LIGO Laboratory / LIGO Scientific Collaboration

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Preliminary Frequency Analysis of the Quadruple Pendulum Controls Prototype (second) Structure

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Check names?

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LIGO Science Collaboration

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Revision 00: October 2005, Limited release.
Revision 01: Includes results from suggestions by Tim and Russell
Revision 02: Includes measurement of wieght
Revision 03: includes results from Stanford

1. Introduction

The purpose of this document is to record the status of the frequency analysis performed on quadruple pendulum controls prototype structures as well as summarizing experimental data collected from the "Stanford" structure, as shown below in *figure (i)*. Furthermore, it will address possible stiffening designs. Please also reference LIGO-T060039 by Tim Hayler et al.

The author would like to point out that the work summarized here should be considered preliminary and that a lot of work still has to be done.

2. Summary

Figure (i): - Pictures taken during assembly!

3. Design Requirement

Reference LIGO-T0X0XXX[1],

4. Existing Mode Cleaner Prototype Structure

[1] LIGO-T0X0XXX (D.Coyne)

4.1 Quadruple Pendulum Controls Prototype Structure

The structure shown has a footprint of XXmm x XXmm x XXmm. It is made from aluminium structural members welded and bolted together at the Central Engineering Services (CES) at California Institute of Technology.

FEA carried out prior to the design and manufacture of the structure provided a first resonance mode that met the requirements.

4.2 The Experimental Set-

The structure is shown in *figure (ii)*.

The resonant frequencies of the structure were obtained by exciting the structure and measuring the response. The measured signal was amplified using a pre-amplifier, monitored on an oscilloscope and analyzed using a spectrum analyzer. The structure was excited using a externally driven shaker. The analyzer, in the swept sine mode (LIN SPEC 1 LOG MAG), drove the shaker over a frequency range 20 Hz to 500 Hz. An example of the output from the spectrum analyzer can be seen in *figure (?)*. Structural resonances were checked using the FFT mode of the spectrum analyzer, a hammer and the accelerometer.

All of the experimental data was obtained on an 80-ton Milling table in CES. The table is shown in *figure (iii)*.

Figure (iii): - 80 ton Milling Machine in CES

4.3 Method and type of Clamping

The number and type of clamps used to fix the structure to the table was varied during the course of the experiment.. *Figure (iv)* shows a plan view of the base of the structure and small squares representing the position of the clamps.

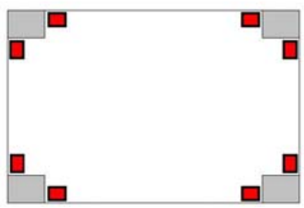


Figure (iv): - Plan view of the base of the structure showing the two main positions used for the clamps. The clamps shown are represented by small squares.

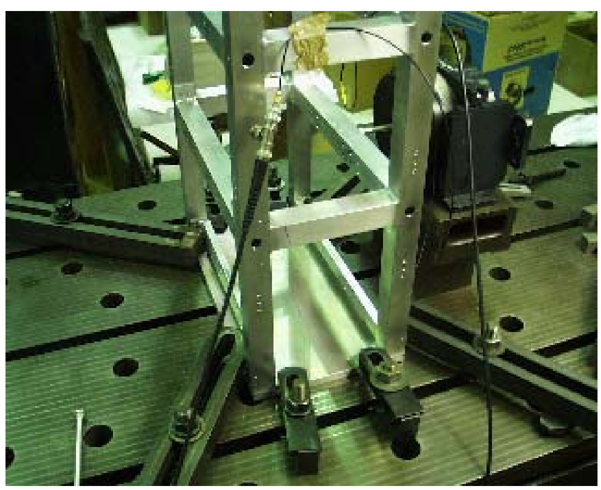


Figure (v): - Large Clamps

4.4 Experimental data

For each set of data points, the first two resonances of the structure were measured. From *figure (vi)* it can be seen that the shaker was positioned at a central location on the structure with the tip of the pusher resting against one of the crossbars. The accelerometer, B&K type 709, was fixed to the structure, vertically above the position of the shaker, close to the top plate, using bees wax. Strain relief was provided for the accelerometer cable. All of the results were carried out in air.

