LIGO Laboratory / LIGO Scientific Collaboration

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Vibration Absorber: Final Design Review

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v4 - see notes on DCC file card

Introduction

The goal of this report is to present the vibration absorber designed to damp the suspension structural modes. This device has been designed:

- To be simple to assemble and install
- To add minimum mass to the structure
- To not take footprint on the optic table

It will be installed on the suspension structures: Quad, HLTS, HSTS, OMC, TMS and OFI.

In the first part of this document, we present the results of investigations showing the coupling between seismic platform and suspension structures. Then, we present the techniques investigated to damp these resonances.

In the second section, we present in details the device designed for aLIGO: the vibration absorber. Then, we present the testing results.

In the third section we present the aLIGO layout of vibration absorbers.

The last section is the FDR check list.

1 Presentation of the R&D investigation

This section presents the results of investigation on SUS/SEI couplings and three methods investigated during the past year: struts, corner brackets and vibration absorber. The vibration absorber has been chosen for aLIGO because it is the most compact solution

1.1 SEI/SUS couplings

aLIGO suspensions will be attached to two types of seismic isolation systems : the BSC-ISI platform and the HAM-ISI platform. The BSC-ISI prototype commissioning allowed us to identify couplings between the platform and the Quad structure suspended from the optical table (Fig.2: BSC-ISI transfer functions, versus quad hammering test).

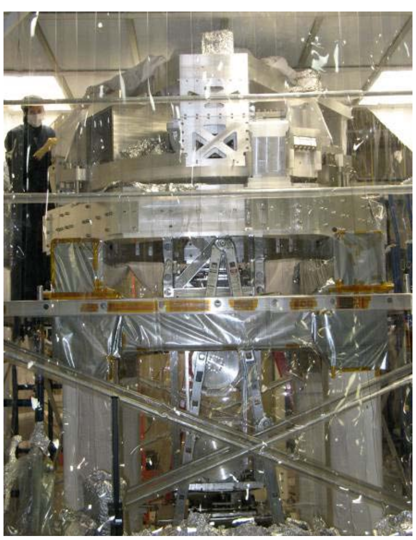


Figure 1 : BSC-ISI/Quad platform

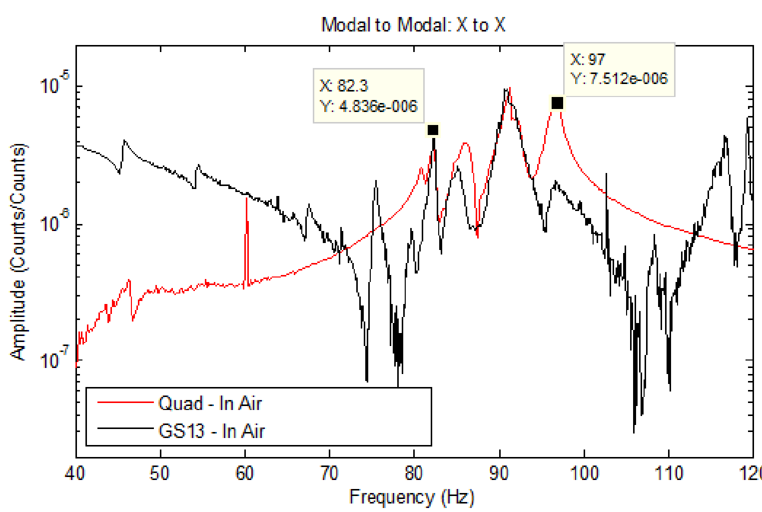


Figure 2: modes correlation

The eLIGO HAM-ISI commissioning also allowed to show how important it is to damp some of the structure resonances to improve the global transfer function of the platform. The high numbers of modes and their high Qs are limiting factors of performances and it is a source of instabilities for the SEI platform. Thus, solving these issues with an active method is going to be difficult and not robust. In the next section we present the techniques investigated to damp these resonances.

2.1 Struts

A first approach to damp modes was to rigidify/damp the structure with struts. For example, a strut device system has been built for the OMC Frame in order to damp its modes. The strut design consists of a 1”x1” aluminum beam set at the seismic table and angled at approximately 60 degrees.

Viton© is constrained between the strut’s plate and the OMC Frame. Screws and washers are used to thread into the OMC Frame through the strut’s plate without touching the plate (using Viton© between the screw heads and the plate). One of the setup tried involved placing a Viton© pad parallel to the strut. It was clamped between a plate that was attached to the OMC Frame and the strut. See the pictures and schematic below.

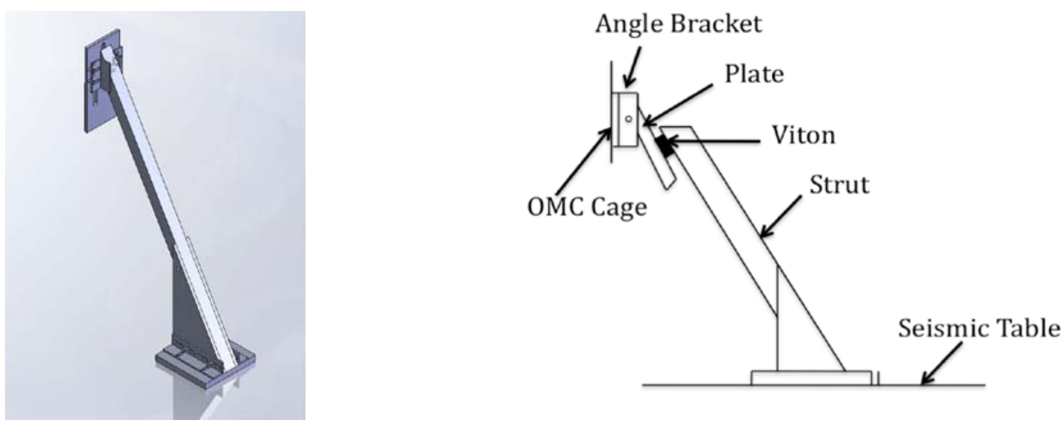


Figure 3 : Vertical setup schematic

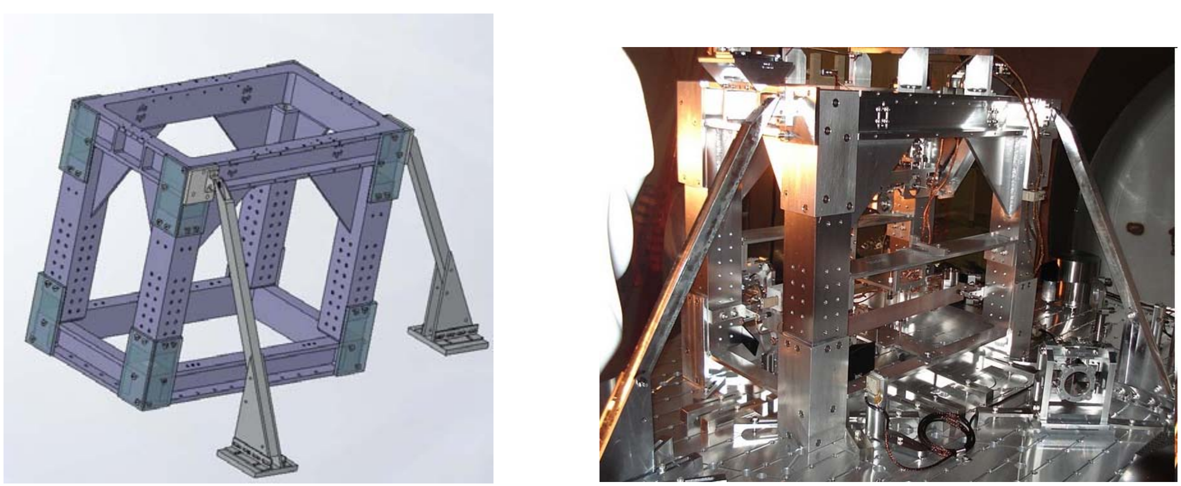


Figure 4 : General overview of the OMC structure with struts

Promising results have been obtained by using struts. The Qs of the main modes have been reduced drastically and no additional modes have been created by the struts, as shown in Figure 5.

