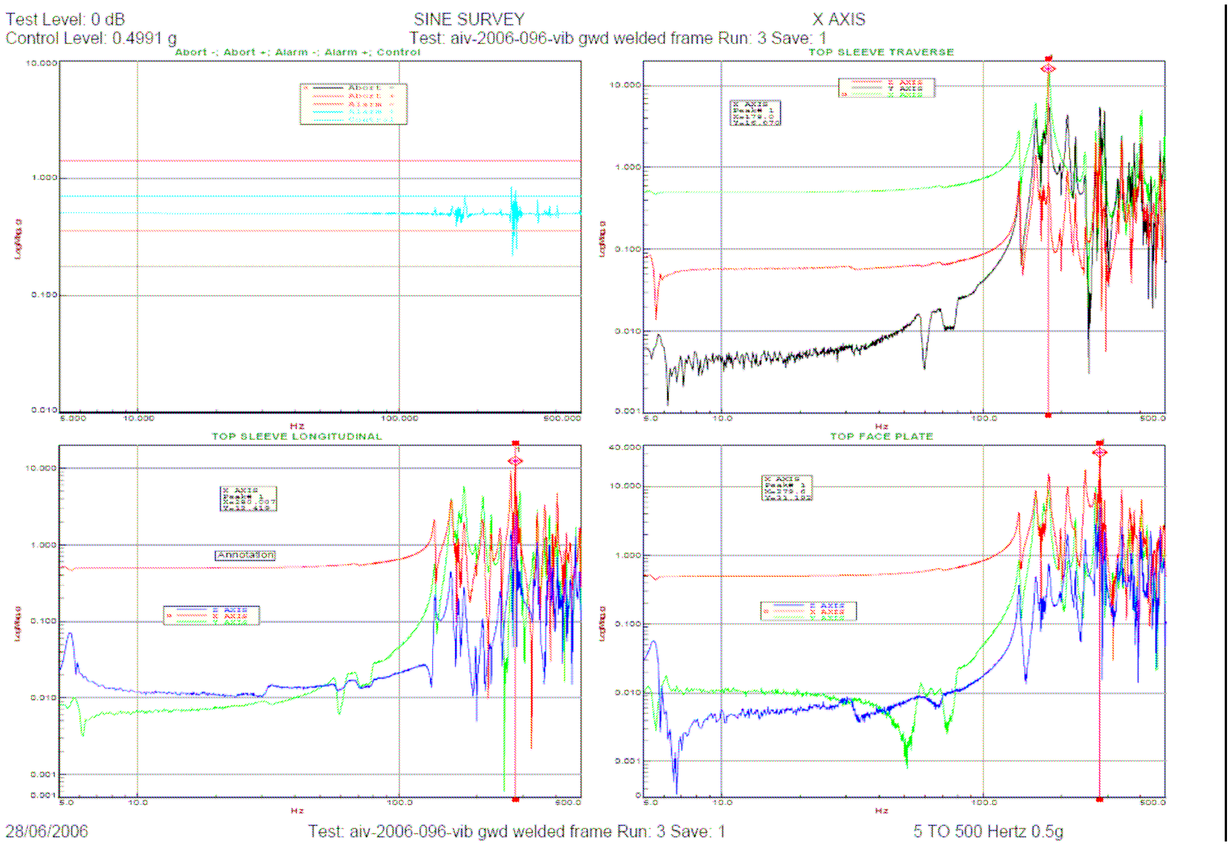
Test Level: 0 dB
Control Level: 0.4991 g
SINE SURVEY
Test: aiv-2006-096-vib gwd welded frame Run: 3 Save: 1
X AXIS
Abort -; Abort +; Alarm -; Alarm +; Control
TOP SLEEVE TRAVERSE
TOP SLEEVE LONGITUDINAL
TOP FACE PLATE
Annotation
Hz
28/06/2006
Test: aiv-2006-096-vib gwd welded frame Run: 3 Save: 1
5 TO 500 Hertz 0.5g

