ABSTRACT

During the launching phase, satellites are undoubtedly faced to severe mechanical environment, which appears to be one of the most critical issues to cope with. To protect the onboard mechanisms during these critical phases, one solution is to uncouple them from the structure thanks to passive dampers based on elastomeric materials. The mechanical behavior of these isolators can be compared with a mechanical filter which limits the random and shock levels transmitted to the mechanisms.

A second interest of these rubber dampers can be found during the mission too. Indeed, they can be used to reduce the propagation of the micro-vibrations coming from mechanisms to the structure, and so to limit the disturbances of the onboard instrument.

That is why this solution was implemented inside the EXPERT reentry vehicle. New elastomeric dampers were designed under Thales Alenia Space contract to decouple four equipments: The Inertial Moment Unit (IMU), the power subsystem (PCDU), the data handling unit (DHU) and the Beacon. The aim is to protect them from the dynamical environment met during the launch and during the reentry phase too. To get there, visco-elastic dampers are based on Smactane SP rubber and coupled with the using of visco-constraint layers for the IMU particular case.

The technical trade-off and design issue which has led to the final designs will be presented in parallel with the constraints in term of mass, size and transfer function performances. Main results obtained with the qualification and flight models will be given. The nonlinear behavior of rubber parts will be demonstrated by comparing the performances under shock levels with the performances under random levels too. But finally main guidelines will be given to take into account the difficulties linked to the rubber materials.

INTRODUCTION

Since many years, pyrotechnics devices are largely mounted inside spacecrafts, such as bolt initiators, pyrovalves, pyrotechnic transmission lines..., in particularly to release some subsystems or to unlock some mechanisms. These devices offer a number of functions with a low onboard weight but with a major disadvantage: Their using induces a shock wave with a very high level which can damage adjacent equipments.

To prevent these damages, a simple solution can to move away the sensitive equipment from the shock wave but today, the using of compact installations limits this solution. Another way is to limit the transmission of “pyro energy” to the equipment, by the decoupling of it with the using of damping material.

This way was worked by SMAC under a Thales Alenia Space contract, in order to protect four equipments implemented inside the EXPERT reentry vehicle (ESA program):

- The Inertial Moment Unit (IMU)
- The power subsystem (PCDU)
- The Beacon
- The Data Handling Unit (DHU)

As it easy to tune the modulus of a compounded rubber, it was possible to use similar design of dampers even if these four equipments are strongly different.

After presenting the main technical specification, this paper will focus on the chosen design and material using which enables to obtain the performances established during the qualification step.
1-TECHNICAL SPECIFICATIONS

1.1 Main characteristics of the equipments

The following table gives the main mechanical characteristics of the four equipments which have been protected from dynamic and shock levels during all the mission time of the EXPERT Re-entry vehicle:

<table>
<thead>
<tr>
<th>Mass (Kg)</th>
<th>Number of interface points</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMU</td>
<td>0.8</td>
</tr>
<tr>
<td>PCDU</td>
<td>5.8</td>
</tr>
<tr>
<td>BEACON</td>
<td>1.6</td>
</tr>
<tr>
<td>DHU</td>
<td>9.0</td>
</tr>
</tbody>
</table>

As suggested by the figure 1, and 2, all the four equipments presents a CoG centred regarding the localisation of the interface points in the support plan (In Plan, “IP”).

Figure 1. View of the interface points of PCDU

But for the Out Of Plane (OOP), it is not right: The most critical case is met with the PCDU, its CoG PCDU is 80mm distant from the interface points. So rocking modes will be detected for all IP dynamic tests and will decrease the effectiveness of the dampers by disturbing the transmissibility curves.

1.2 Mechanical environment

The mechanical environment is similar for all the four equipments, and it is mainly defined following the 3 axis by:

- A high qualification sine levels between 60 and 130Hz (7.1g)
- A high random level inside the 100-1000Hz bandwidth (0.4 g²/Hz, 3min) during 3min
- A high SRS shock: 100g at 100Hz, 2000g from 1kHz to 4kHz
- A 100 to 160Hz forbidden band

1.3 Thermal environment

The thermal environment is defined by the 0°C-30°C temperature range. But as rubber materials are sensitive regarding the temperature, new assessments were performed in order to get more accuracy temperature, and finally it was established the 15°C operational temperature for the dampers.