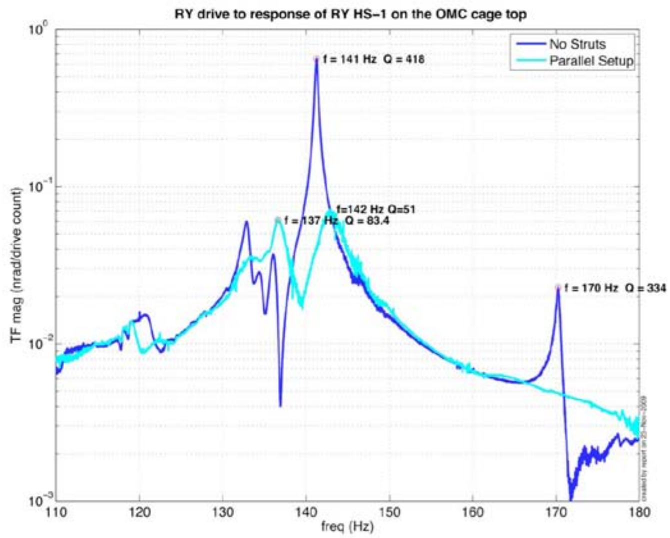


Figure 5

Some similar experiments have been done on the HLTS structure, with very good results too (a factor of 10 for some resonances).

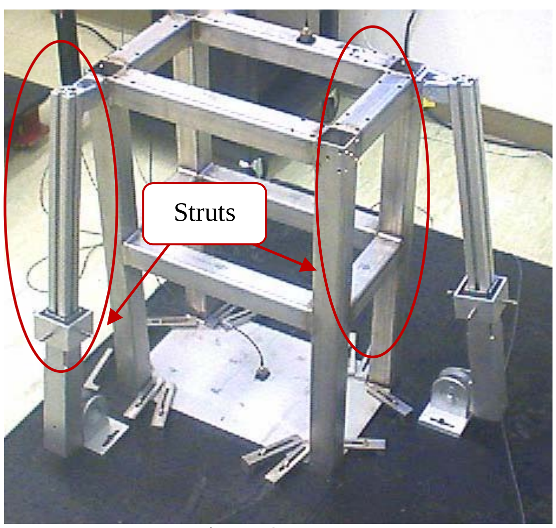


Figure 6

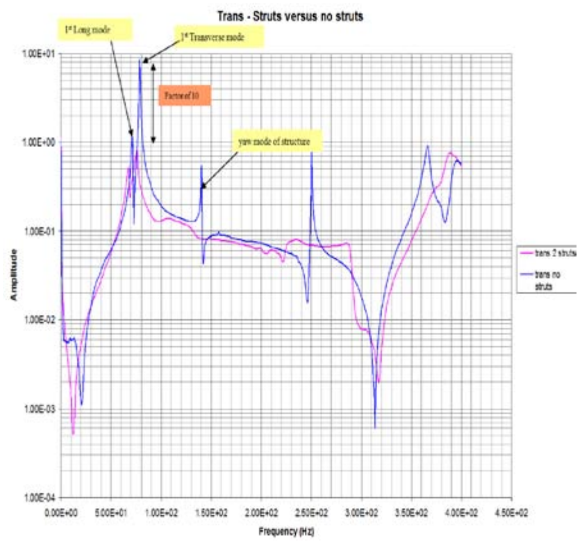


Figure 7

2.2 Corner bracket

The approach consists of adding steel brackets in each corners of the structure. Thanks to a FEA, we know that the corners are the most deformed points of the system. Rigidifying and damping those points should suppress or damp some internal frequencies. Some tests have been done with Viton© clamped between the brackets and the structure frame. For example, such a system was developed on the OMC structure, as shown in the figure below.

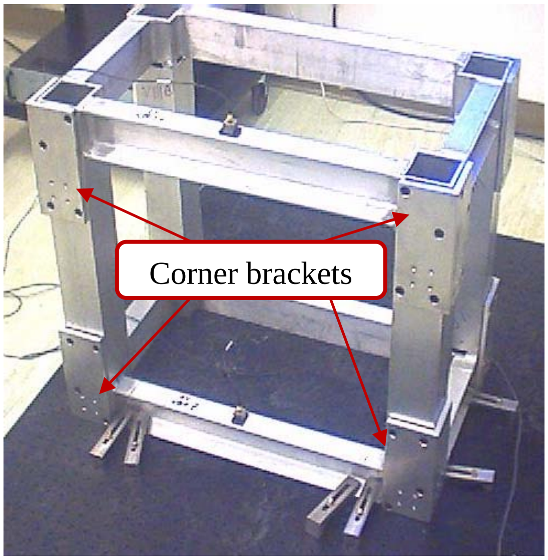


Figure 7

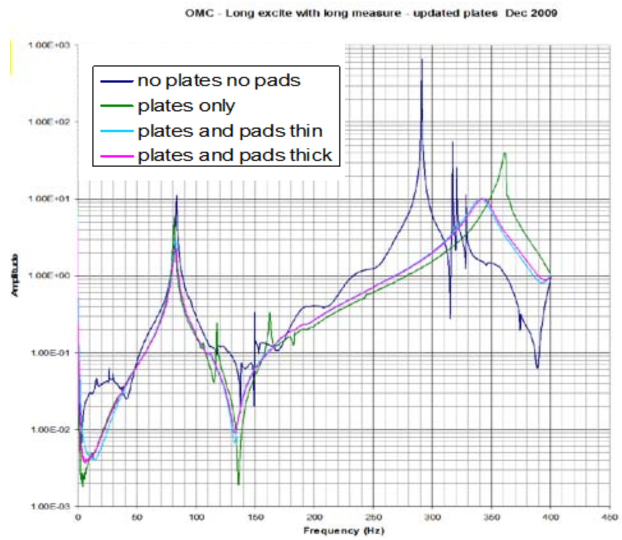


Figure 8

Promising results have been obtained. The Qs of the main modes have been reduced significantly damped.

2.3 Vibration absorber

A vibration absorber is a device that is attached to a structure in order to damp the resonances. Vibration energy is dissipated by the vibration absorber. The difference between a vibration absorber and a tuned mass damper system, is that the frequency of the vibration absorber does not need to be tuned: the damping action is broadband and is going to be efficient on all the low frequency modes of the structure. The Figure 9 shows an example of good results that can be obtained with one vibration absorber on a Quad structure. Section 2 described in details this device.

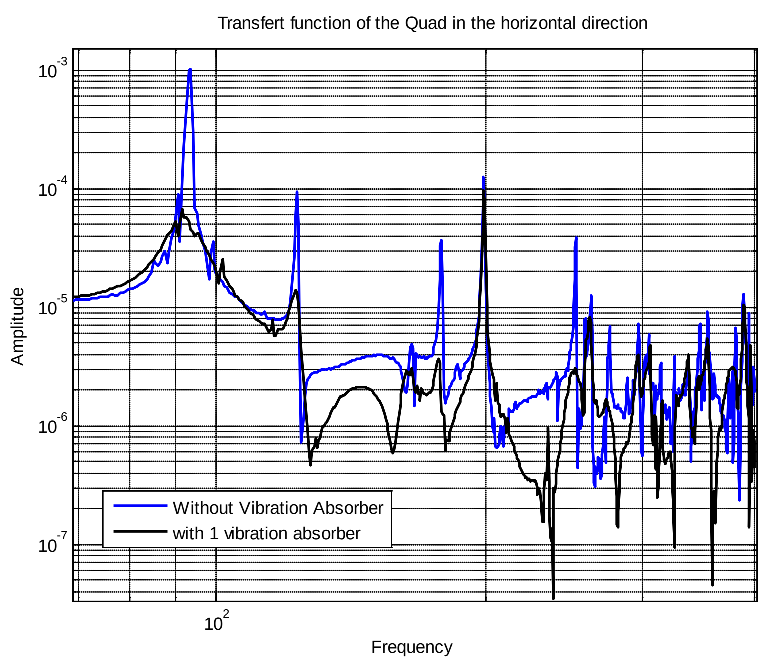


Figure 9

1.4 Conclusion

The table below summarizes the advantages and disadvantages of the three methods. The vibration absorber has been chosen for its good results and the low space it takes in the layout.