Figure 32

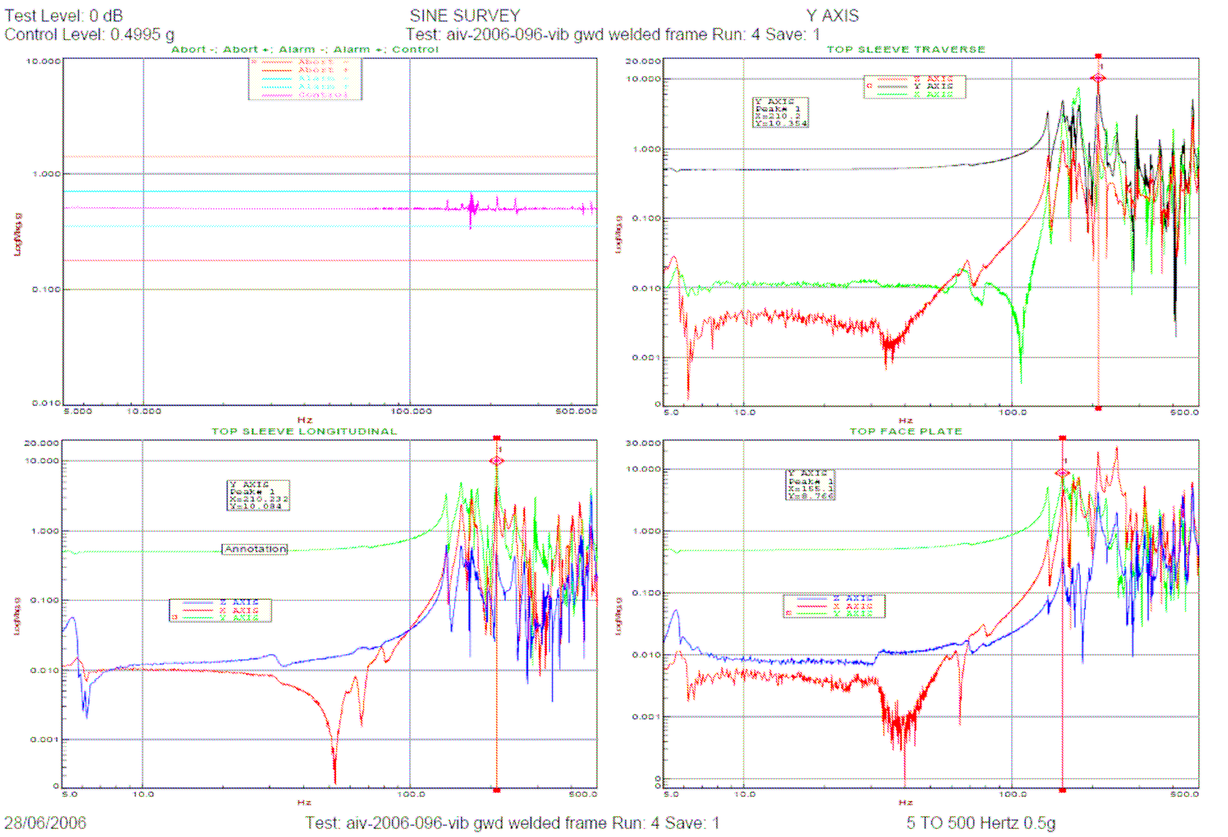

Figure 33.