Prior to measuring each set of experimental data, the response from accelerometer was checked. Before moving on to the next configuration each set of results were recorded and checked. In order to tighten each screw nut combination a 6-inch Alan key was used for the small clamps and a 12-inch Wrench for the large clamps. (Finger tight plus a half turn)
The experimental results measured from three main configurations of the structure were compared directly with the modeled data. Section XXX explains the experimental configurations in more detail.

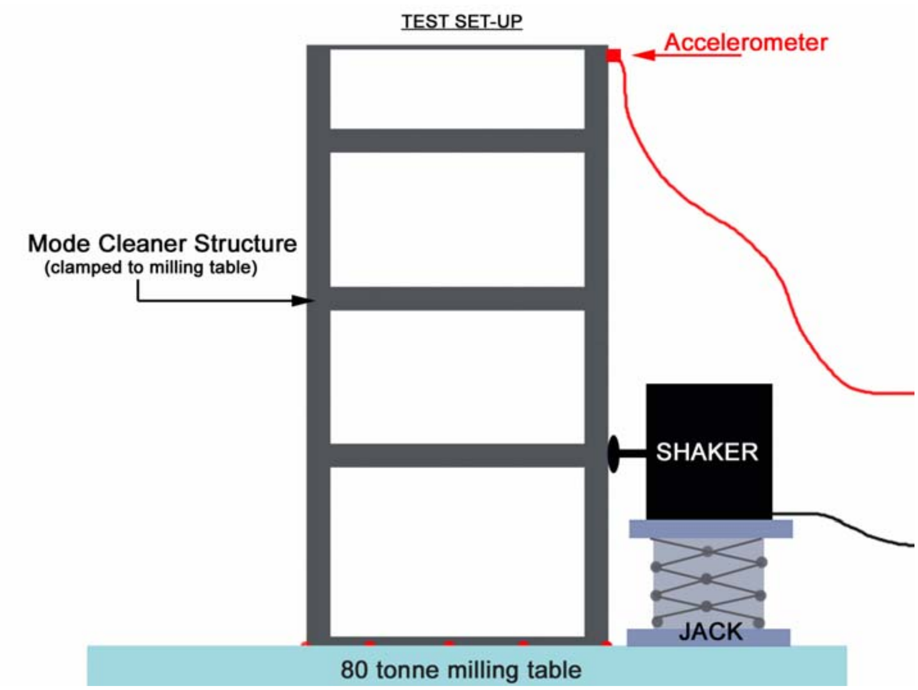


Figure (vi): -Sketch of the structure showing the position of the accelerometer and the shaker, measuring in the transverse mode. Equivalent to set-up used on Quad tests.

4.4 Experimental results cf. ANSYS

	EXPT (Long & Trans)	FEA *	FEA (UK)

A. Overall structure

I. With outriggers and all section bolted down (8 to 10 large dog clamps)

	54 & 63 Hz	84 & 93 Hz	

II. Without outriggers

	36 & 53 Hz	62 & 80 Hz	

III. As per I but with 17 kg clamped on the bottom of the structure

	35 Hz		

	EXPT	FEA *

B. Upper Structure *(NO RING, IT IS WITH LOWER STRUCTURE)*

I. Upper structure with tablecloth and dummy top stage and all section bolted down (8 to 10 large dog clamps)

	[150 Hz] 200 Hz	220 Hz	203 Hz **

** Tablecloth weighs 12.6 kg. Tim Hayler looked into several configurations of the upper structure.

II. Removed Tablecloth

	200 Hz	240 Hz	242 Hz

(I believe 150 Hz is the "dummy" tablecloth! This was confirmed by putting the accelerometer on the tablecloth and the amplitude of the 150 Hz resonance increased by ~ 15 dB.)

III. No tablecloth and extra mass added on top (~17kg)

	160 Hz		162 Hz

(The above example was carried out to help identify the mode and as another data point)

	EXPT (Long & Trans)	FEA *

C. Lower Structure

I. On its own with interface ring & outriggers attached (4 small dog clamps)

	72 & 82 Hz	120 & 121 Hz	111 Hz & 112 Hz +

+ Russell looked into the possibility of a discrepancy between the as built configuration and the one used for FEA. At the same time, he modified the clamping to be more like the experiment.

* It should be noted that the structures used for FEA, in ANSYS Workbench and ALGOR had to be simplified somewhat to remove features that could not be meshed!