System	Advantages	Disadvantages
Struts	- Good damping of the mode by at least a factor of 3. - No creation of new modes.	- Add a lot of mass on the global system. - Need improvement of the optic table of the ISI platform to attach it. - Difficulty to set up the device.
Corner brackets	- Good damping of some modes of the structure. - No creation of new modes.	- Not able to damp all the modes of the system
Vibration absorber	- Excellent damping of the modes of the structure. - No creation of new modes.	- Need several vibration absorbers to damp all the modes of the structure.

Table 1

2. Presentation of the solution chosen for aLIGO: the vibration absorber

2.1 Design

A mass spring system is made of a 4 lbs stainless steel mass and Viton© pads. It is put in a box, made of two clamps. The system can be attached on several locations on the structure, thanks to two attachment brackets. The stress applied on the pads can be controlled by the use of precision washers. More information about the vibration absorber assembly is in document LIGO #E1000133.

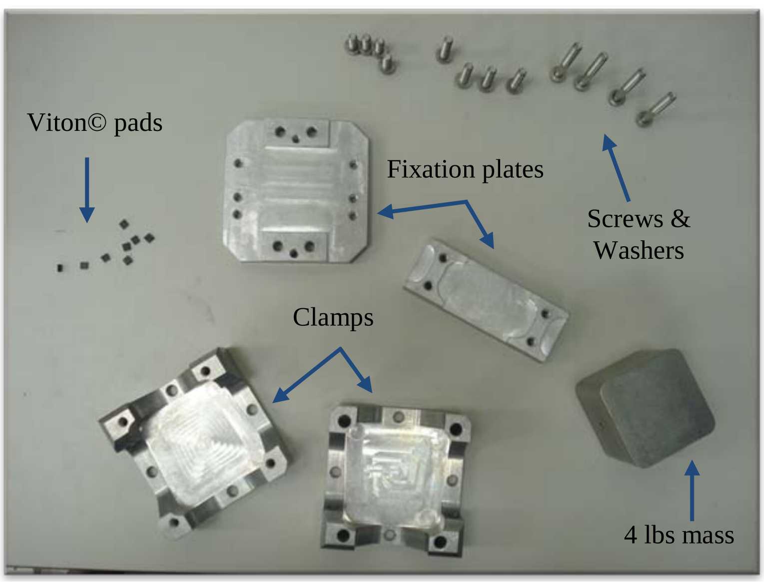


Figure 10

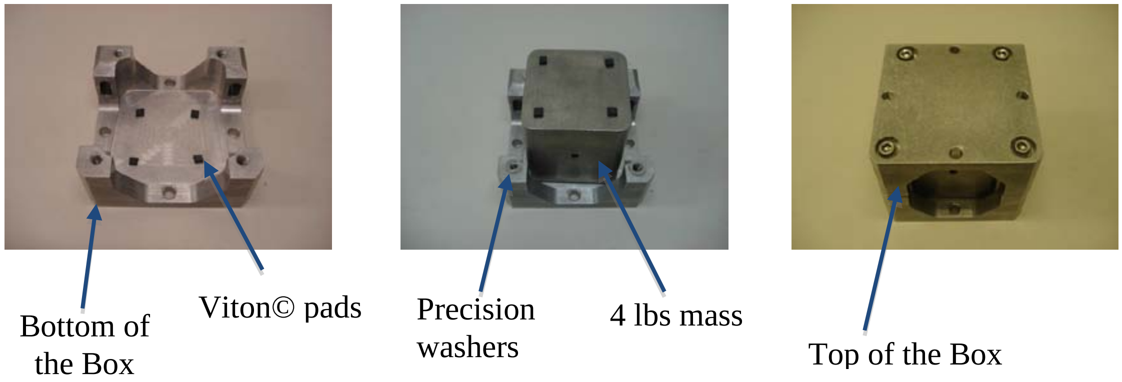
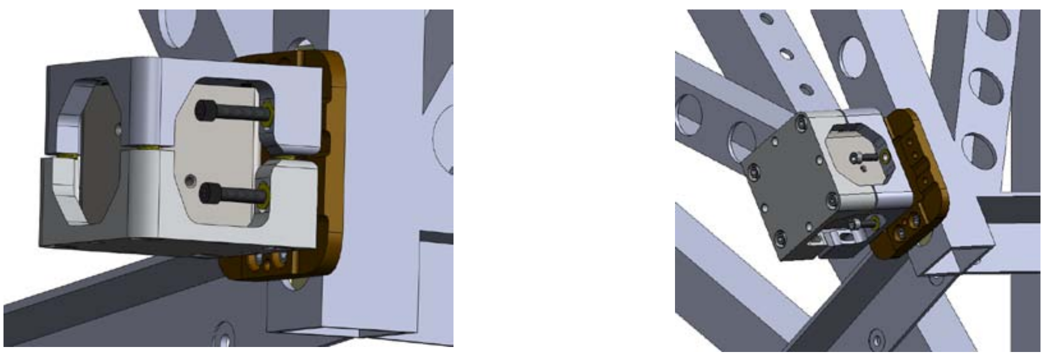


Figure 11

The absorber can be attached to in two configurations:

- Horizontal layer: the pads are in the horizontal plan. The Viton© works mostly in shear.
- Vertical layer: the pads are in the vertical plan. The Viton© works mostly in compression.



Configuration 1 : Viton© layer in the horizontal plan   Configuration 2 : Viton© layer in the vertical plan

Figure 12

2.2 Results on the quad

2.2.1 Experiment presentation

All the experimentations are done in the air on a Quad prototype. This prototype is only made of the upper structure and the sleeve. We did not have the internal structure.
It would have been more realistic to attach the Quad on an optic table. However, the bench we were using for the preliminary testing was not anymore available. Thus, the Quad is suspended by four hooks to make a free structure analysis. This configuration alters the analysis, but should allow to demonstrate the vibration absorber efficiency.

2.2.2 External transfer function

The modal analysis is done using an accelerometer on the Quad and an impact hammer with force sensor. The accelerometer is clamped on the upper structure. The impact is applied on the upper structure.
Transfer functions of accelerometer response over the impact force are taken. The input/output points are shown on the picture above.

This configuration gives us a characteristic transfer function of the quad. The TF is made of 10 data averaging.