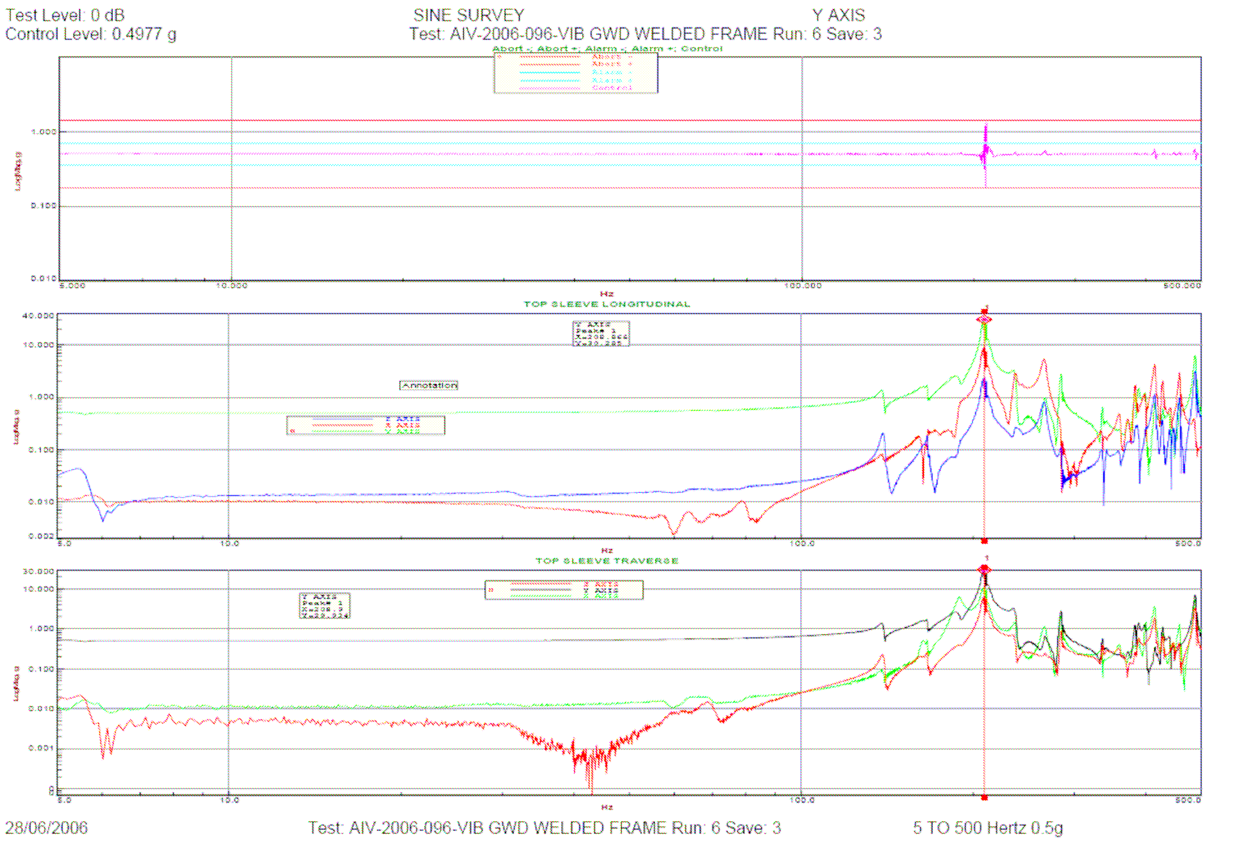

Figure 34.

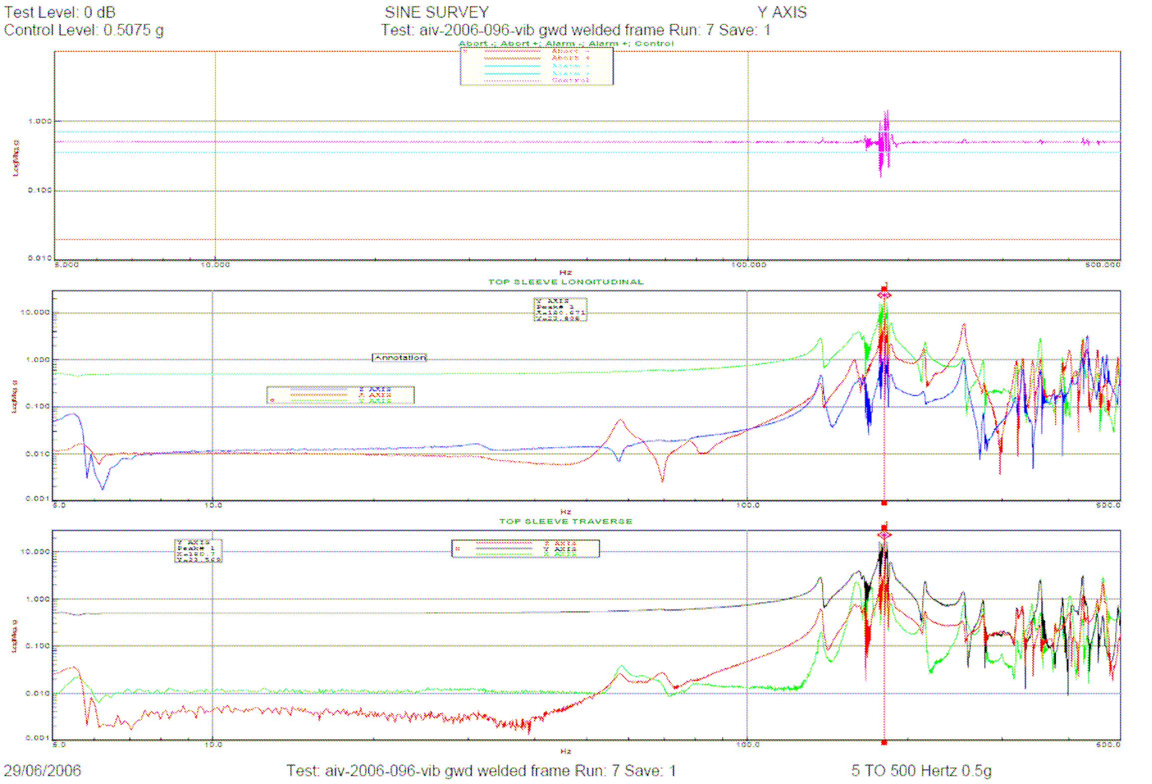

Figure 35.