4.5 Weight of structure

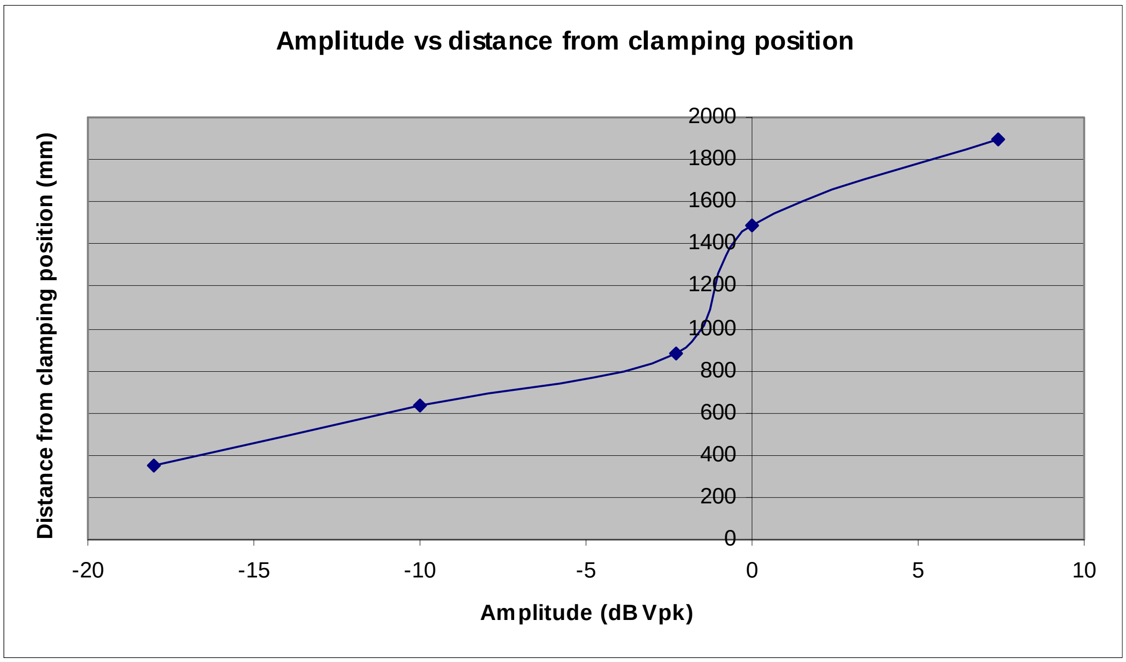
Ken, Mike and I measured the weight of the upper structure, the one currently being used for the suspension, m1 = 63 lbs. ADD PHOTOS & DESCRIPTION OF CONFIGURATION
We also measured the overall structure, Stanford structure, with all of the non-suspended mass and outriggers / stiffeners etc … m2 = 215 lbs. (Remember that the top stage is not as heavy as designed due to interference issue in design of dummy top stage.) ADD PHOTOS & DESCRIPTION OF CONFIGURATION

4.6 Ideas from the design meeting

Russell Jones asked me to modify the configuration of the bolted on sections in the overall configuration, no change! Tim Hayler asked me to remove the ring and try the overall configuration again (without outriggers) f1 = 32 Hz cf. 36 Hz. Not sure if I was able to sufficiently clamp the lower structure to the upper section.