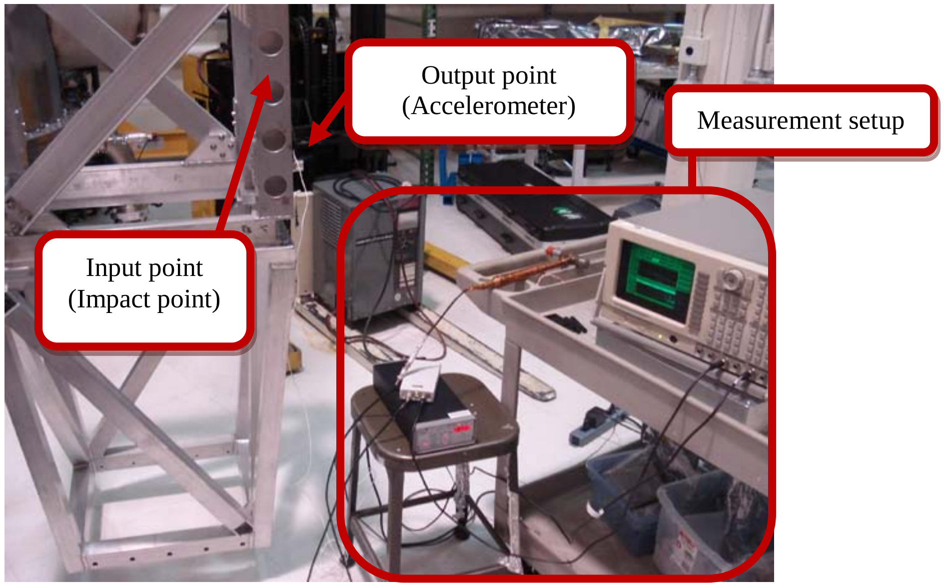


Figure 13

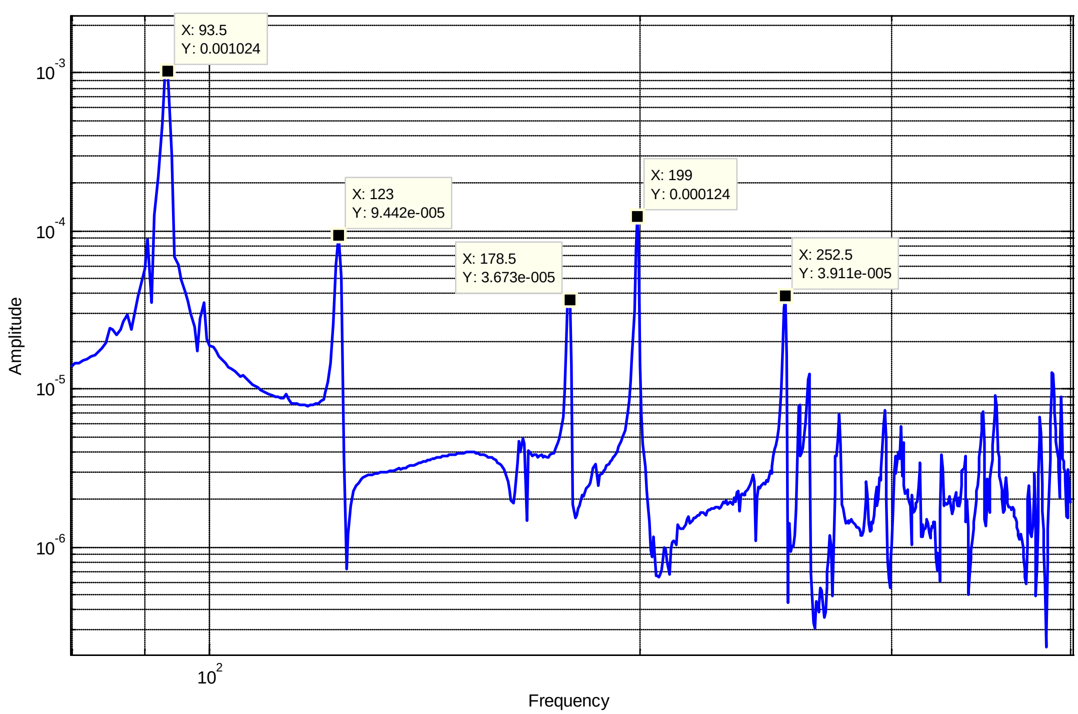


Figure 14

The Quad prototype structure has five main modes between 90 Hz and 260 Hz. These modes are partially damped by the air and are likely to have a higher Q in the vacuum.

2.2.3 Experiment with supported mass

Firstly, we use supported masses. A supported mass is a simple mass put on four pads of Viton©. With this solution we create a mass-spring system in the vertical direction. By trying different spots, this approach allows to understand the modes of the structure, and thus choosing locations before using the vibration absorbers.

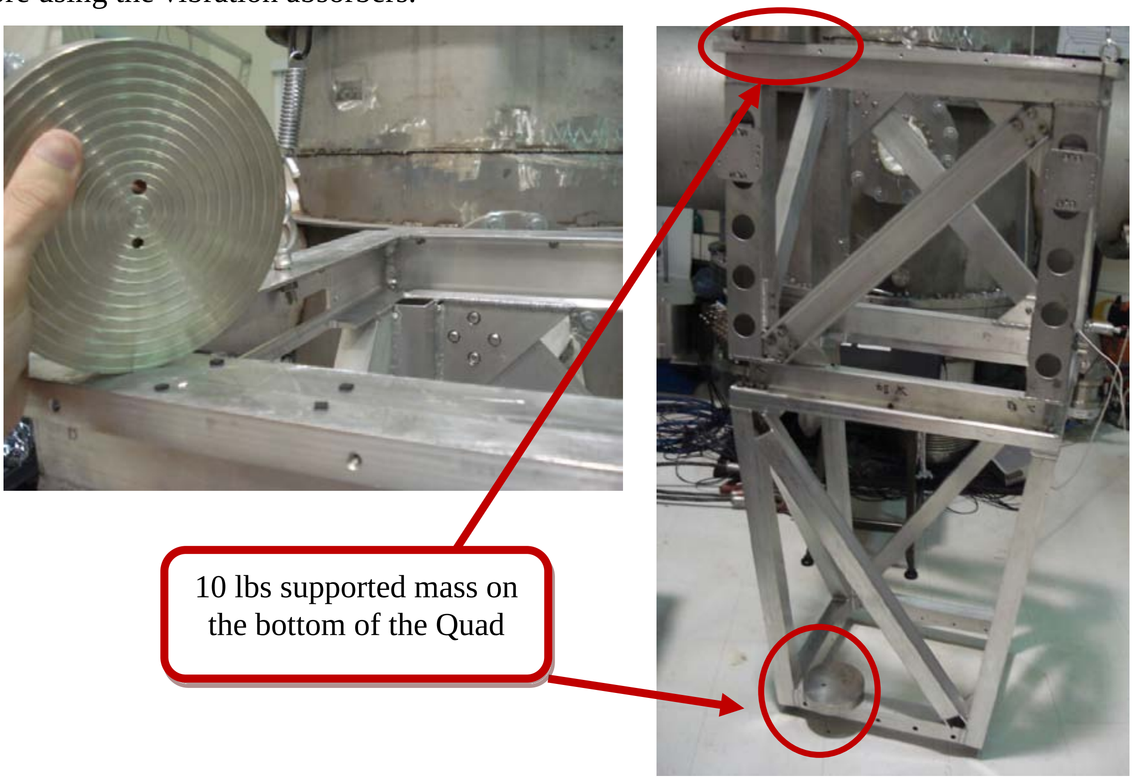


Figure 15

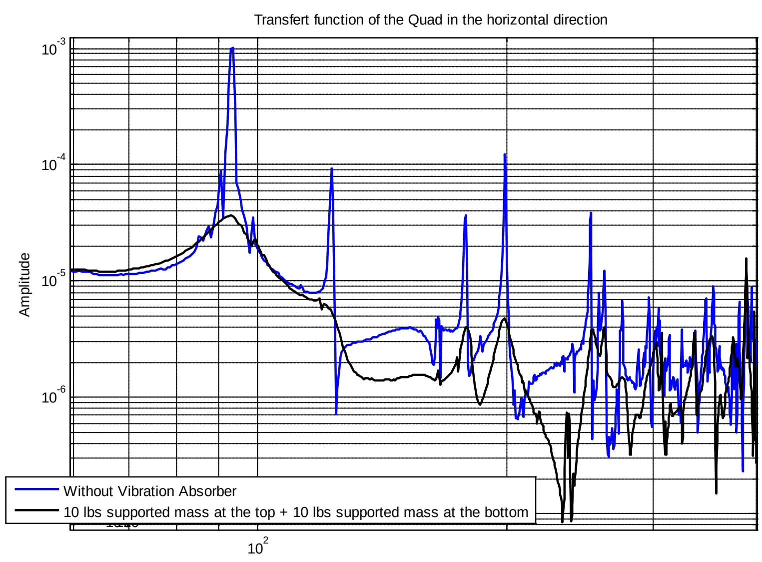


Figure 16

The results obtained with the supported masses are excellent: the goal is to adjust the parameters of the vibration absorber to obtain similar results.

2.2.4 Experiment presentation with the vibration absorber

On the real structure, the vibration absorber must be attached on the lower part of the Quad. In this suspended configuration experiment, we can't bolt them at the bottom. The only spots available are on the upper part. The vibration absorber is attached on the Quad thanks to two plates (plate 1 + plate 2). Those two plates are bolted together and then attached onf the quad.

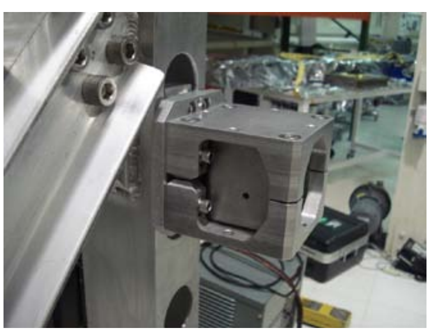
Plate 1

+

Plate 2

Figure 17

The vibration absorber is attached on plate 2.



