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BSC ISI-Quad Modal analysis

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Introduction

The BSC-ISI transfer function show a very high number of modes. These modes are one of the main limitations of performance for the BSC-ISI control.

From a control point of view, theses modes have to be filtered out using elliptic filters, notches or classical low pass for the highest frequencies. It results in two consequences: the first is a big loss of phase; the second is pretty poor control robustness.

These modes are as low as 45 Hz and numerous. Also we have not been able to explain yet why some of these modes shift from one measurement to another.

In order to identify modes and to propose possible correction actions we have been doing a modal analysis on the Quad structure and the ISI. The purpose of this study is to figure out how the substructures are involved in those modes.

This investigation will be carried out in several phases. The first one, presented in this document, focused on the Quad structure and the Optical table. The document is made of the following sections:

1- Experiment presentation

2- Quad external structure transfer functions

3- Quad internal structure transfer functions

4- Quad modes inventory

5- Quad modal shapes

6- Stage 2 optical table transfer functions and modal shapes

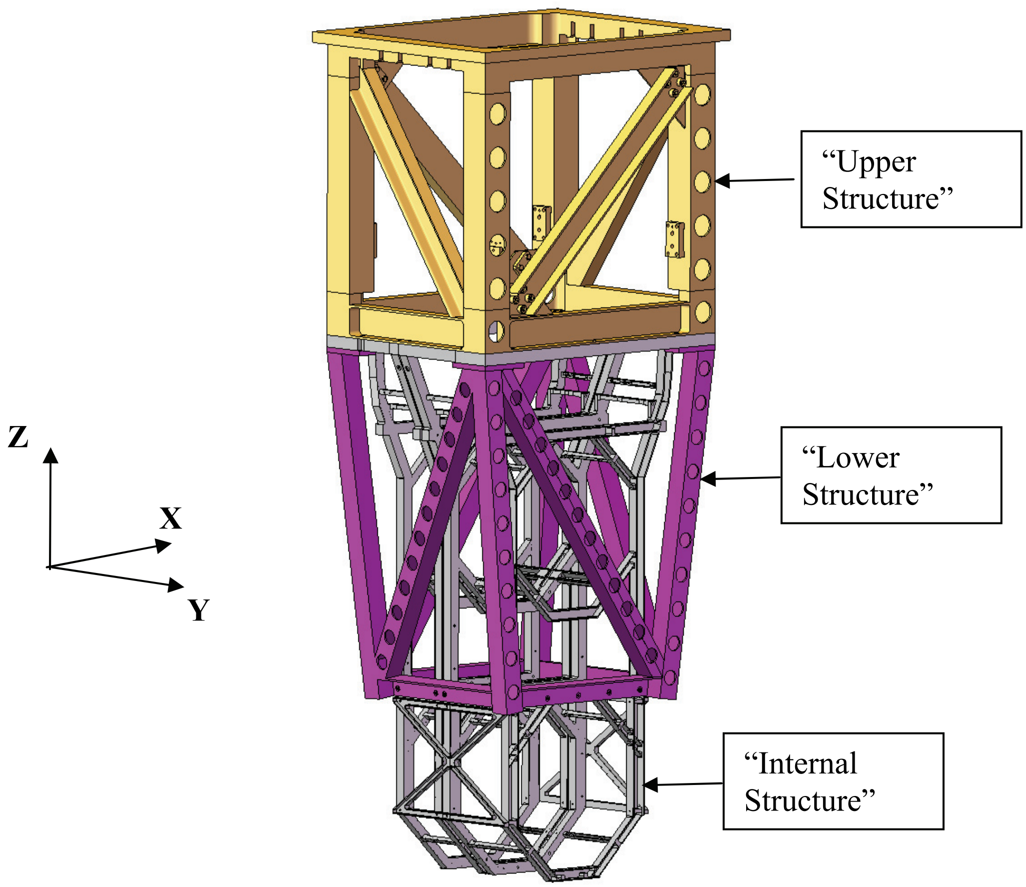
7- ISI transfer functions and modes inventory

8- Comparison of Quad response and ISI transfer function

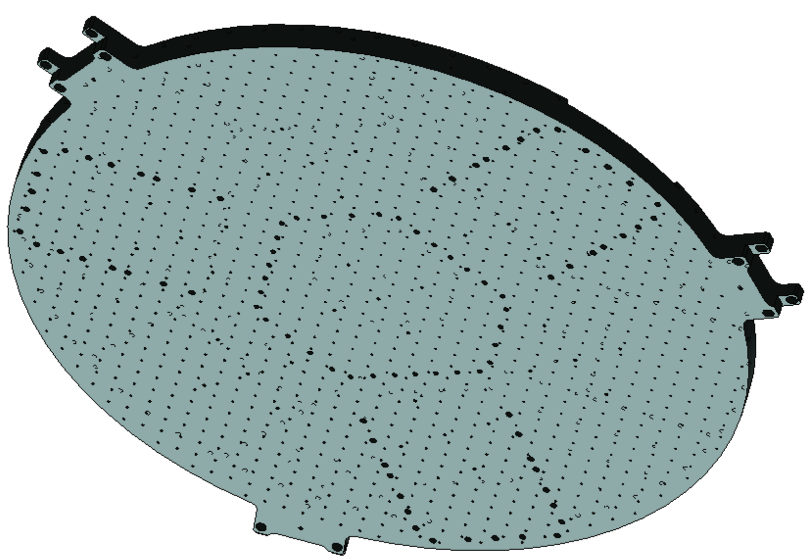
Conclusion

1- Experiment presentation

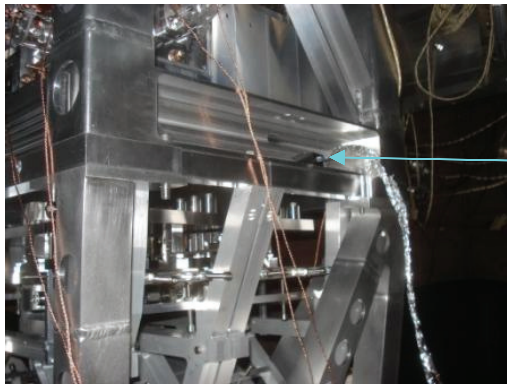
The Quad structure:

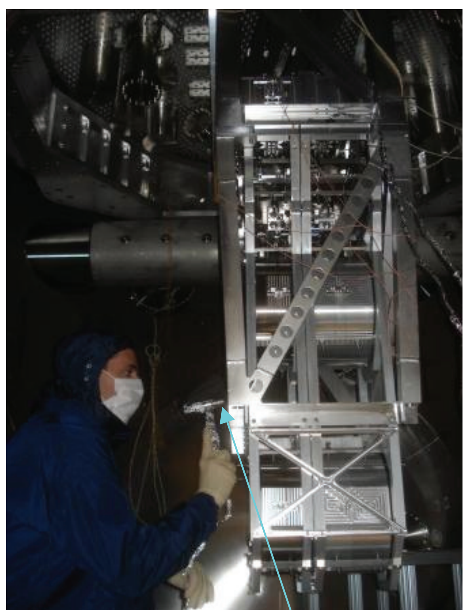


The optical table:



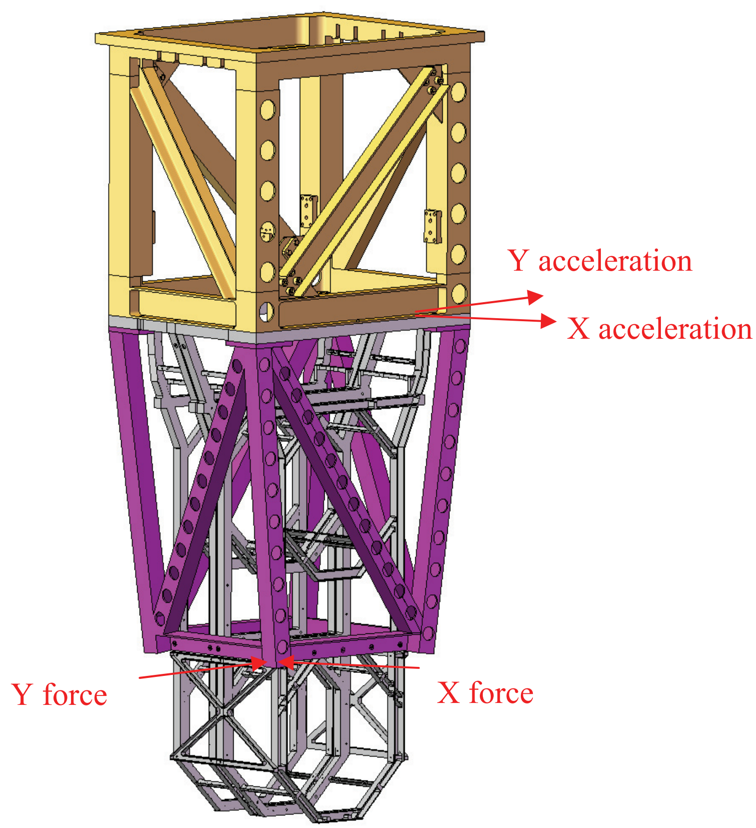
The modal analysis is done using a three axis accelerometer on the Quad and an impact hammer with force sensor. The accelerometer is clamped at the interface between the lower structure and the upper structure. A choc is applied at each of the point where we want to extract the modal displacements.