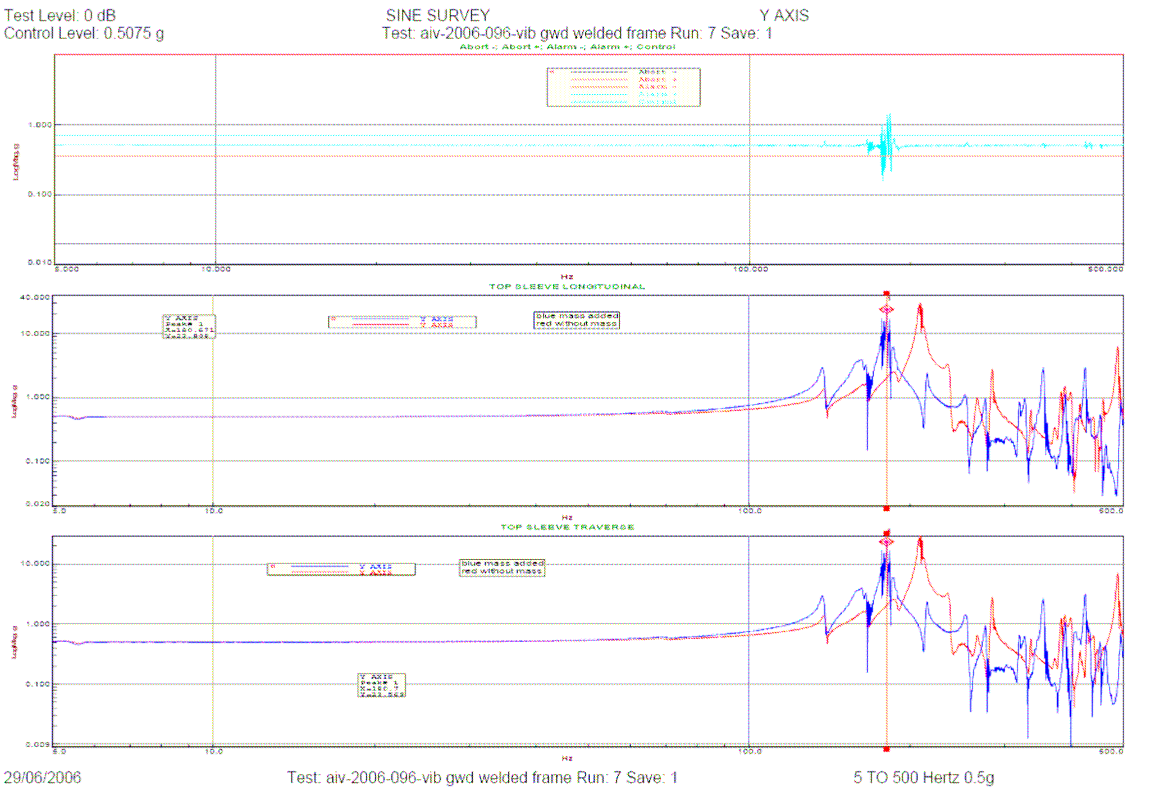

Figure 36.