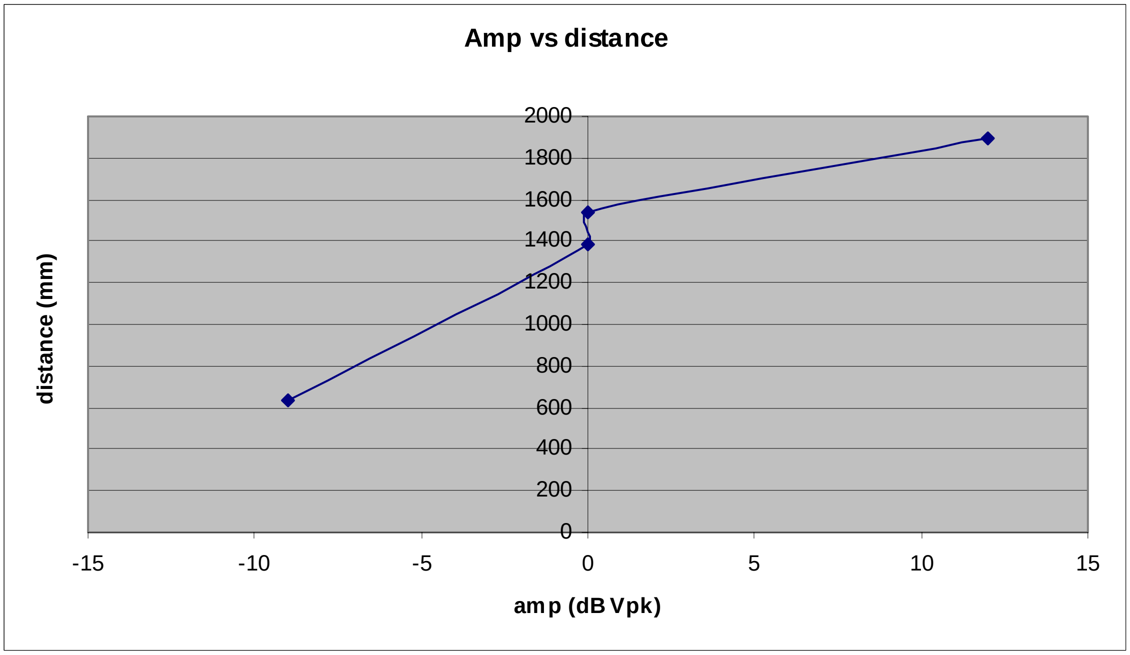
4.7 Mode shapes

Mark Barton and I investigated the mode shapes of the first two modes of the overall structure, namely 54 Hz and 63 Hz. From the work done the authors believe these are the longitudinal and transverse modes.

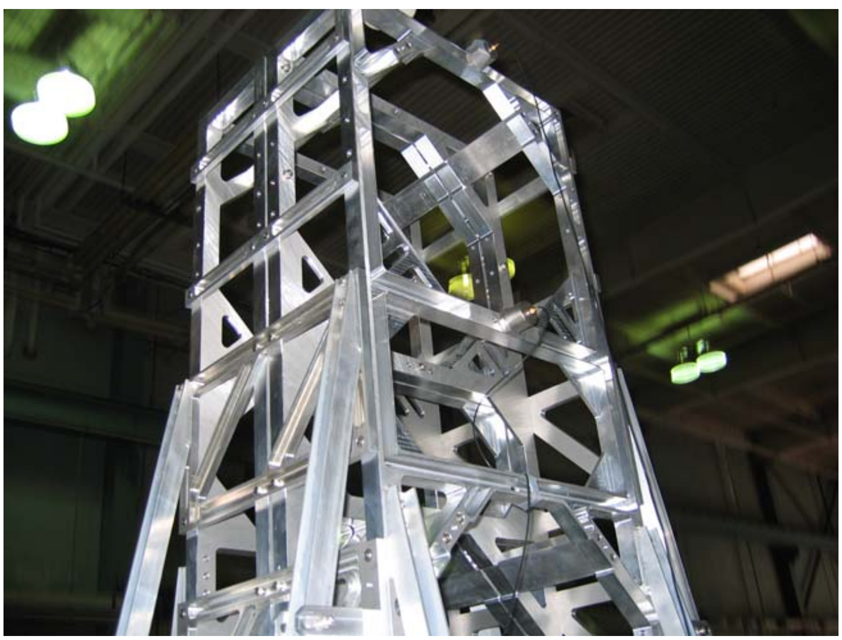


Graph (1): Longitudinal mode of overall structure (54 Hz)

NB: The distance from the lower structure to the clamping position at he milling machine is 770 mm



Graph (2): Longitudinal mode of overall structure (63 Hz)