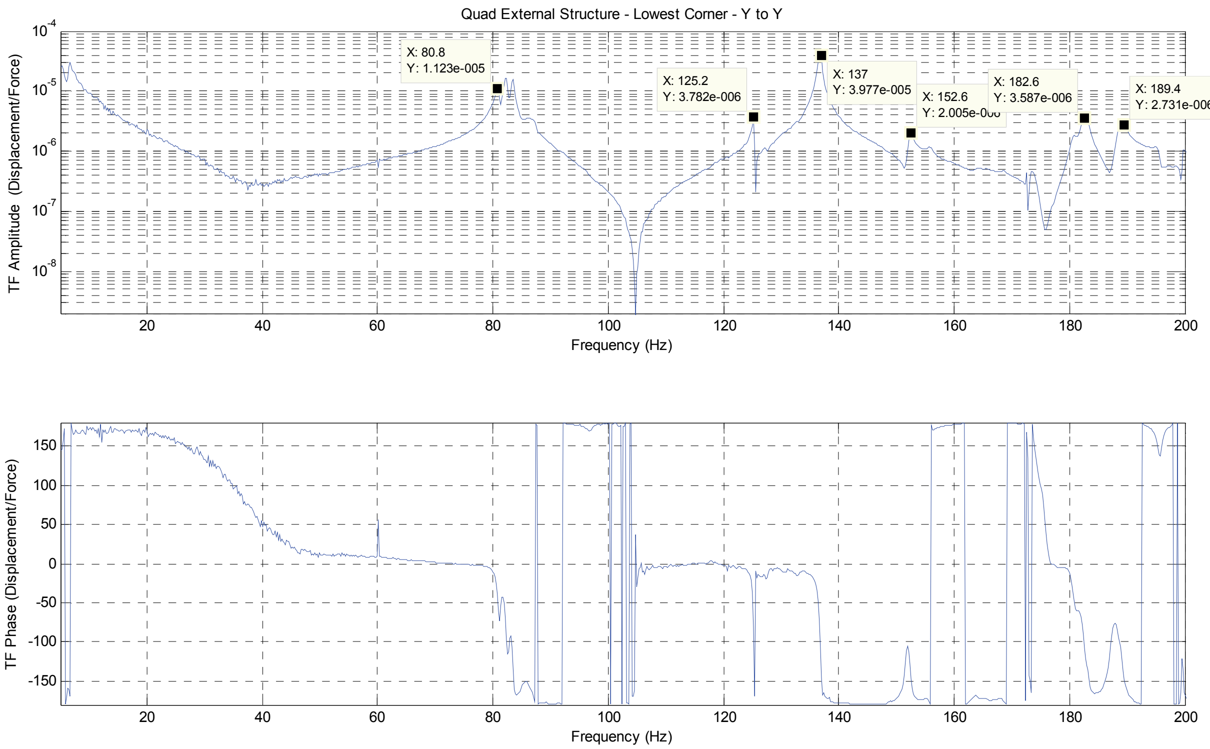
2 - External Structure transfer functions

We call external structure the “Upper Structure + Lower Structure”. Transfer functions of accelerometer response over the impact force are taken. The input/output points are shown on the picture below.

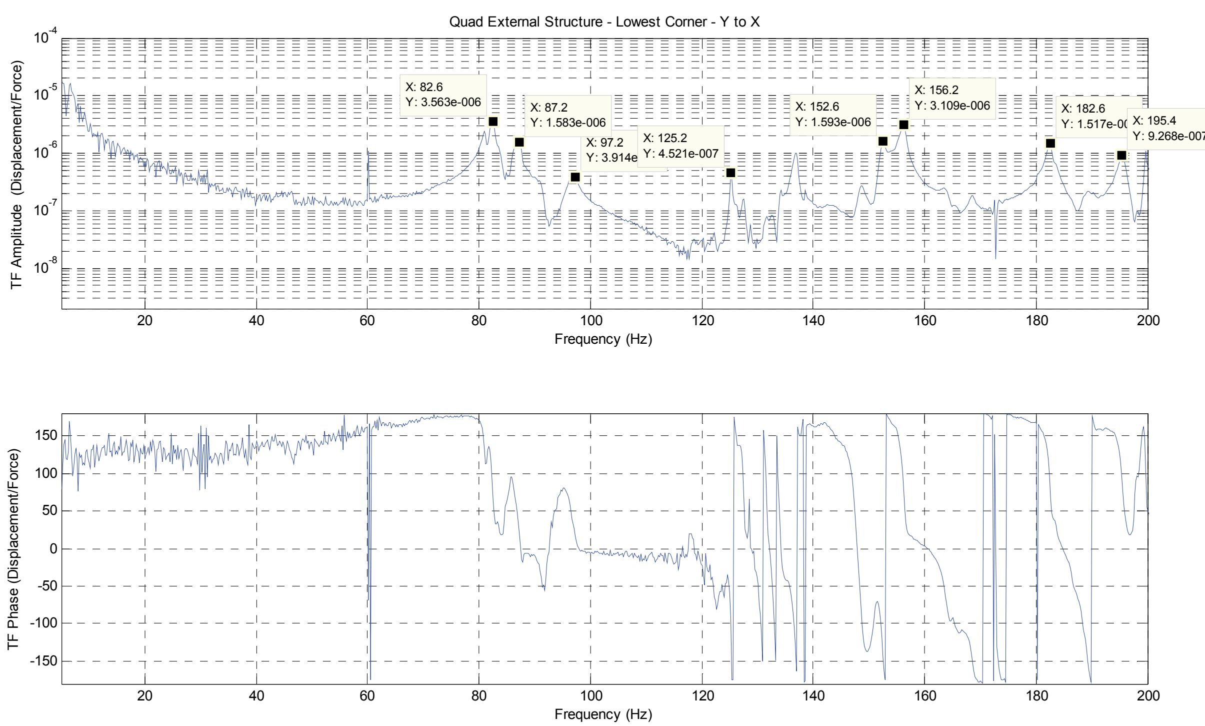


These two inputs and two outputs give us four characteristic transfer functions of the quad structure. Each of these TF is made of 10 datas averaging. They are presented in next pages.

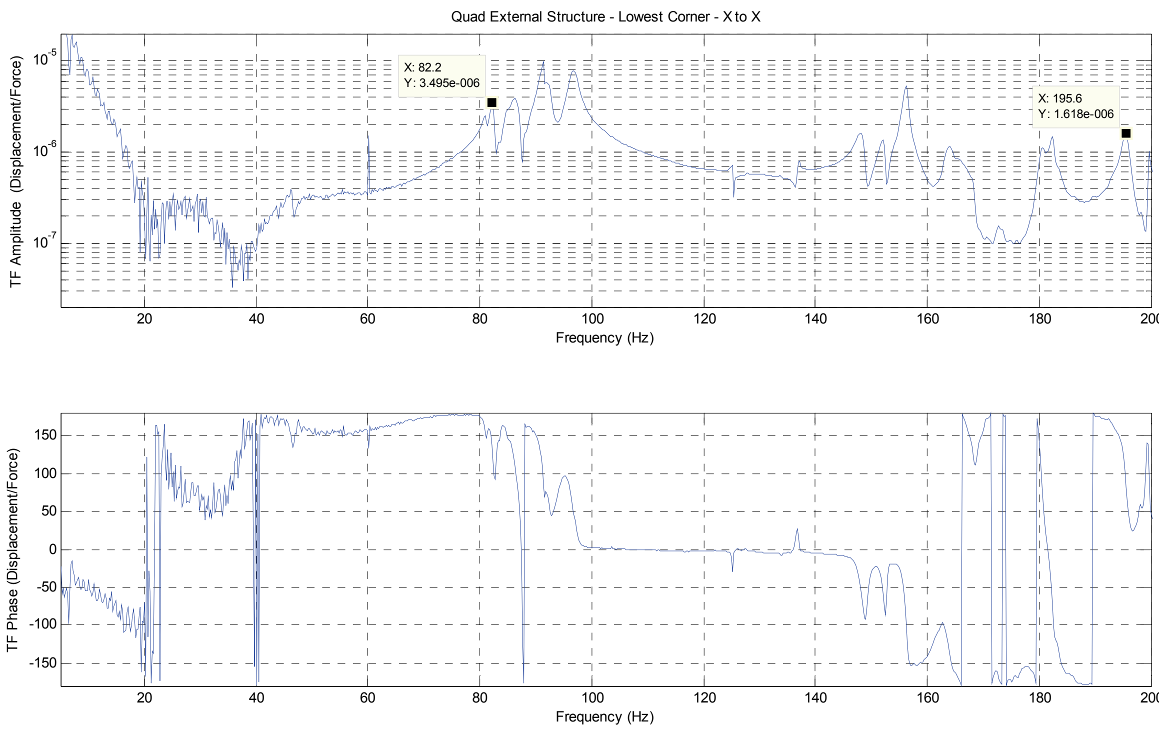
1.1 Y to Y:



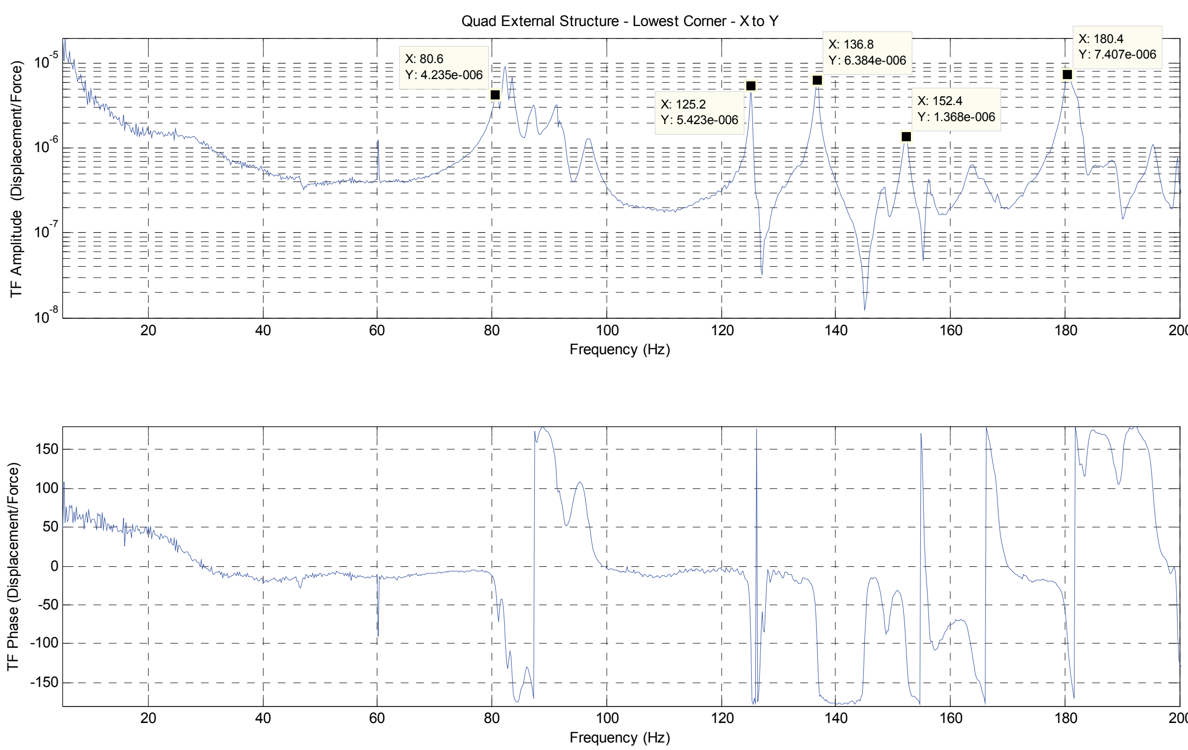
1.2 X to Y :



1.3 X to X :



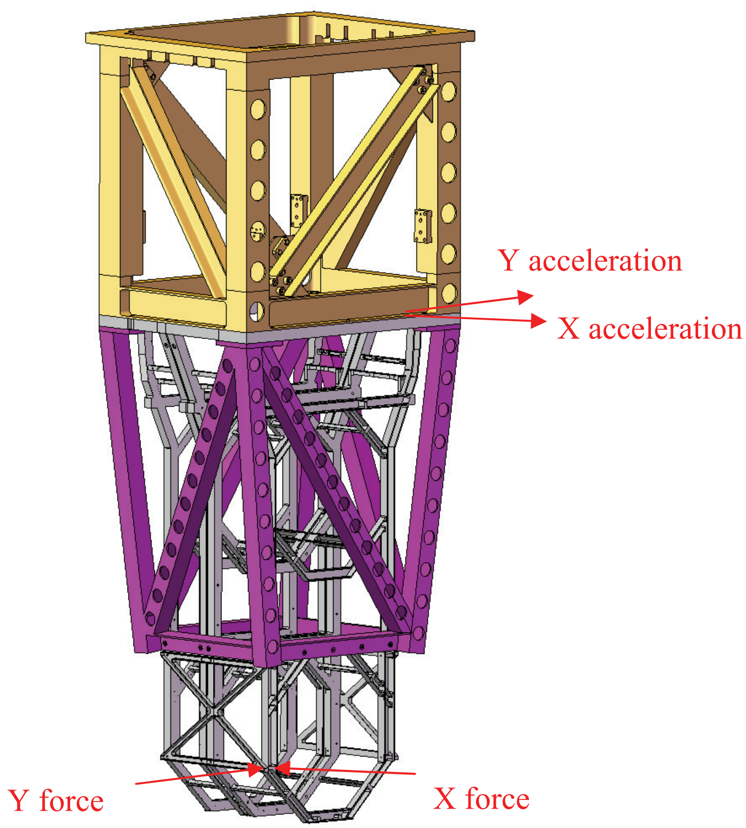
1.4 X to Y :



3. Internal Structure

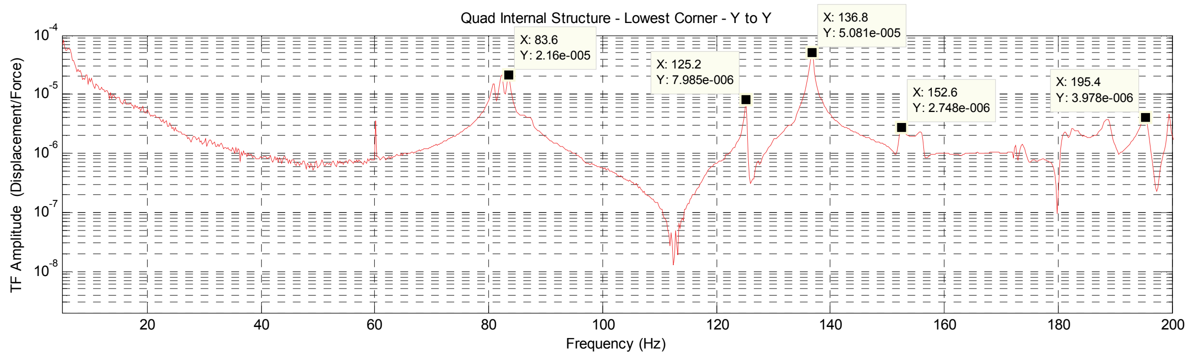
Like we did on the external structure, we take four transfer functions on the internal structure to find its modes.

The purpose of this section is to figure out if the internal structure moves and deforms with the external structure or if it has its own modes.