APPENDIX 2

Bash test results

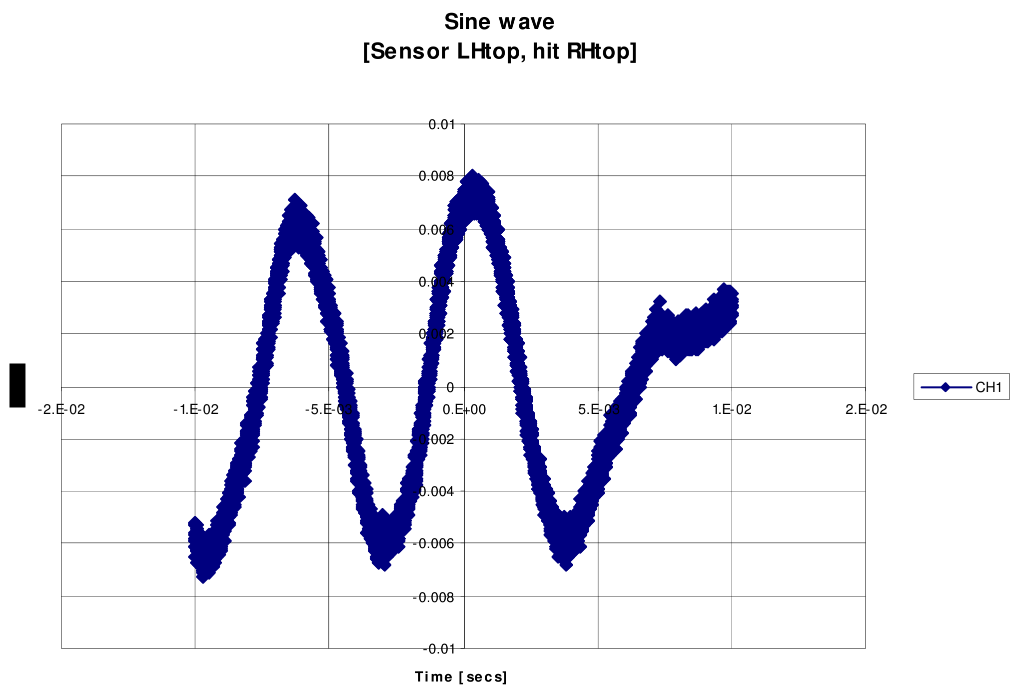

Figure 37.