Configuration 1

Configuration 2

Figure 18

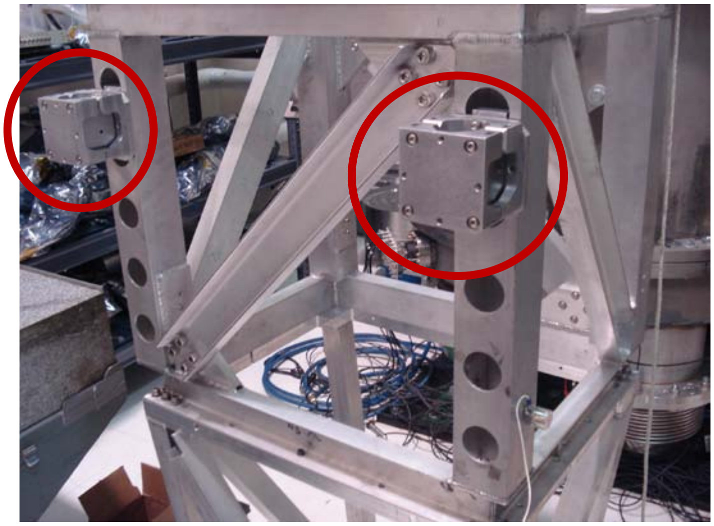


Figure 19

2.2.5 Quad external structure + vibration transfer function

The figure below presents the transfer function of the Quad without absorber, with one absorber (two possible configurations: horizontal or vertical layer), and finally with two absorbers (three possible configurations : horizontal-horizontal, vertical-vertical or horizontal-vertical).

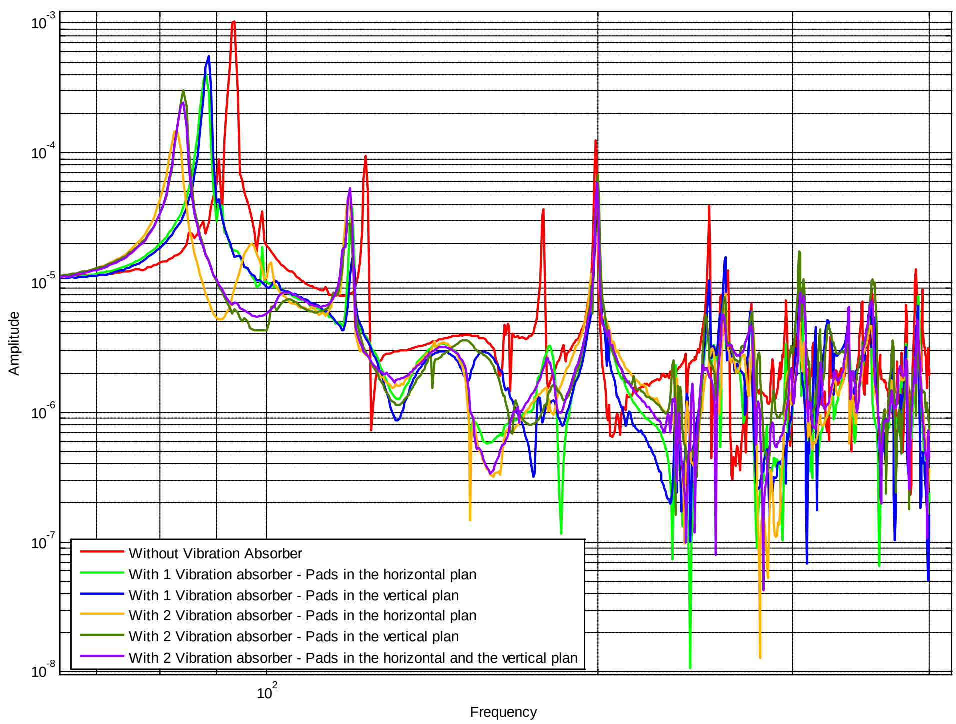


Figure 20

Without vibration absorber, we can see five modes between 100 Hz and 400 Hz. With one or two vibration absorbers, the first mode is very well damped. The fourth mode is not damp because it is due to the lower part of the Quad. The best configuration is the use of one vibration absorber with pads in the horizontal plan : thanks to the vibration absorber, the mode at 103 Hz goes from a factor Q equal at 18 to a factor Q of 5. However, the results are not as good as with the supported masses. We need to adjust some parameters to improve the efficiency of the vibration absorber.

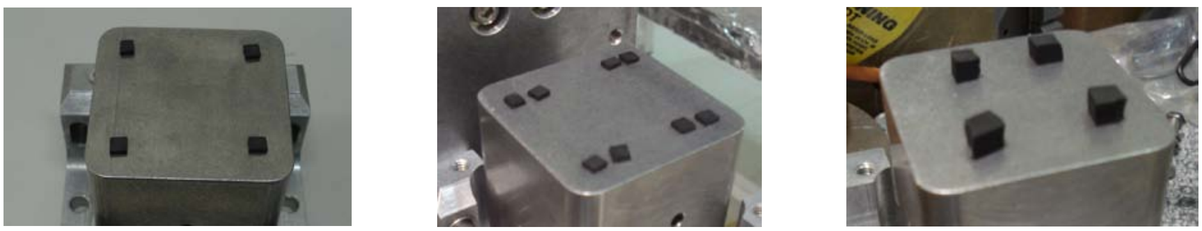
2.2.6 Adjustment of parameters

A vibration absorber is made with Viton© pads. Two parameters are very important:

- the size : each pad is going to have a definite size, which is going to influence the stiffness properties of the material.
- the constraint : the clamps of the vibration will impose a force on the pads, which can influence the efficiency of the damper.

<u>Pads stiffness</u>

The goal of this part is to observe the evolution of the damping effect of the vibration absorber with the stiffness of the pads. Three different sizes of Viton© are used.
Case 1 – "*Nominal pads*" – 8 pads, 0.18" square x 0.06" thick
Case 2 – "*Stiff pads*" – 16 pads, 0.18" square x 0.06" thick
Case 3 – "*Soft pads*" – 8 pads, 0.18" square x 0.24" thick



Nominal pads Stiff pads Soft pads

Figure 21

Only one vibration absorber is attached on the upper structure on the Quad, in the same configuration as previously. The three cases are tested with the pads in a horizontal plan. Soft pads allow the mass of the vibration absorber to have a motion most important in the box.

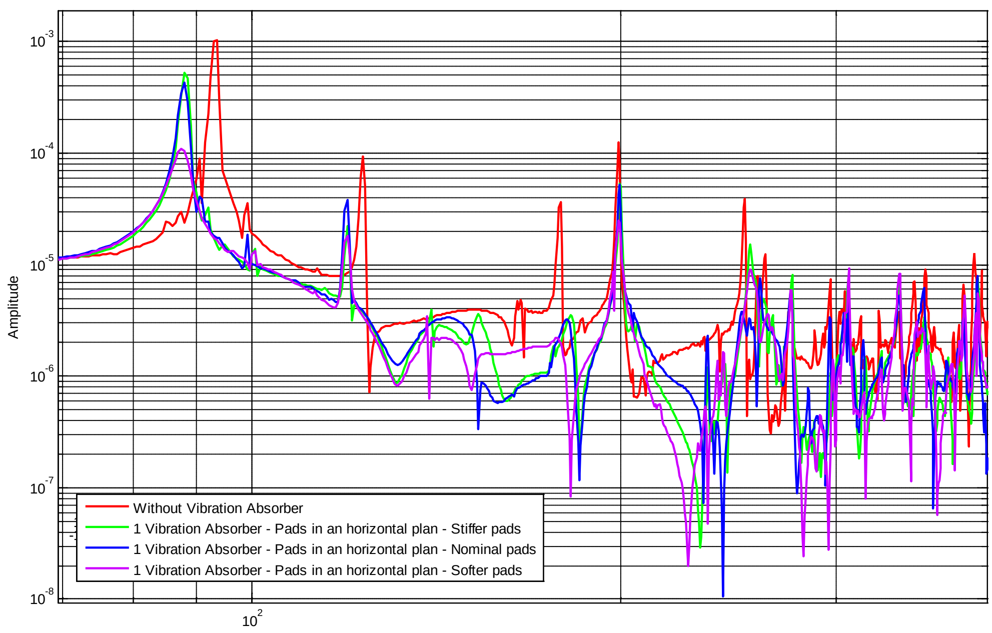


Figure 22

Pads Constrain

We adjust the preload applied on the pads by changing the numbers of washers between the two brackets of the vibration absorber. For this test, nominal pads are used, put in a horizontal plan