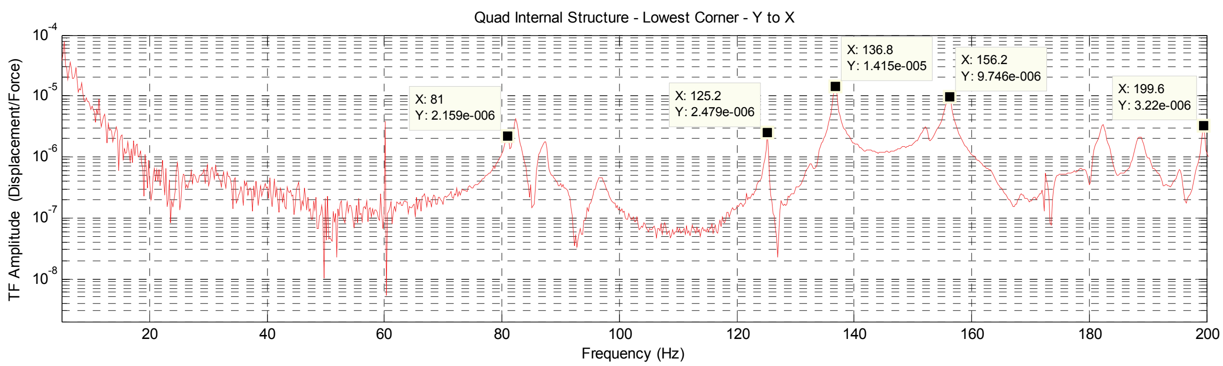


These two inputs and two outputs give us four new transfer functions to be compared with the 4 previous "characteristic" TF. Again, each of these TF is made of 10 datas averaging. They are presented in next pages.

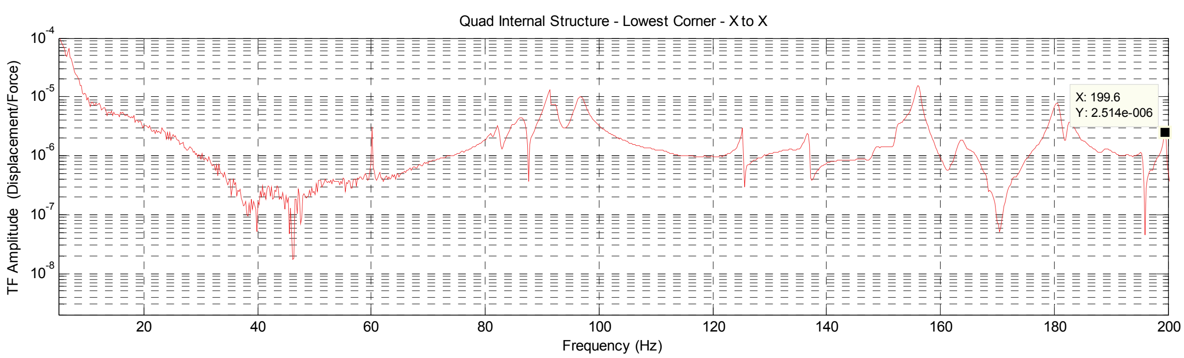
3.1 Y to Y:



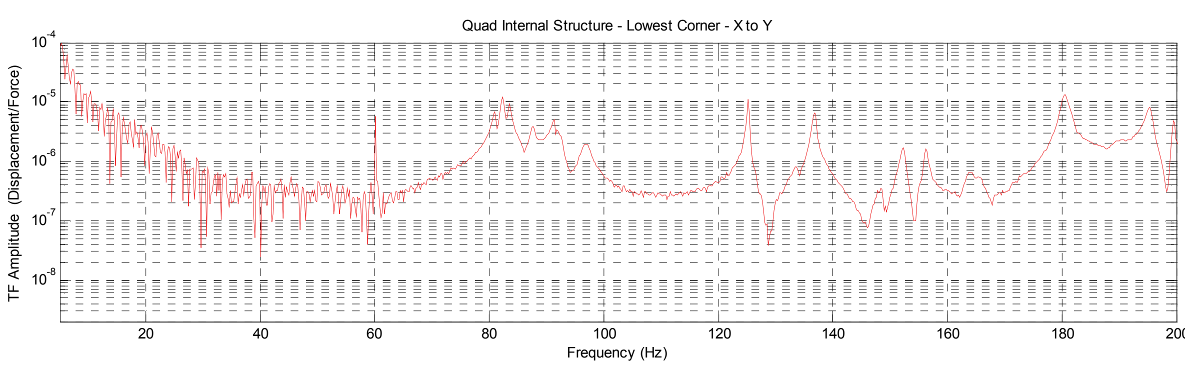
3.2 Y to X:



3.3 X to X:



3.4 X to Y:



4-Quad Modes Inventory

The table below shows all the modes we can see in the Quad transfer functions. The cross show in which transfer functions those modes appear significantly.

		Ext. Structure				Int. Structure			
Mode #	Freq (Hz)	Y to Y	Y to X	X to X	X to Y	Y to Y	Y to X	X to X	X to Y
1	80.8	+			+	+	+		+
1'	82.4	+	+	+	+	+	+	+	+
1"	83.6	+			+	+			+
2	86.2		+	+	+			+	
3	91.4			+	+			+	+
4	97		+	+	+		+	+	+
5	125.2	+	+		+	+	+	+	+
6	137	+	+		+	+	+	+	+
7	148.2			+					+
8	152.6	+	+	+	+	+	+		+
9	156.2		+		+	+	+	+	+
10	164.2			+	+			+	+
11	180.6			+	+			+	+
12	182.6	+	+	+			+	+	
13	189.4	+				+	+		
14	195.4		+	+	+	+	+		+
15	199.6						+	+	+

The «internal structure » and « external structure » show very similar transfer functions. It means they move and deform very well together.

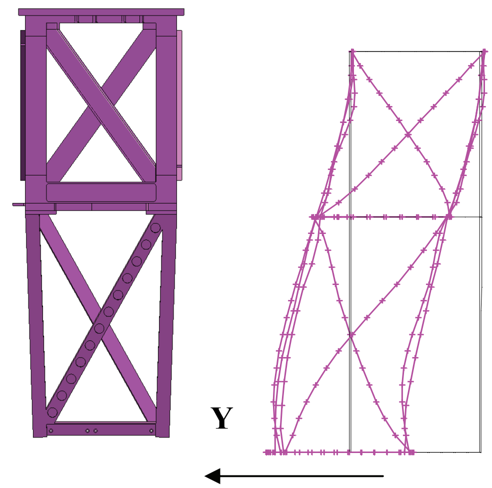
From there we decided that extracting the modal shapes of the external structure was good enough to understand the global behavior of the entire Quad structure (in other words, no need to study carefully the modal shapes of the internal structure).

Next sections show the modal shapes of the principal modes appearing on the characteristic transfer functions.

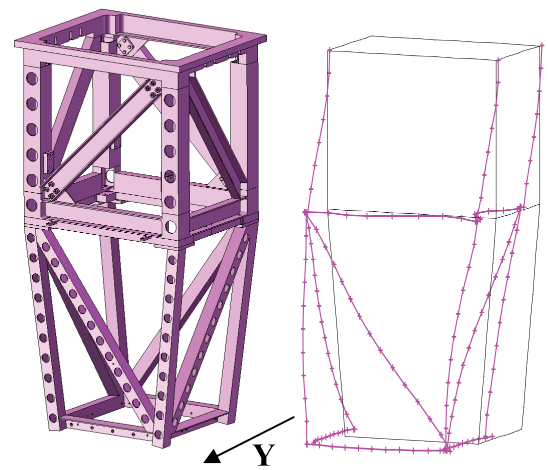
5- Modal shapes

The table on next pages shows the modal deformation of the Quad. The quad structure has a first bending mode in the Y direction (along its short width) at 81 Hz. It has then bending modes mostly along Y (i.e mode at 86.2Hz), bending modes coupling X and Y (i.e. mode at 91.2Hz) and bending modes mostly along X (its large width) at 97.2Hz. Some torsion modes (125.2Hz, 137Hz, 156Hz) are then shown lower in the table. The mode at 137Hz is mostly a rigid body rotation with a local deformation of the two upper u-beams.