2-PRINCIPLE OF A SHOCK ISOLATOR USING RUBBER

As showed by the figure 4, a shock isolator based on the using of rubber material can be schematized by a low stiffness part located between the structure and the equipment to protect from the shock wave.
With such a system, the shock levels are reduced by two means:

- Firstly, thanks to the mechanical filter effect induced by the low stiffness of the isolator. Basically, the transfer curve between the equipment and the structure is like a “low pass filter”: the dynamic levels are filtered for all frequencies upper than the cut off frequency.

- Secondly, thanks to the damping effect induced by the viscoelastic properties of the selected rubber material: Inside the rubber, kinetic and strain energy are converted into heat, by complex physical effects. Various factors affect the damping effect, like the chemical composition of the viscoelastic material, the state of internal stress, the environmental temperature, . . .

3-MAIN MECHANICAL ASSESSMENTS

For each of the four equipments, the main design task for the dampers is to withstand the launch random levels which are strong from 60Hz and to decrease significantly the shock levels from 200 Hz. Finally, the design of the dampers will be driven by the following characteristics of the transmissibility curve, taking into account the temperature sensitivity and the levels sensitivity too:

<table>
<thead>
<tr>
<th></th>
<th>In Plane</th>
<th>Out Of Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMU</td>
<td>35-40 Hz</td>
<td>&lt;3</td>
</tr>
<tr>
<td>PCDU</td>
<td>30-40 Hz</td>
<td>&lt;2.5</td>
</tr>
<tr>
<td>BEACON</td>
<td>50-60 Hz</td>
<td>&lt;2.5</td>
</tr>
<tr>
<td>DHU</td>
<td>30-40 Hz</td>
<td>&lt;2.5</td>
</tr>
</tbody>
</table>

To get these low Q factor values, all the dampers will be based on SMACTANE® SP rubber.

4-PROPERTIES OF SMACTANE® SP RUBBER

SMAC TANE® SP rubber is a viscoelastic material developed and moulded by the SMAC company. It is based on a synthetic rubber and was compounded to maximise the damping properties in a wide range of temperature and frequencies, and specifically for space applications.

4.1 Main Static properties

<table>
<thead>
<tr>
<th></th>
<th>Tension</th>
<th>Shear Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Tensile (MPa)</td>
<td>10.9</td>
<td>6.6</td>
</tr>
<tr>
<td>Max Elongation (%)</td>
<td>800</td>
<td>840</td>
</tr>
<tr>
<td>100% Modulus (MPa)</td>
<td>0.71</td>
<td>0.41</td>
</tr>
</tbody>
</table>

4.2 Dynamic properties

Usually they are described by the master curve which plots the storage modulus and the damping factor versus the frequency for a dedicated temperature as showed by the figure 6.
All these mechanical properties can be easily tuned by modifying the black carbon rate inside the compound. Thus, with a same geometry part, it is possible to tune its stiffness from 1 up to 2 ratio range.

4.3 Out gassing properties

The SMACTANE® SP rubber was compounded to be compliant with the usual ESA out gassing requirements:

- **TML**: 0.88% (<1%)
- **RML**: 0.79% (<1%)
- **CVCM**: 0.02% (<0.1%)

4.4 Manufacturing aspects

The dampers using rubber are manufactured by moulding. During the moulding phase, the rubber can be bounded on various metallic substrates. Finally complex parts can be obtained with the appropriate metallic interface.

5-DESIGN OF THE DAMPERs

For each of the four equipments, the design of their associated dampers is based on the same geometry: a rubber conical shape, as presented by the figure 7, and moulded with SMACTANE® SP rubber.

![Figure 6. Damper based on rubber conical shape](image)

With this conical shape, the axial/radial stiffness ratio can be easily tuned by changing the angle of the cone. And the global stiffness is easily driven by the thickness of the rubber.

5.1 Dampers for the IMU

The protection of the IMU from the vibratory environment is based on 4 dampers. To avoid rocking mode and so to get better performances, the stiffness center of the IMU dampers is aligned with the CoG of the IMU. To get there, specific aluminium brackets were designed in accordance with the available interfaces and sufficient stiff to not cancel the functionality of the dampers. Then all parts (brackets, dampers and IMU) are screwed together (see figure 8).

![Figure 7. IMU Dampers](image)

5.2 Dampers for the PCDU

Like to the IMU, the best solution to protect the PCDU would be to align the stiffness center and the CoG. But it is not possible to do that due to a restricted allowable area around this equipment. The solution is finally to implement 10 dampers clamped on the base of the PCDU and screwed on the structure even if that induce rocking modes (see figure 9).