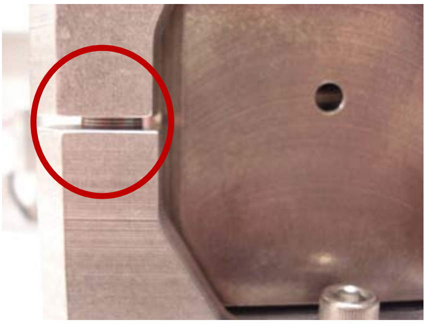


Figure 23

Figure 24 presents the transfer function of the Quad without absorber, with one absorber – 1 washer between the two clamps, with one absorber – 2 washers, and like that until 4 washers. Beyond four washers, the mass is not sufficiently locked in place.

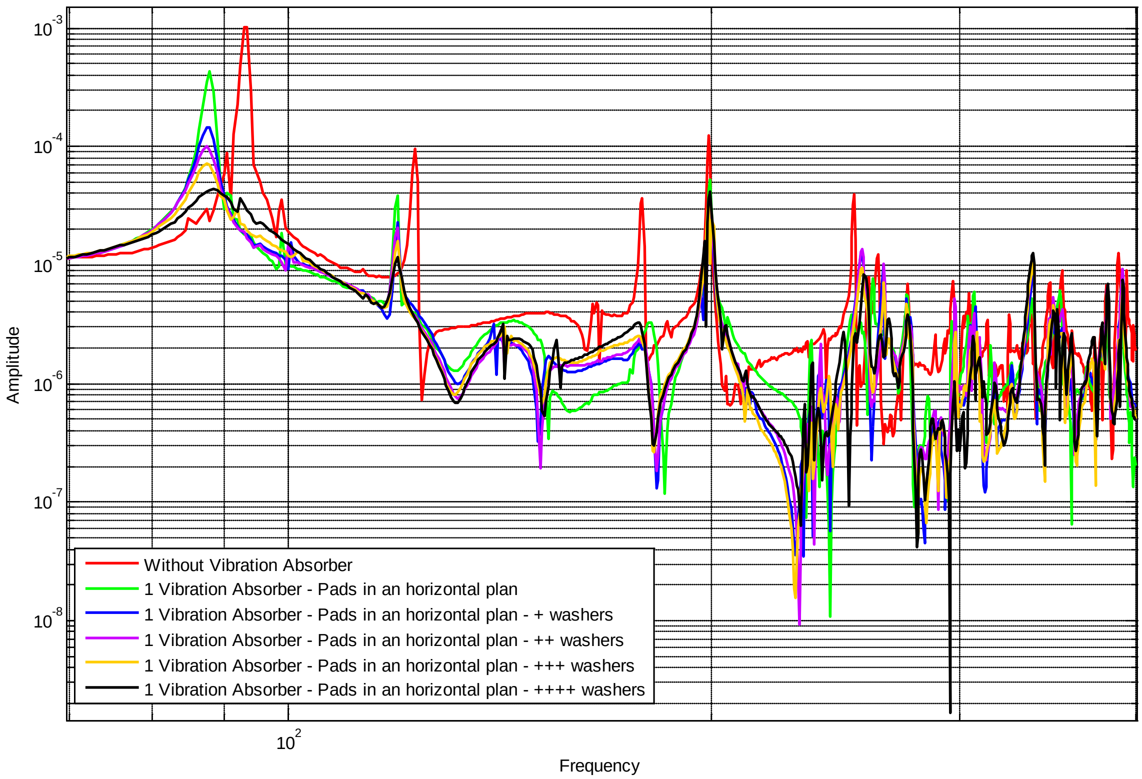


Figure 24

The preload applied on the pad is a very important parameter. Too much constrain reduces the efficiency of the vibration absorber. With less preload, we obtain results as good as with the supported mass device. One of the resonances is not damped because it is due to the lower part of the Quad, where we could not install a vibration absorber.

2.3 Results on the HLTS

2.3.1 Experimental Presentation

All the experimentations is done in air on a mock-up. The structure is clamped on a bench using dog clamps.

2.3.2 Transfer function

The analysis is done using an accelerometer on the HLTS and an impact hammer with force sensor. The accelerometer is clamped on the top part of the structure, where we observe the most displacement. An impact is applied on the top of the structure in two directions : in the longitudinal and in the transverse direction.
Transfer functions of accelerometer response over the impact force are taken. The input/output points are shown on the picture below.