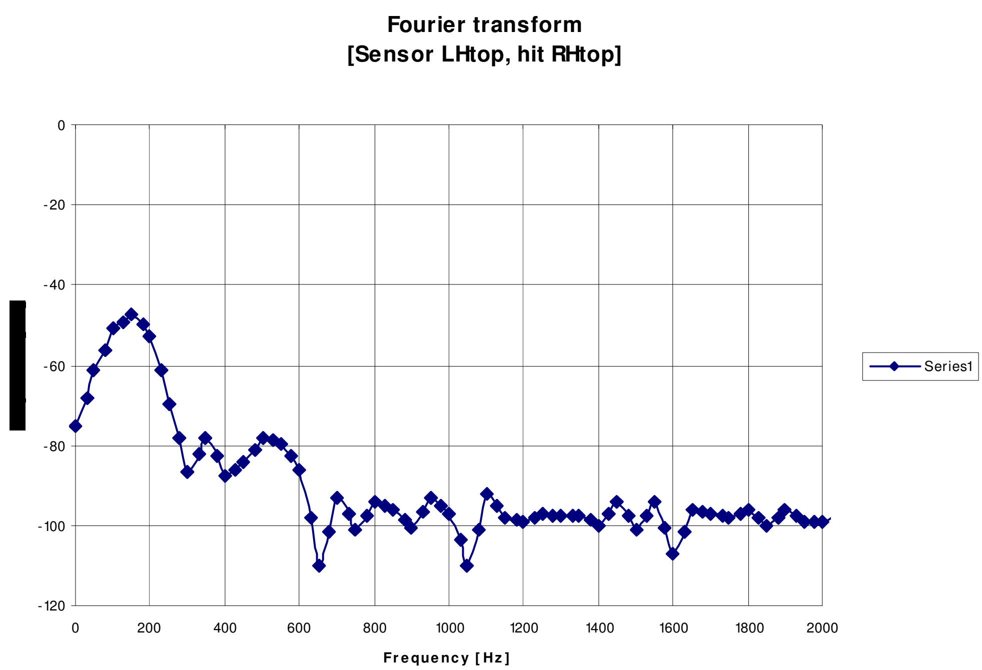

Figure 38. Fundamental frequency 150Hz

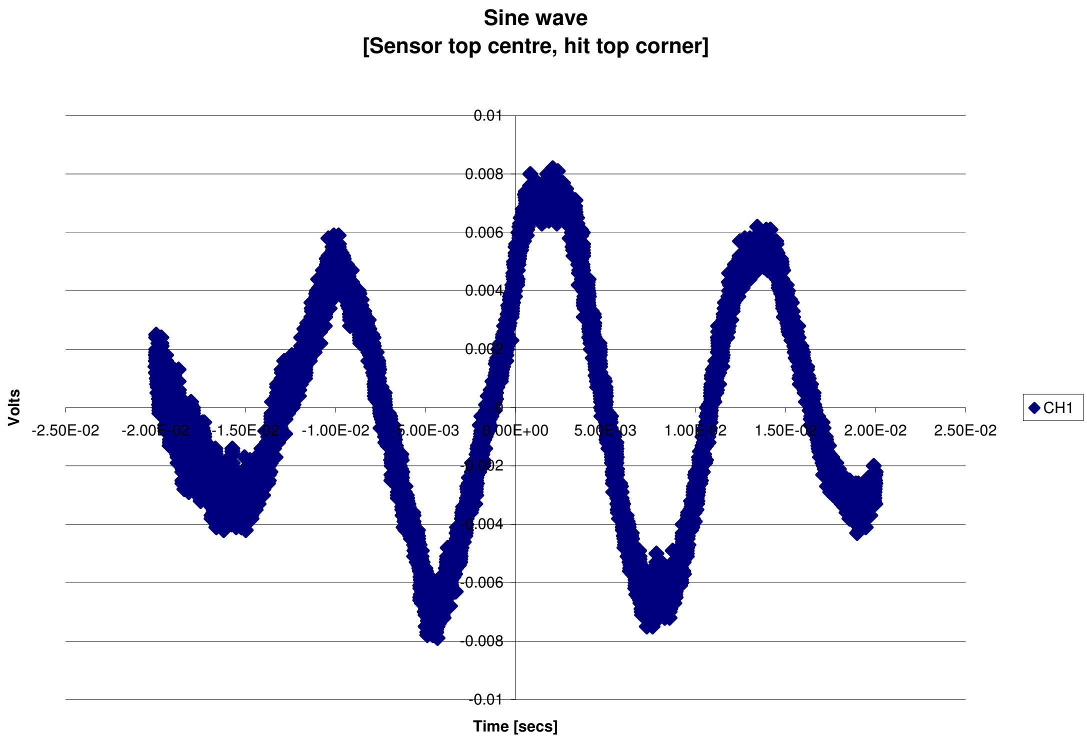

Figure 39.