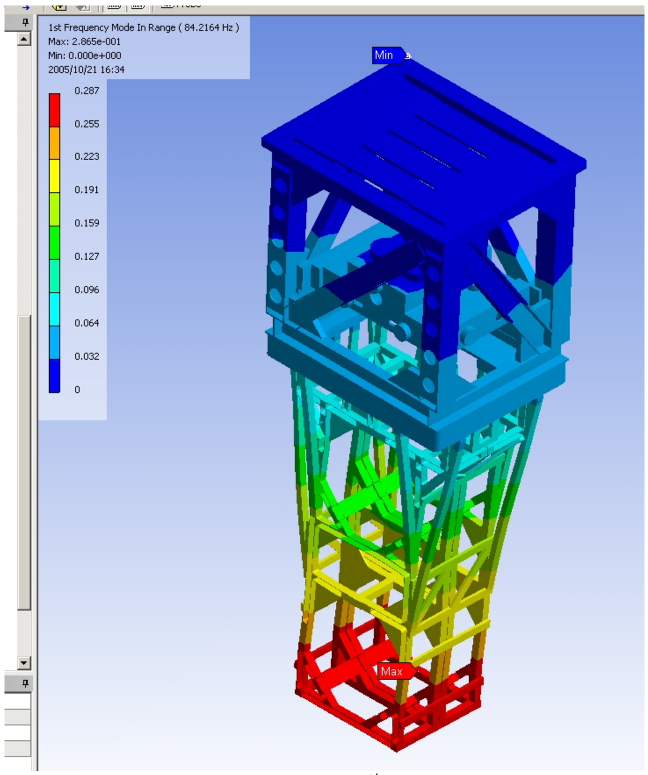
Photograph (3): - Of the mode shape experiment

4.8 Bolted connections

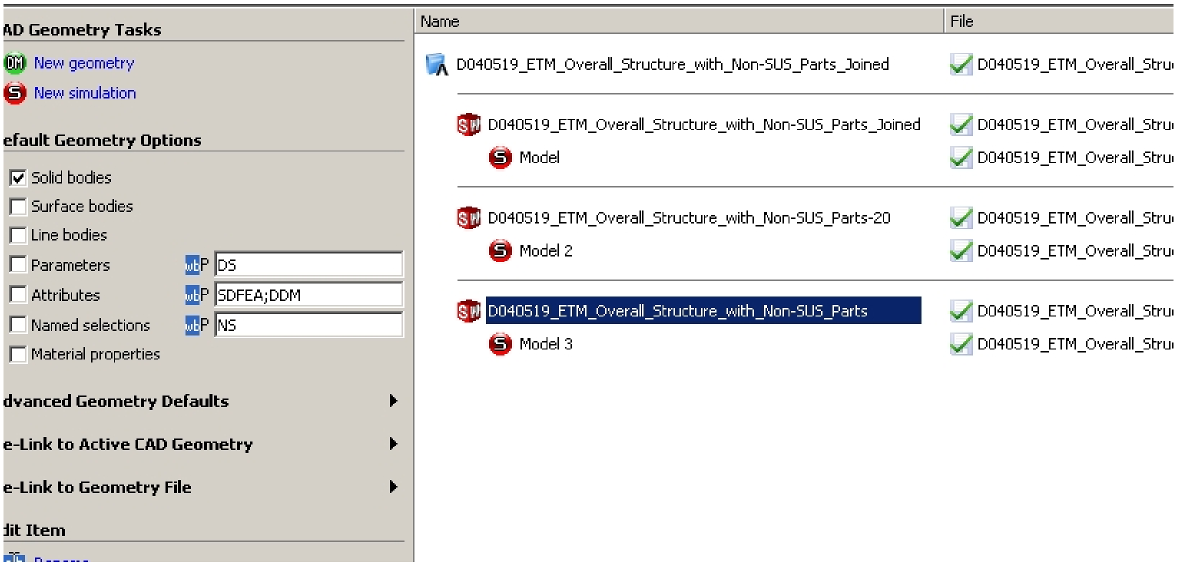
Add appendix with page from ASI talk.
Add sheets from Tim Hayler's notes on the 22nd November 2005