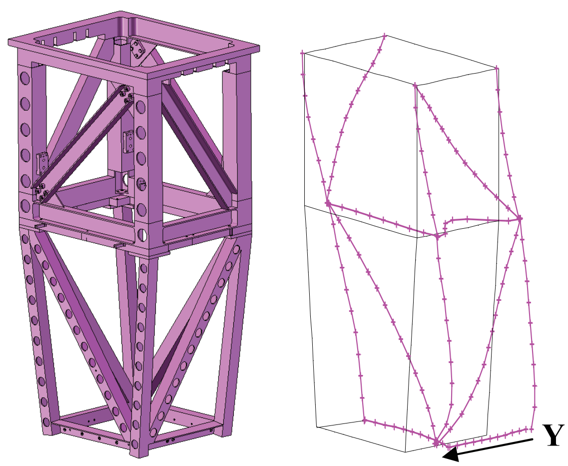
Mode @ 81Hz: Y-Bending. ***Side view :***



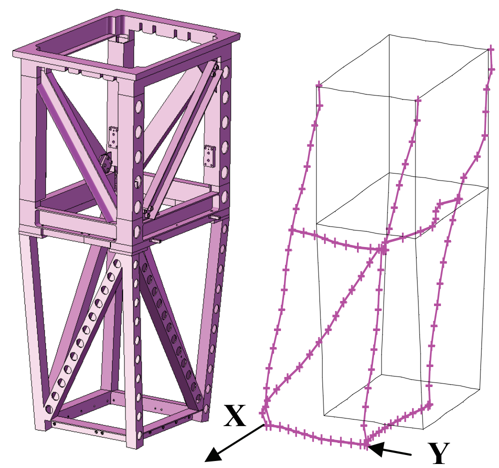
Mode @ 81Hz ***Iso view :***



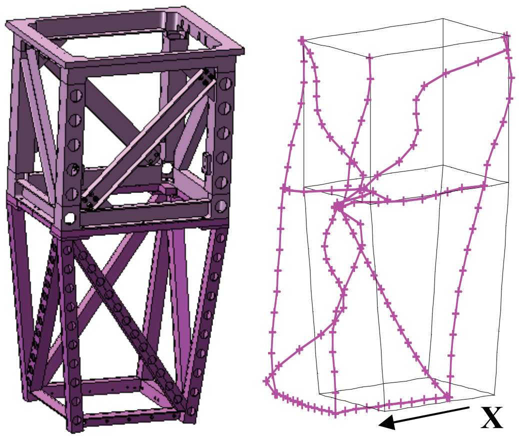
Mode @ 86.2Hz: Y-Bending. ***Iso view :***



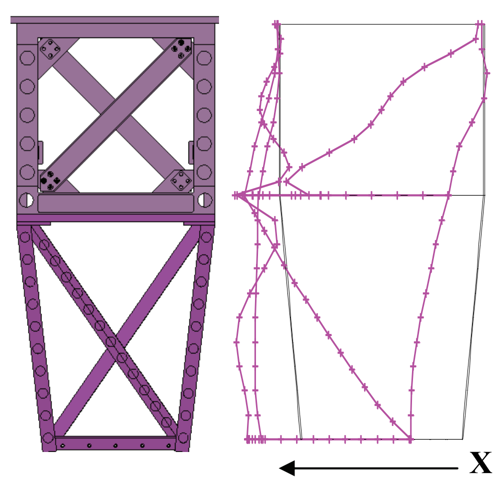
Mode @ 91.2Hz : X-Y-Bending.***Iso view :***



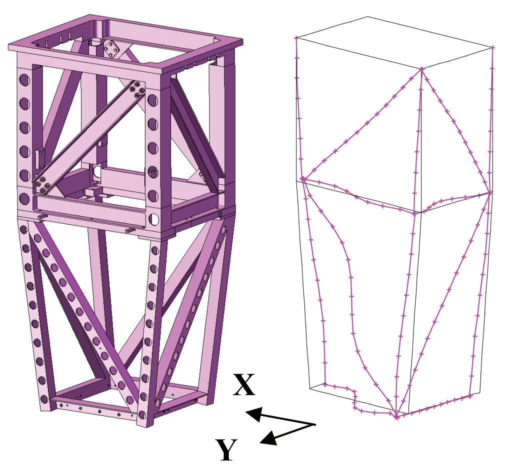
Mode @ 97.2Hz: X-Bending. ***Iso view :***



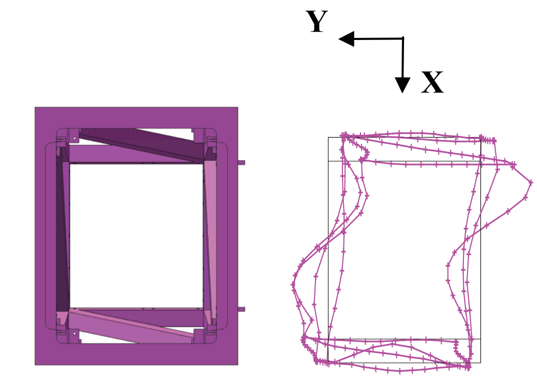
Mode @ 97.2Hz: X-Bending. ***Side view :***



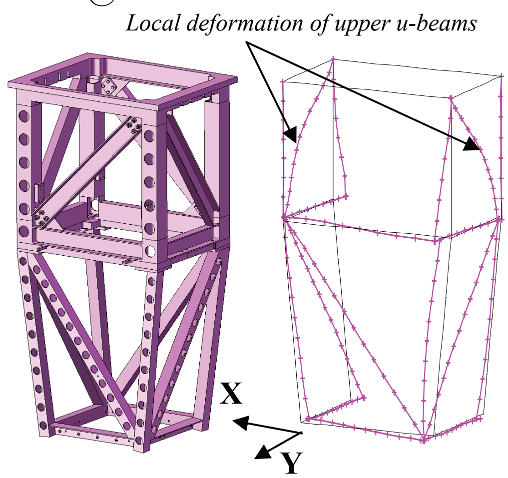
Mode @ 125.2Hz: torsion. ***Iso view :***



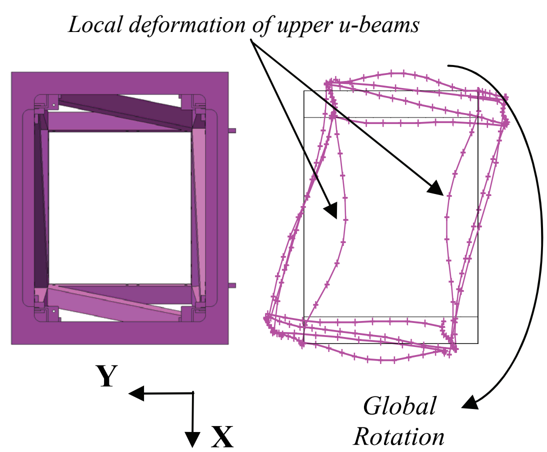
Mode @ 125.2Hz: torsion. ***Top view :***



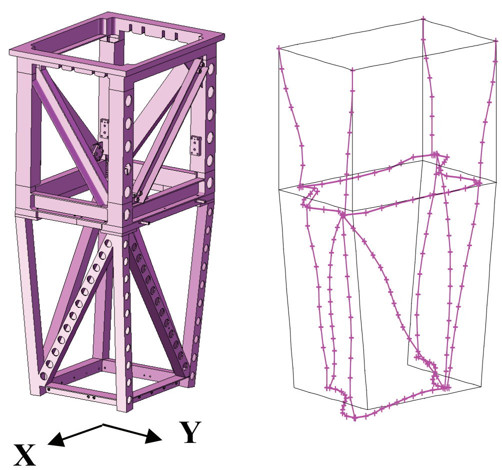
Mode @ 137Hz: torsion. ***Iso view :***



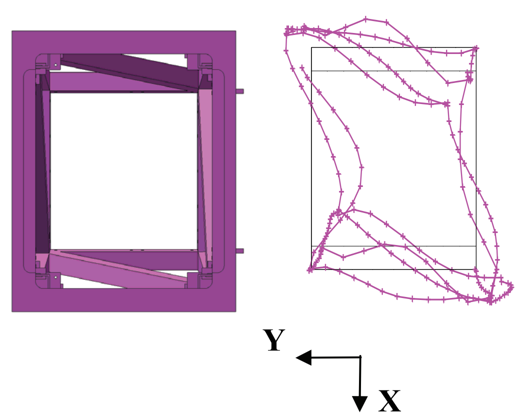
Mode @ 137Hz: torsion. ***Top view :***



Mode @ 156.2Hz: torsion. ***Iso view :***

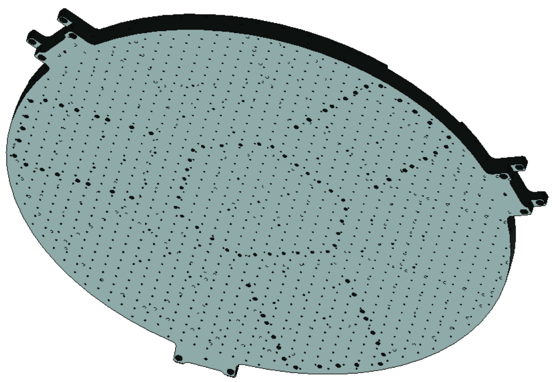


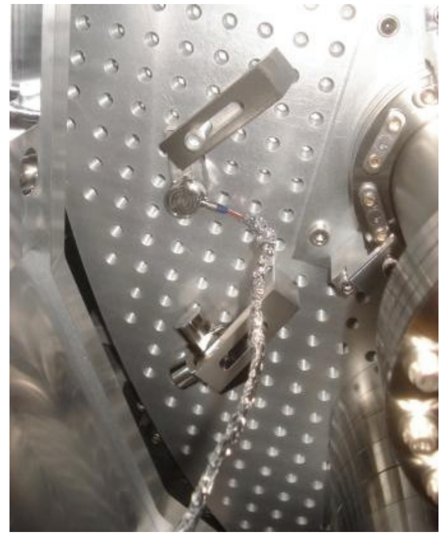
Mode @ 156.2Hz: torsion. ***Top view :***