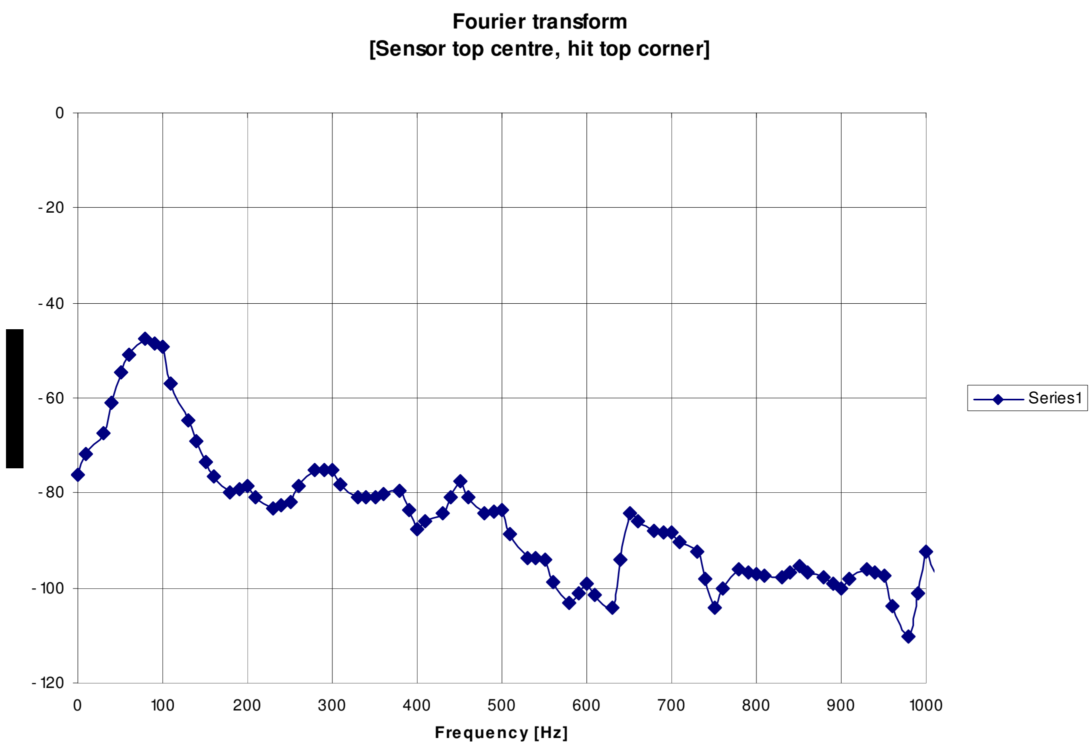

Figure 40. Fundamental frequency 80Hz

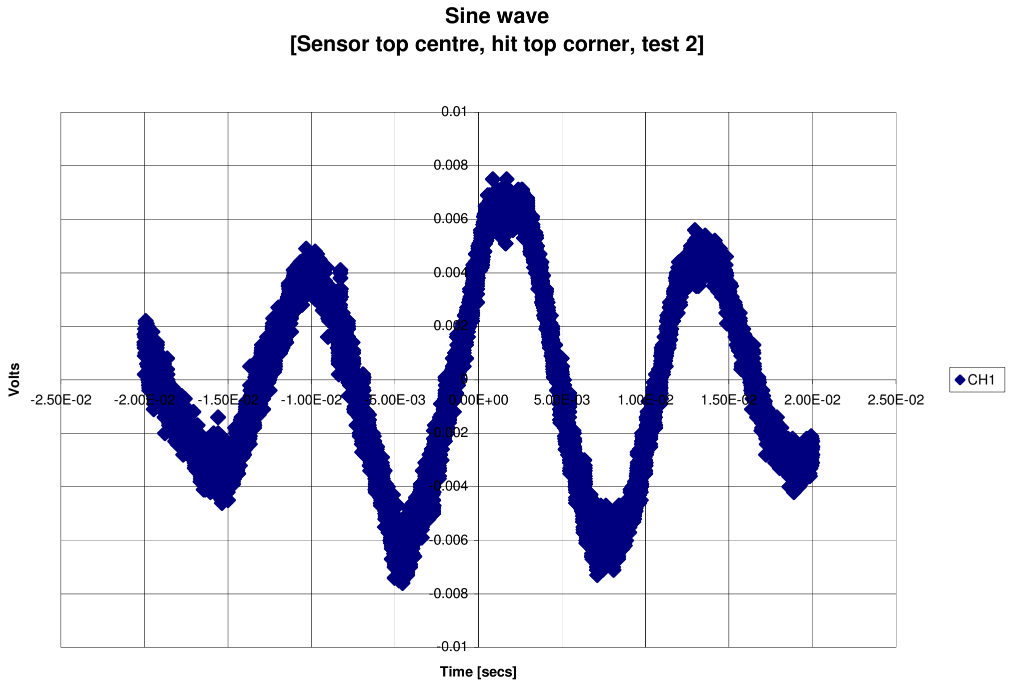

Figure 41.

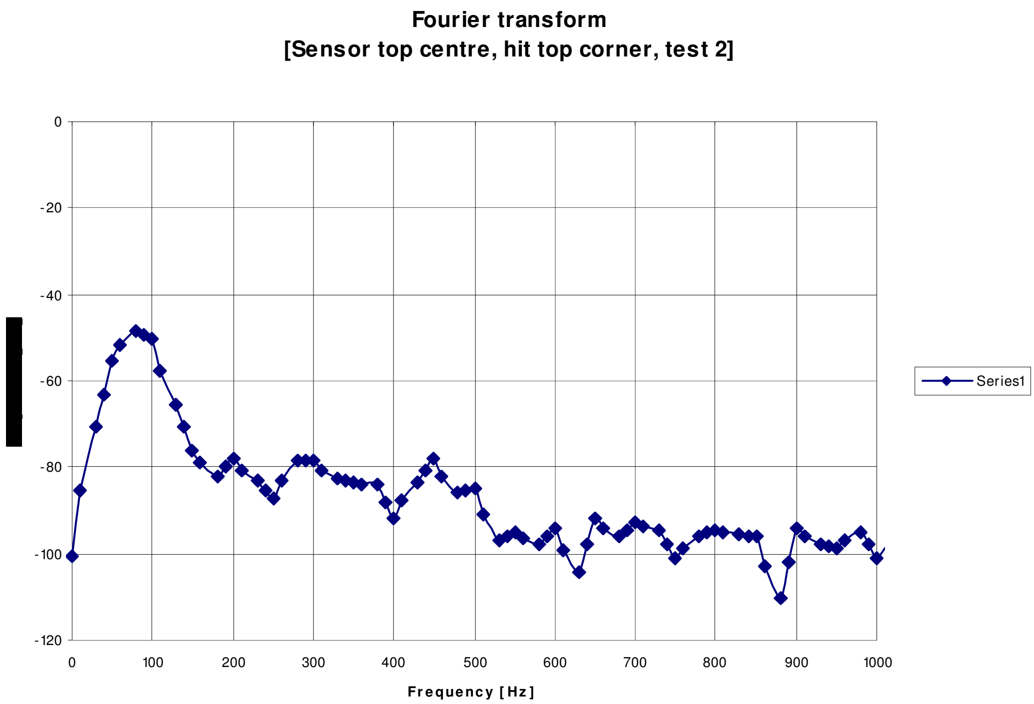

Figure 42. Fundamental frequency 80Hz

APPENDIX 3

For reference; the frequency results of a structure that does not have a removable member but is a wholly welded structure.