4.9 Ideas from Design Meeting

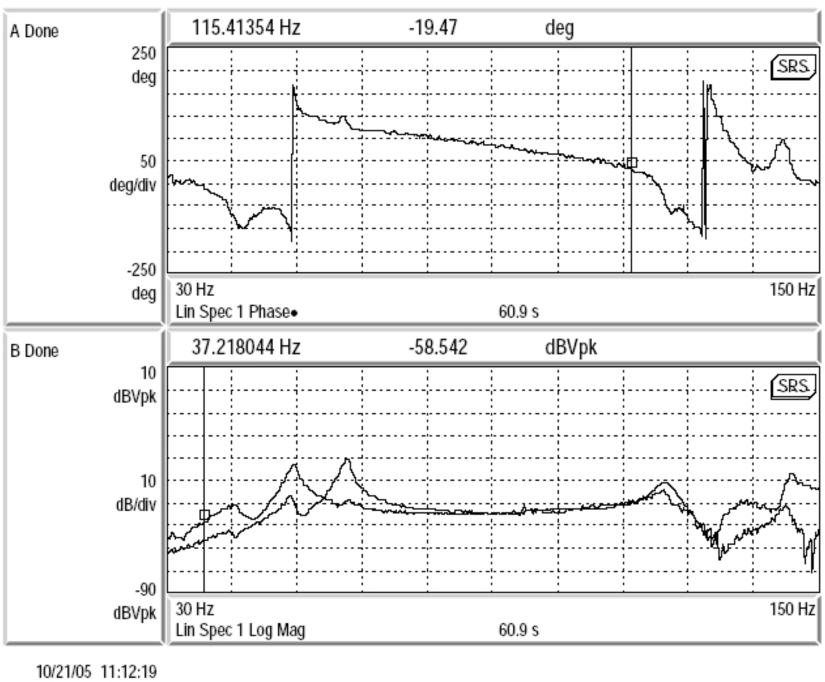
Add e-mail list



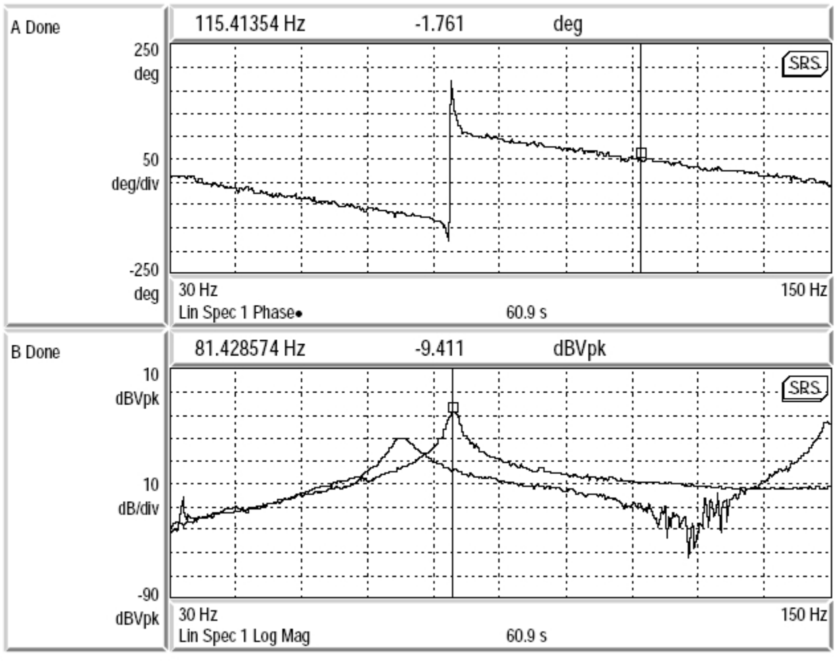
FEA of overall structure, 1st resonance shown



Extract from ANSYS, FEA, showing how to select options to stay within 120,000 nodes limit



Overall Structure, showing both longitudinal and transverse frequencies



Lower Structure, showing both longitudinal and transverse frequencies

4.10 Finite Element modeling (ANSYS)

4.10.1 Introduction

ANSYS version 9.0 (and recently 10.0) University Advanced. Each result was checked in ALGOR for comparison.

4.10.2 Input Data

A joined part of the assembly from SolidWorks 2005 was exported directly to ANSYS 9.0 or 10.0

For the results obtained in ANSYS, the following input data was used.

TBC

4.10.3 Post Processing

4.10.4 Configurations of the structure used in the modeling and experiment

4.11 Experimental results and photos

Add information from excel sheet that includes all of the traces collected and photos.

4.12 Stanford Results

B. Lantz measured 61 Hz and 73 Hz when he placed the "2nd" structure on the technology demonstrator at Stanford. (cf. Caltech 54 Hz and 63 Hz) I would suggest this could be down to the way the structure was clamped or the interaction between the technology demonstrator and the suspension structure.

5.0 Conclusions

TBC