![Figure 8. PCDU Dampers](image)

5.3 Dampers for the BEACON

The BEACON isolator is based on four dampers. In the nominal configuration (without dampers), there are metallic brackets on each side of the BEACON to clamp it on the structure. These brackets are too flexible regarding the stiffness of the dampers. So a re-design of them was necessary, in accordance with the nominal interface and with stiffness requirements (see figure 10).
5.4 Dampers for the DHU

The configuration of the DHU dampers is similar to the PCDU dampers: 6 dampers clamped on the bottom of the equipment (see figure 11).

6-MAIN QUALIFICATION TESTS RESULTS

All the qualification dynamical tests were performed at 15±1°C.

6.1 Results on IMU

The performances of the dampers are very similar following the 3 axis, with a 1st mode equals to 38 Hz with a 1.7 Q factor under random qualification levels.

6.2 Results on BEACON

As expected, no rocking mode can be identified. But noise can be noted in the 500HZ range which could be related to the 1st mode of the external aluminium bracket.
For the OOP tests, the behaviour of the dampers is characterised by a 62 Hz 1st mode linked to a 1.9 Q factor under random qualification levels.

As expected, for the IP tests, as expected a 1st rocking mode can be detected at 32Hz and a 2nd mode at 85Hz. The risk with such low frequency is the displacement of the equipment overpass the allowable area under high vibrations and that failures appear inside the damper rubber. To check that, a dedicated instrumentation based on displacement sensors was carried out to evaluate the maximum displacement of the dummy mass under qualification random test. These measurements show a maximum displacement slightly lower than 3mm under random qualification levels, which is in accordance with the specification.

7-PYRO-SHOCK ATTENUATION

The target of these rubber dampers is to protect the equipment from random levels, but from pyro-shock levels too. The PCDU and IMU examples were selected to illustrate the performances of the dampers in damping of shock levels.

7.1 Configuration tests

- **Pyro-shock source**: Two pyro-hammers were mounted at the pyrolock location of the EXPERT vehicle model under the cross structure cross panel. The pyro input loads obtained with this configuration is in accordance with the request shock loads.
- **Instrumentation and axis definition:**

To check the shock levels viewed by the PCDU, an accelerometer was bounde d on its bottom plate (see figure 18).

![Figure 18. Localisation of the “PCDU” accelerometer](image1.png)

Another accelerometer was b ounded on the top of the IMU (see figure 18).

![Figure 19. Localisation of the “IMU” accelerometer](image2.png)

The measurements coming from these two accelerometers will be compared with the measurements given by a third accelerometer (called “c ross panel”) bounded on the structure panel where the dampers are clamped.

- **Test temperature:**

The test was performed at around 22±3°C.

### 7.2 SRS Results

The figure 19 presents the SRS results obtained for the IMU accelerometer (green curve), the PC D accelerometer (red curve) and the “cross panel” accelerometer (blue curve) computed with Q=10.

![Figure 20. SRS results with Q=10](image3.png)

If we compare the shock levels viewed by the 2 equipments to the levels registered by the “cross panel” accelerometer, there is a very significant attenuation was obtained thanks to the using of SMACTANE® SP rubber:

- For the IMU is between -18dB and -26dB at around 1kHz, and between -33dB and -40dB at around 10kHz for the 3axis.

- For the PCDU, the attenuation is between -15dB and -18dB at around 1kHz and between -15dB and-26dB at around 10 kHz.
CONCLUSION

The compatibility of the SMACTANE® SP with space environment has enabled the development of 4 dampers system for EXPERT re-entry vehicle and for others various damping systems which looks forward limiting the vibrations and shock transmission through the equipments during the launch phase. This is a simple solution with the following interest:

-No electrical interface: this is a completely passive solution with no electrical supply and no control to lead on the system

-Low weight (the density of rubber is slightly upper than 1)

-Volumeless: rubber process has the advantage not to use additional screws and other clipping elements, it is a material directly bound to the metallic frame.

-Excellent damping: the quality factor obtained during dynamic solicitations always remains lower than 3.

And moreover, thanks to the possibility to tune the stiffness of the rubber by modifying easily its compound, the final design can be achieved quickly by no changing the initial moulding tools.