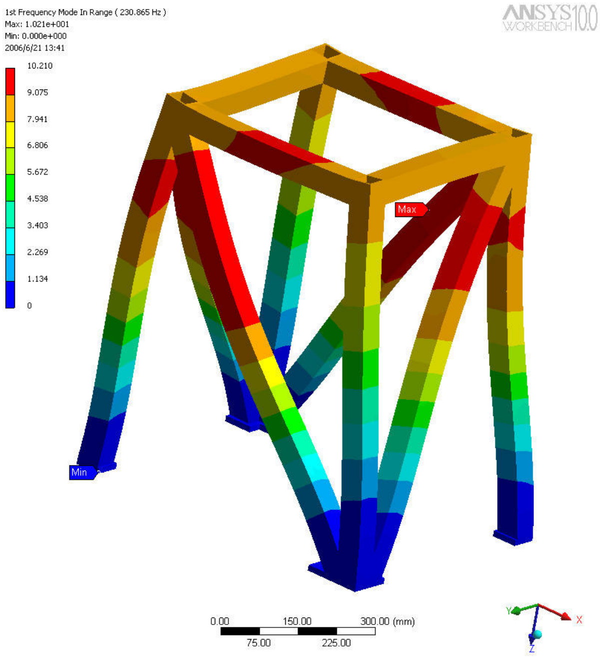

Fig 45. Sleeve as a uniform all welded structure, first frequency 231Hz

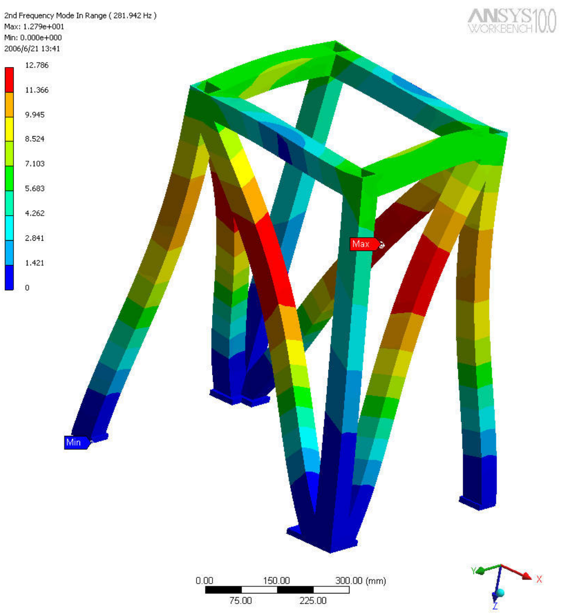

Fig 46. Sleeve as a uniform all welded structure, second frequency 282Hz

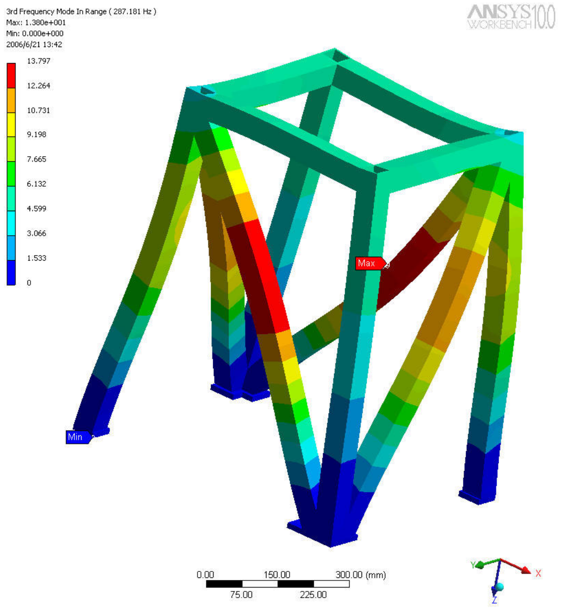

Fig 47. Sleeve as a uniform all welded structure, third frequency 287Hz