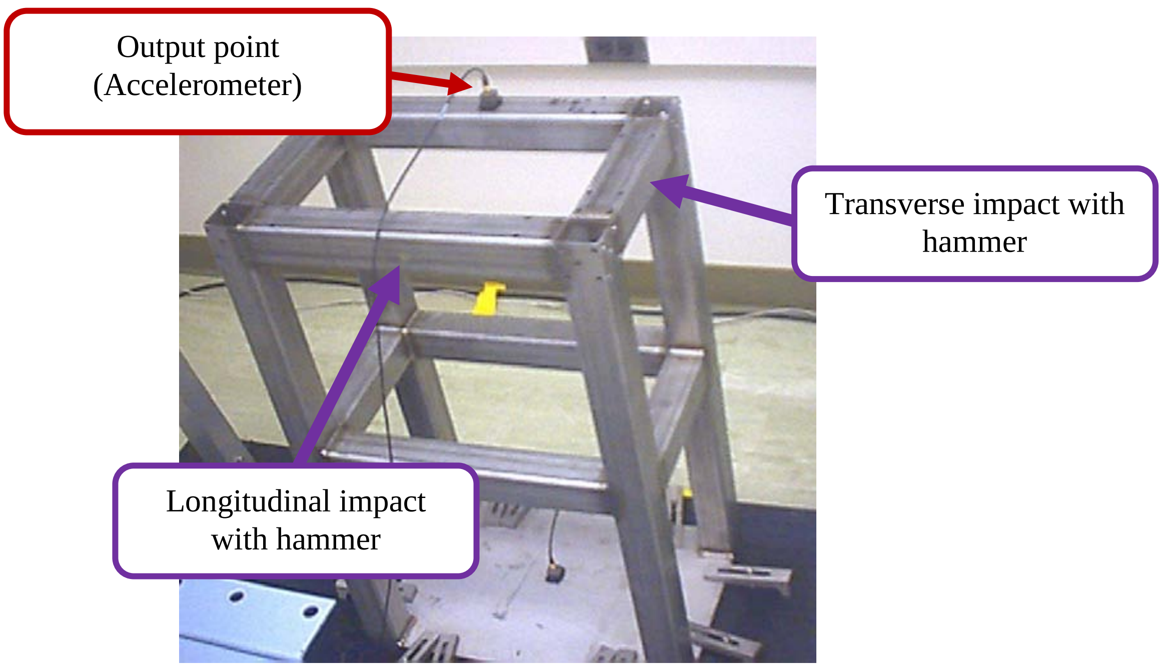


Figure 25

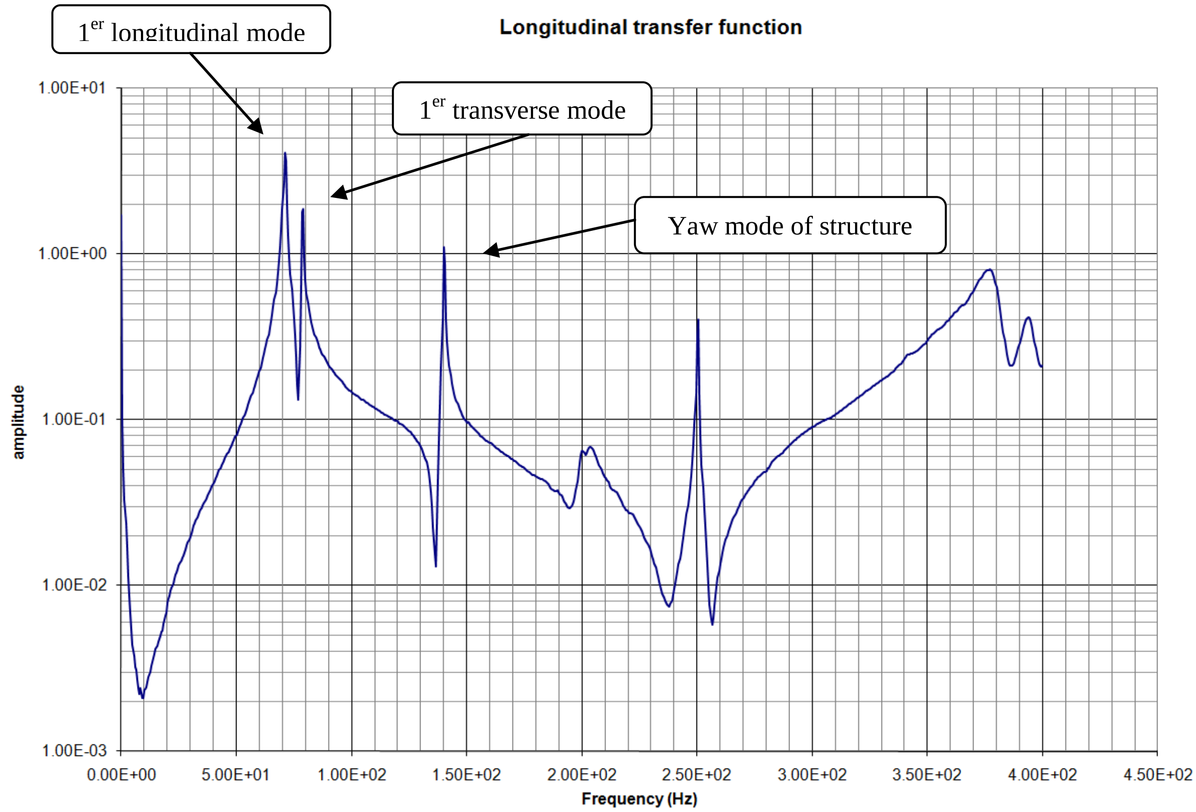


Figure 26

3.3.3 Experiment presentation with the vibration absorber

The test with vibration absorber has been done with two different thicknesses of Viton©.
Case 1 - "*Two Stainless Vibration Absorbers*" - 8 pads, 0.18" square x 0.06" thick
Case 2 - "*Two Stainless Thicker Viton*" - 8 pads, 0.18" square x 0.12" thick
It should be noted that all vibration absorbers were added to the top cross bar on the mock-up HLTS.

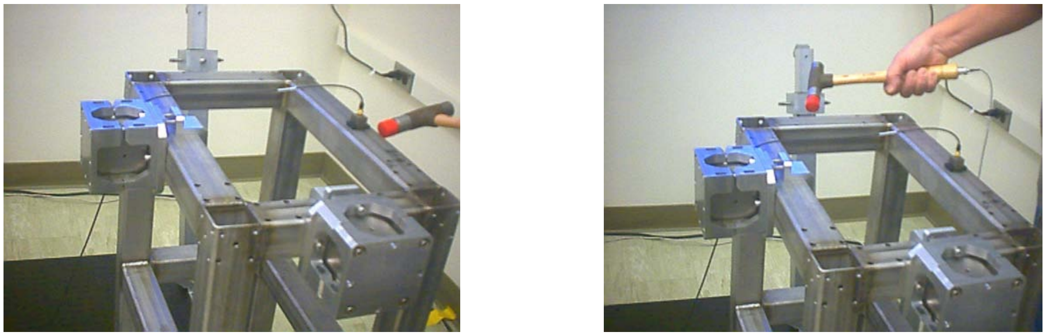


Figure 27

The Figure 28 presents the transfer functions of the HLTS without absorber, with one absorber (two possible configurations: horizontal or vertical layer), and finally with two absorbers. As well as a 4lb stainless steel absorber, we also tested an aluminum version, where the stainless steel block was replaced by an equivalent sized aluminum version.

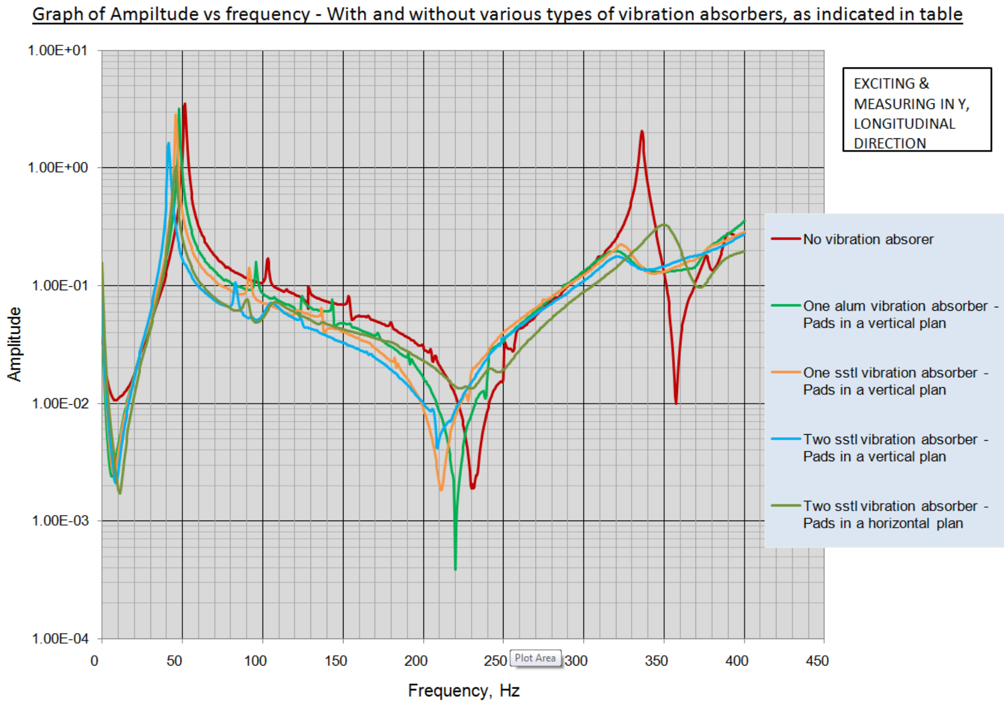


Figure 28

Without vibration absorber, we can see some modes between 50 Hz and 400 Hz. The aluminum mass seems to be to light to damp the modes. The best configuration is the use of two vibration absorbers with pads in the horizontal plan.

3.3.4 Adjustment of parameters

Constraint

The same type of experiment has been done on the HLTS. This time, we suppressed the load applies by the top clamp by removing it.