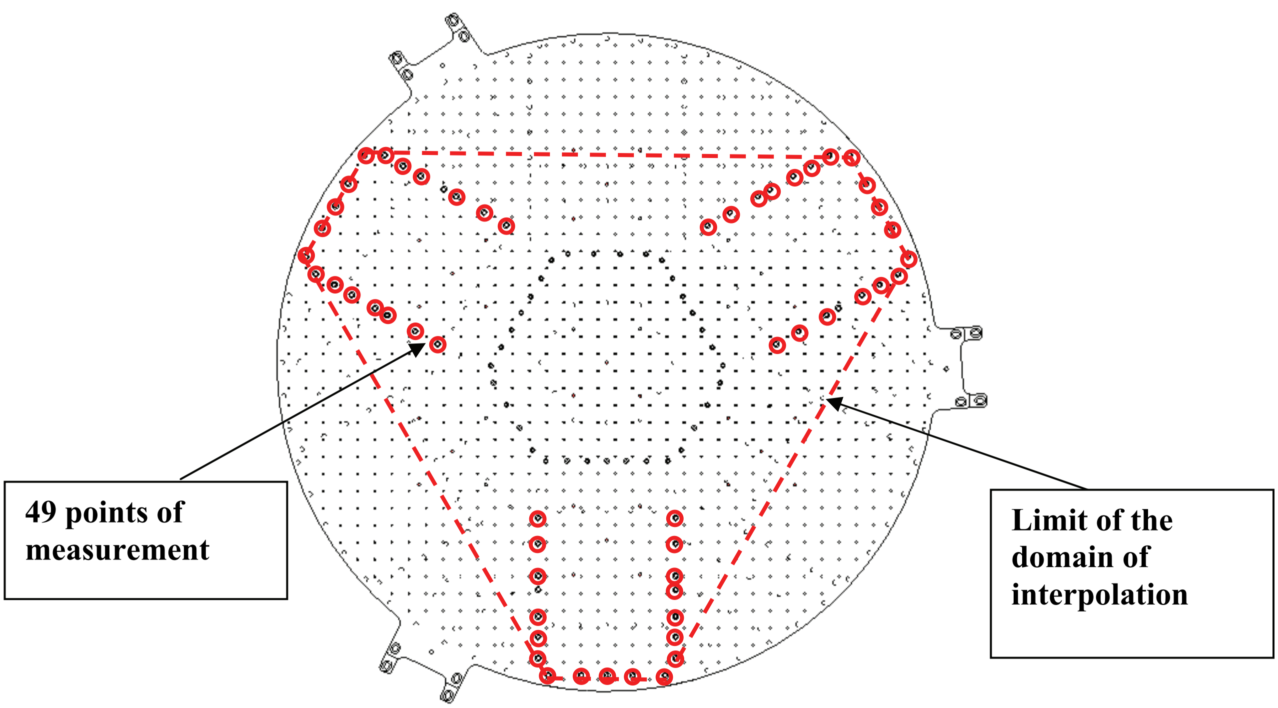
6- Stage 2 Optical table

On the figures below: a CAD of the optical table and a picture showing how the accelerometer was attached on the optical table.

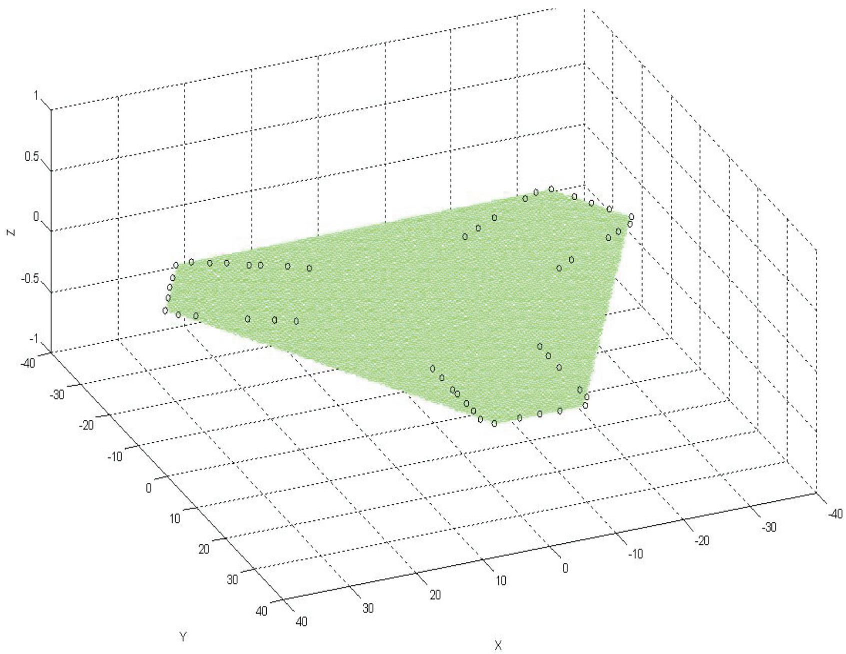




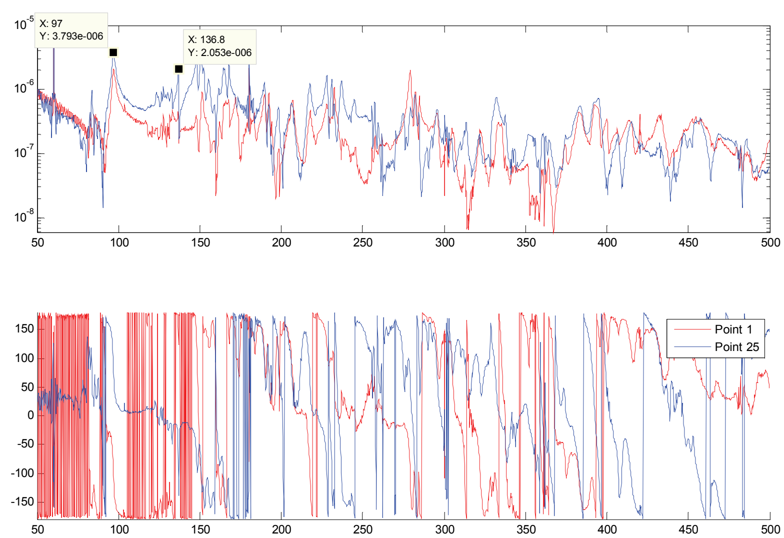
Next figure shows the measurement points used on the optical table (red circles). The dash lines show the limit of the domain of interpolation used in the code to plot the modal shapes:



The same points and domain are shown on a Matlab plot. The code extract the amplitude and phase of each of these points of measurements (black circles) and then make the interpolation on the domain shown in green.



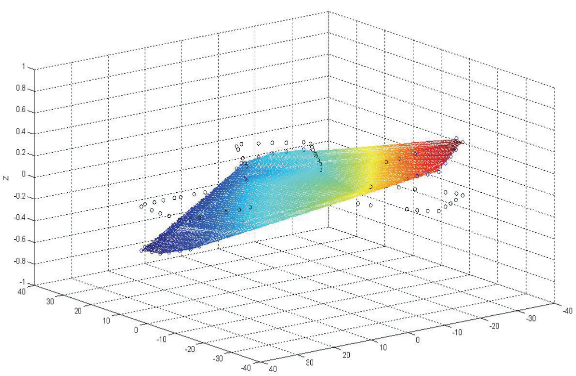
Typical transfer functions:



The plot above shows two typical measurements for two different points of the optical table. The peaks at 97Hz and 137Hz have clean amplitude and phase so we can extract the modal shapes.