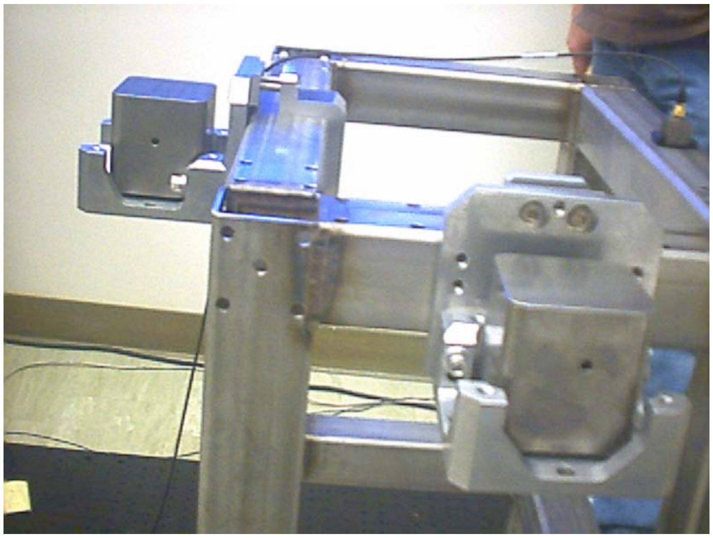


Figure 29

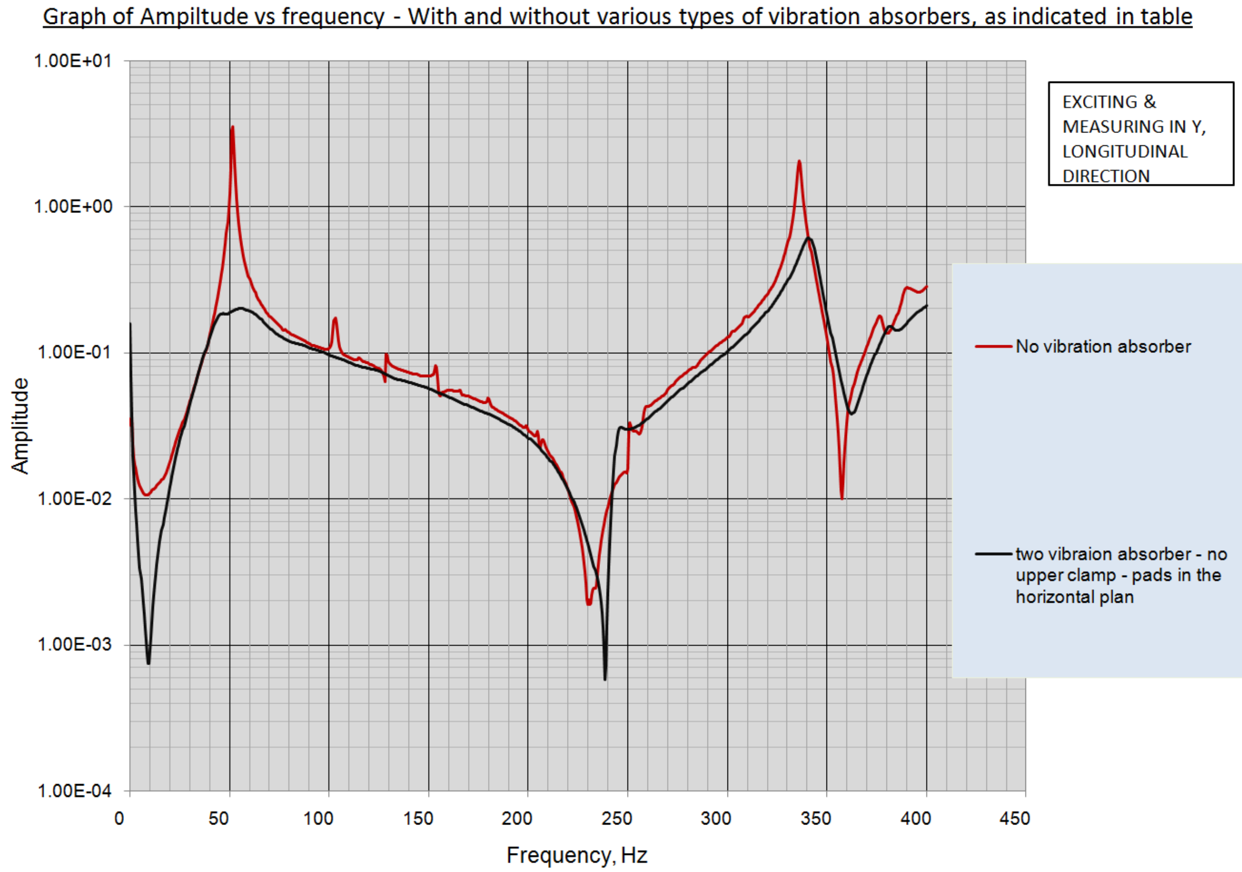


Figure 30

The constraint applied on the mass also seems to be an important parameter in this case. The idea is to find a good compromise between performances and stability of the mass between the brackets.

3. Conclusion and Layout

The vibration absorber permits to significantly damp modes of the HLTS, OMC and structure in a passive way. It is simple, light and easy to install. One of the parameter we really need to take care about is the load apply on the top pads. To have a good efficiency, this load must be as little as possible.

Based on the good results obtained with the vibration absorber, we propose to install the device on the aLIGO suspension structures. The document LIGO# C1001399 gives the quantity of vibration absorbers required for each structure and an estimate cost. The document LIGO# C1001414 describes the "Interface of Vibration absorbers to all suspension structure assemblies".

4. FDR Check list

All of the following documents are linked from the FDR page, LIGO-E1000297-x0.

Final requirements – any changes or refinements from PDR?

The goal of the vibration absorber is to help damping as many structural resonances as possible. We propose to define a goal that would be to damp all the resonances below 500Hz, and to obtain a Q of 5 or less. This goal is based on the tests results obtained during the R&D phase. Since it might not be reached on all structure, we'll call it a goal (or objective) rather than a requirement.

Resolutions of action items from PDR:

Not applicable.

Subsystem block and functional diagrams:

Not applicable.

Drawing package (assembly drawings and majority of remaining drawings):

The drawing package is linked on the FDR main page. Assembly drawings are:

LIGO-D1000954: 5 Lbs Vibration Absorber for SUS SEI - Vertical Config

LIGO-E1000133: 5 Lb Vibration Absorber for Sus SEI - Assembly Instruction

Final parts lists:

See BOM in assembly drawings.

Value Engineering: -

The team is also looking at the current from a value engineering point of view. In LIGO-T1000502: Vibration Absorber suggested changes and Enhancements we will look at cost, ease of assembly, transport and installation in more detail.

Final specifications:

See section 2 & 3 of this document.

Final interface documents:

See LIGO-C1001414: Interface of Vibration absorbers to all suspension structure assemblies, for interface with the suspensions structures.

Relevant RODA changes and actions completed:

LIGO-M1000047: RODA - Decision to modify HAM structures (HLTS, HSTS, OMC)

Signed Hazard Analysis

LIGO-E1000354: Vibration Absorbers Hazard Analysis

Final Failure Modes and Effects

LIGO-E1000354: Vibration Absorbers Hazard Analysis

Analysis Risk Registry items discussed:

LIGO-E1000354: Vibration Absorbers Hazard Analysis

Design analysis and engineering test data:

Section 2 of this document.

Software detailed design:

Not applicable.

Final approach to safety and use issues:

LIGO-E1000354: Vibration Absorbers Hazard Analysis

Production plans:

In progress. We are working on the plan to procure Viton meeting all requirements and specifications.

Plans for acquisition of parts, components, materials needed for fabrication:

For the machined parts, we have companies with experience making in vacuum alum and stainless parts lined up. For Viton, we recently worked with Green Rubber who provided us Viton meeting all requirements and specifications.

Installation plans and procedures:

LIGO-E1000133: 5 Lb Vibration Absorber for Sus SEI - Assembly Instruction.

LIGO-C1001414: Interface of Vibration absorbers to all suspension structures assemblies, for interface with the suspensions structures.

Final hardware test plans:

More testing is scheduled for this week at LASTI. (Installation on the Quad in the chamber scheduled for Thursday Sep, 2). This phase of testing will permit to evaluate the benefits of the device on the Quad and BSC-ISI coupled dynamics.

More testing is scheduled on stiff table at Stanford (Between Caltech and Stanford we will work on re-measuring HLTS, HSTS and OMC with 1/4" viton under low (3%) compression.)

Fit check will be done HLTS, OMC, Quad and FM / BS at Hanford and Livingston.

Final software test plans:

Not applicable.

Cost compatibility with cost book:

LIGO-C1001399: Cost Estimate for the Vibration Absorbers including attachment.

Quantity required: -

The quantity required is also included in the cost estimate document, LIGO-C1001399.

Fabrication, installation and test schedule:

In progress.

Lessons learned documented, circulated

See section 1,2 & 3 of this document.

Problems and concerns

No major problems or concerns.