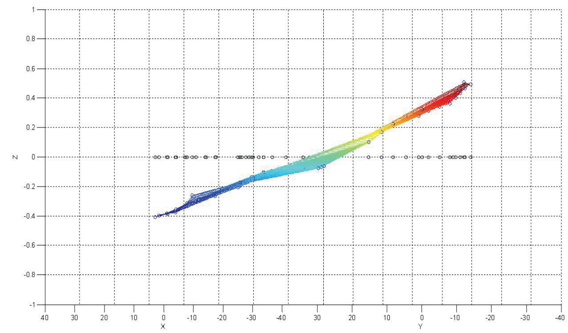
Modal Shapes

Mode @ 97 Hz:



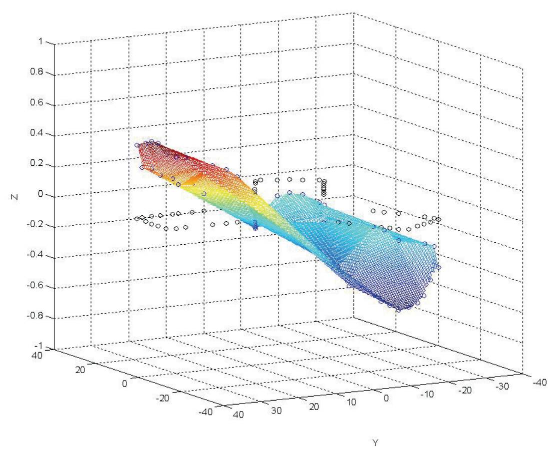
Isometric view

Mode @ 97 Hz:



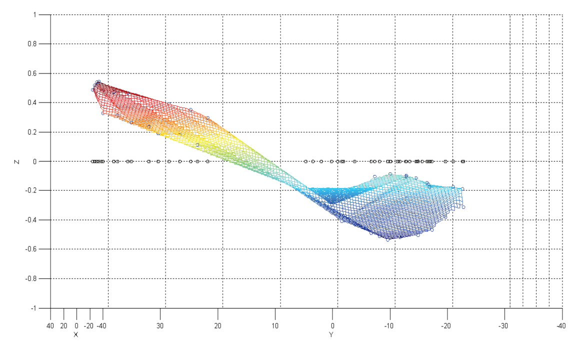
Side view

Mode @ 137 Hz:



Isometric view

Mode @ 137 Hz:



Side view

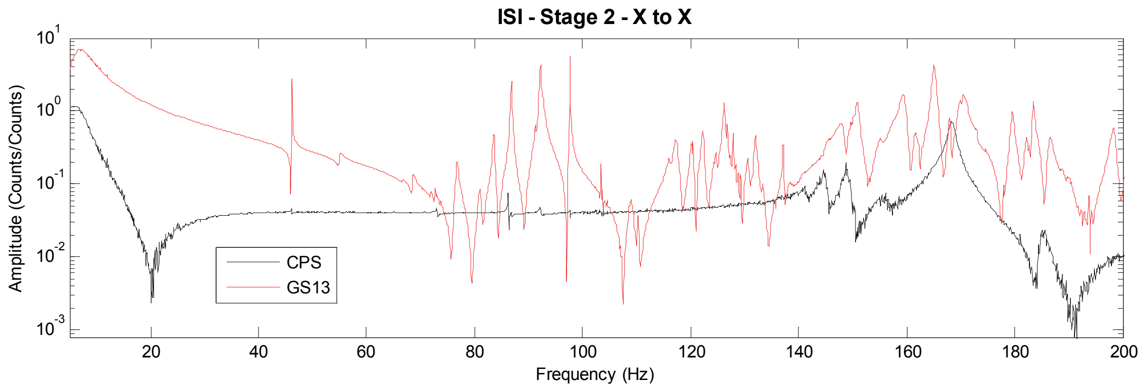
- Mode at 97Hz. It's mostly a rigid body mode of the optical table due to a bending mode of the Quad in the X-direction.
- Mode at 137Hz. It’s a deformation mode of the optical table. We find the first mode of deformation of Stage2 to be at 121Hz, although the data quality is not very good at this frequency.

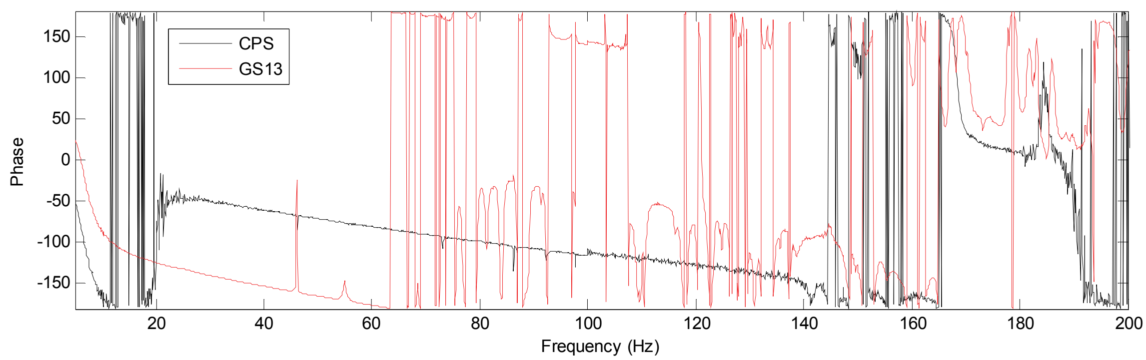
ASI finite element analysis predicted a first mode on stage-2 at 171Hz, with no ballast and no payload. We currently have ~700pds of hockey pucks + the quad on the optical table, + the keel masses and balancing masses upper on stage-2. So it's no surprising that the predicted mode at 171Hz lower to 121Hz with all this additional mass.

We'll continue our investigation with a close look on the rest of stage-2, stage-1 and the deformations close to the instruments.

7 – The ISI TF

Next plot shows the ISI transfer function in the X direction. These transfer functions are from ISI coil driver to GS13 in the general coordinate basis.



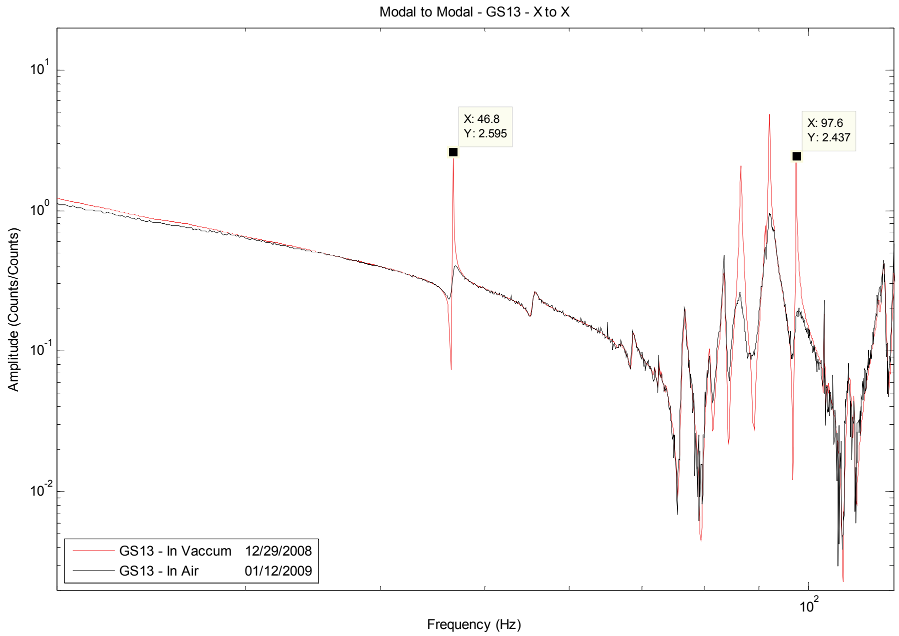


Modes visible in the X to X TF:

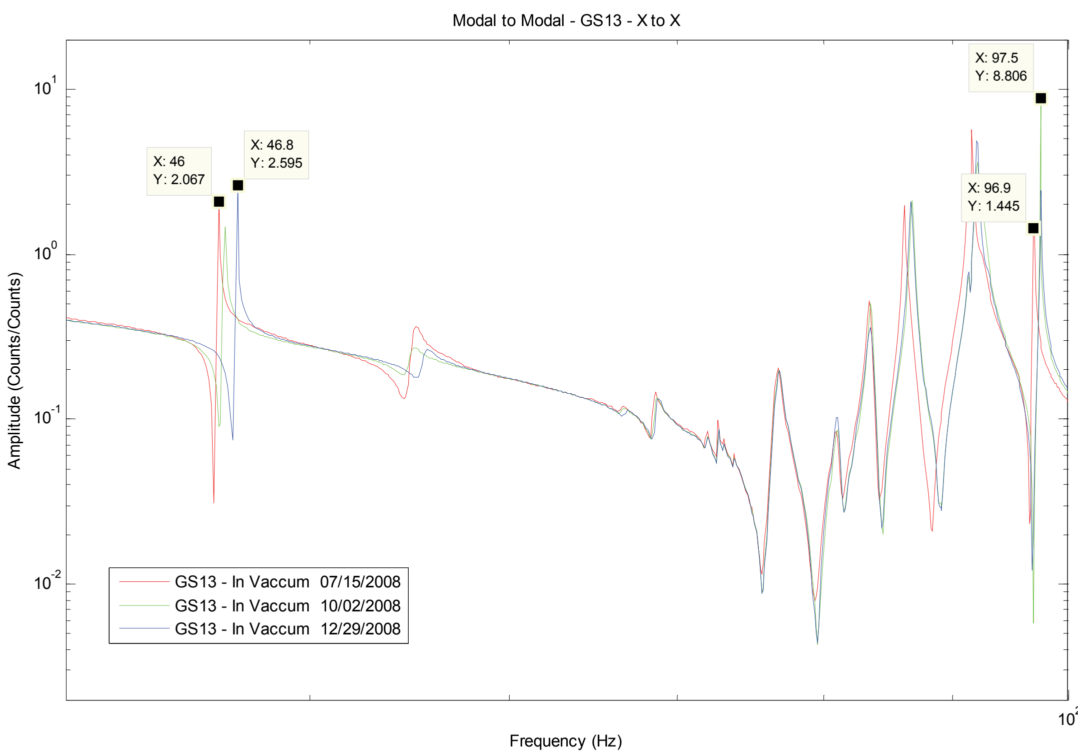
Mode #	Freq (Hz)	Mode #	Freq (Hz)	Mode #	Freq (Hz)	Mode #	Freq (Hz)
1	*46.2*	11	*109.1*	21	*147.7*	31	*198*
2	*55.3*	12	*110.3*	22	*150.8*		
3	*68.7*	13	*117.4*	23	*159.4*		
4	*76.7*	14	*120.4*	24	*161.4*		
5	*81*	15	*122.3*	25	*165.1*		
6	*83.6*	16	*126.2*	26	*167.8*		
7	*86.8*	17	*127.9*	27	*170.9*		
8	*92.1*	18	*130.6*	28	*179.4*		
9	*97.7*	19	*132.1*	29	*183.4*		
10	*103.4*	20	*137.1*	30	*186.7*		

8- Comparison of Quad response and ISI transfer function

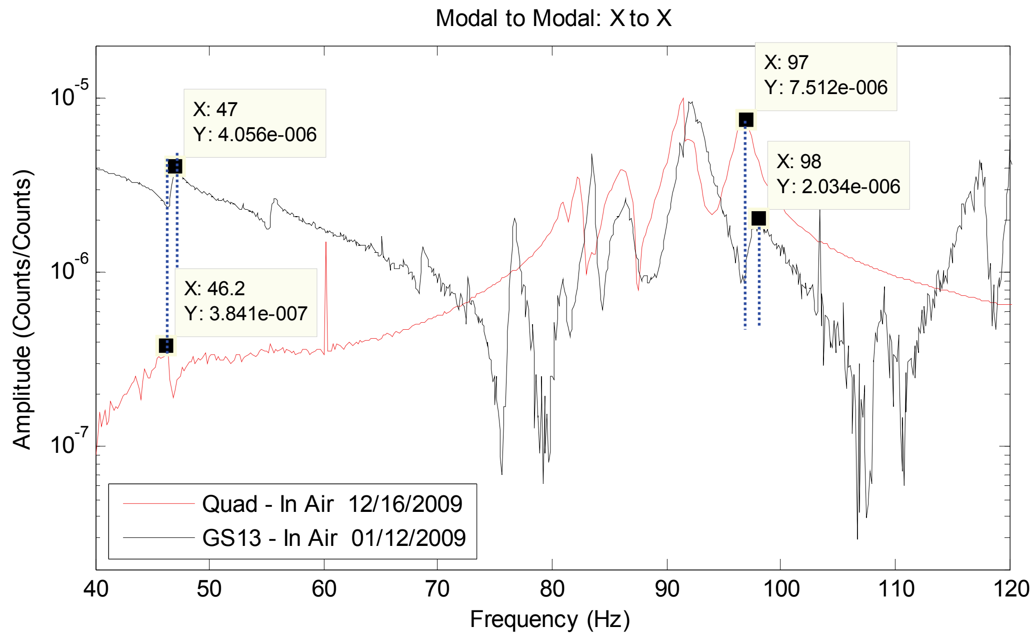
In air in vacuum comparison: the plot below shows how the Qs of the modes of the ISI are sensitive to the air. The Quad transfer functions, taken in air, must be compared with the ISI transfer functions taken in air.



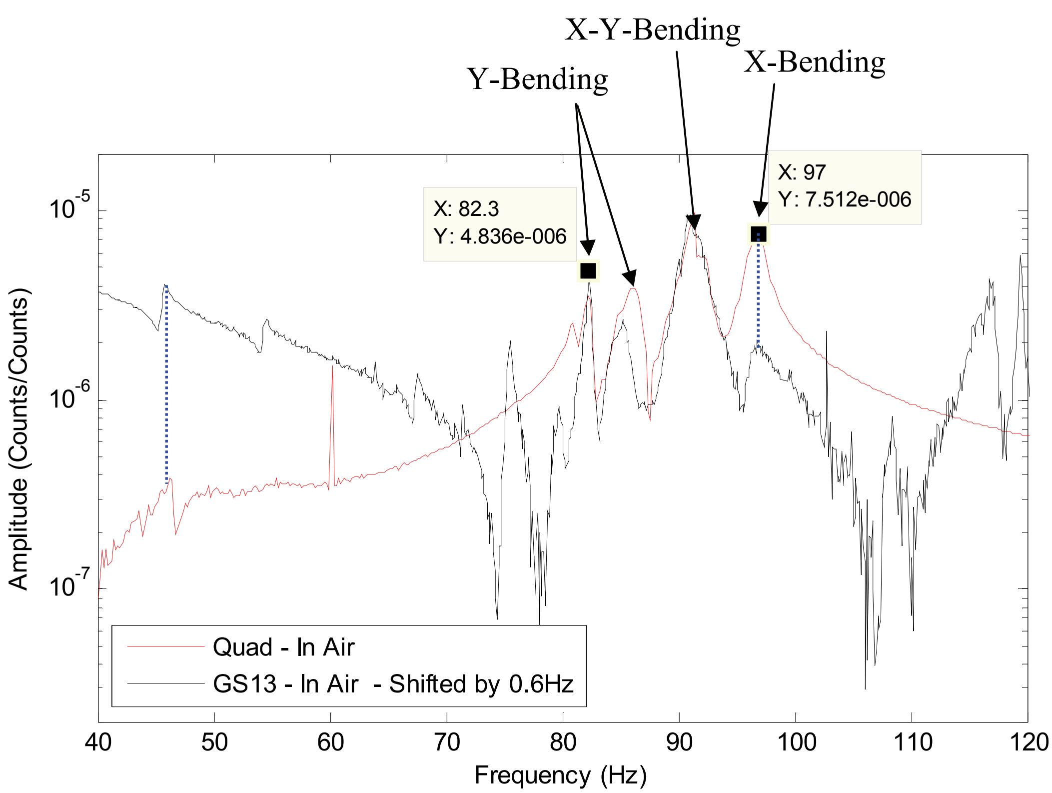
Another important point to take into account in order to make a good comparison of ISI responses and quad responses is that the modes shift in frequency over time. The plot below shows the mode shifting for the ISI responses measured at various dates:



The plot below is a comparison of ISI transfer functions (ISI coil driver to GS13, in air) with Quad transfer functions (impact hammer to accelerometer). The plots show that there is a shift of 0.6Hz to 1Hz on the modes measured on the ISI and the modes measured on the Quad about a month earlier:



On the plot below the ISI response is shifted of 0.6Hz in order to align the modes:



Once the frequency shift is compensated the transfer functions peaks and shapes match pretty well in the 80Hz-100Hz bandwidth.

Conclusion :

- We have identified the first modes of the Quad structure and the Optical table. The first bending mode of the Quad were measured at 81Hz and the first deformation modes of stage 2 were measured are bit above 120Hz, with a bending mode identified at 137Hz.
- The Quad response (impact hammer to accelerometer) has been compared with the ISI transfer functions in air (ISI actuators to GS13). On the plot comparison, the ISI transfer function has been shifted by 0.8Hz in order to align the modes of the quad with modes of the ISI. On the plot obtained, the Quad response and ISI response comparison permits to think that the Quad structure deformation is involved in most of the modes we can see in the ISI transfer functions between 80Hz and 100Hz.
- We must continue our investigation to identify the modes below 80Hz and other possible local modes on the ISI.