EQUIPMENT DAMPER ORIGINAL DESIGN AND QUALIFICATION RESULTS

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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. Various solutions can be investigated to protect the onboard equipments during these critical phases. Actually, theses vibratory damages can be reduced at the same time by optimising the architecture of the satellite but also by local actions aiming more on the propagation of the vibrations and thus limiting the transmission of the vibrations through the whole equipment.

The latter solution also called "passive solution" is developed by *SMAC* under the **CNES** contract to protect along all six degree of freedom the small reaction wheel, chosen for the MYRIADE microsatellite family, from random vibrations and shocks. This original solution consists in uncoupling the reaction wheel from the satellite structure by an isolator system made out of a high damping viscoelastic material: the *SMACTANE®*.

Technical trade-off and design issue, that has led to select the final flight configuration, will be discussed in parallel with the design constraints in term of:

- mass and size, due to the lack of space onboard MYRIADE platform,
- and transfer function performances, addressing low cut-off frequency and quality-factor limitation at cut-off frequency.

In particular, the solution implemented in order to minimize coupling phenomenon between axis will be particularly described.

Main features of the flight models and the qualification tests results will be given.

Despite many advantages, it is well known that damping viscoelastic materials have some disadvantages, like their non-linear behaviour depending on the mechanical levels applied and their poor thermal and electric conductivity.
So, to conclude, we try to show how new ways seem to be promising and keep all interest in using viscoelastic materials in space applications.
On the one hand, the way to specify the damping performances and to characterize them will be in particular discussed.
On the other hand, an alternative solution to the thermal braids here selected is currently investigated under CNES R&T funding to avoid additional parts and also parasitic stiffness in parallel of the elastomer mounts. The first tests results of a new kind of elastomeric material developed will also be addressed.

1. INTRODUCTION :

During the launching phase, satellites and their equipments undergo complex and critical vibratory environment which can damage definitively the onboard equipments. Several solutions can be considered to protect the onboard equipments during these critical phases. Vibratory damages can be reduced by optimising the satellite architecture but in the same time, local actions can limit the transmission and propagation of the vibrations to the onboard equipment.

The latter solution also called "passive solution" is developed by ***SMAC*** under a **CNES** contract to protect the reaction wheel chosen for the "MYRIADE" microsatellite family from random vibrations and shocks during the launching phase. The original solution consists in an insulating system based on damping elastomeric mounts reducing the transmitted levels between the satellite structure and the reaction wheel. Damping properties and reduced volume are the main ways to carry out this original development.

After presenting the reaction wheel characteristics and damping objectives, this paper will focus on the chosen design and material using which enables to obtain the performances established during the qualification step.

2. REACTION WHEEL DESCRIPTION :

The reaction wheel to protect is the small reaction wheel chosen for the MYRIADE microsatellite family and commercialised by **TELDIX**. In this paragraph main reaction wheel characteristics are presented to understand the development of the damping isolator.

Main mechanical characteristics of this wheel are given in the wheel reference as shown
fig I:

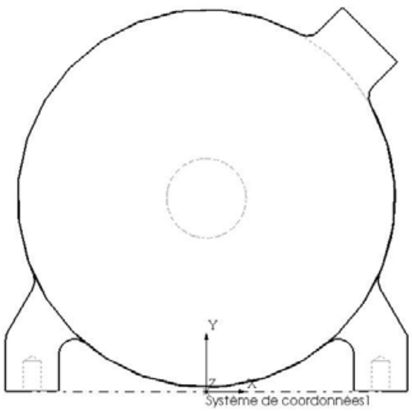

Fig I : the wheel reference

- **Weight** : its weight is about 0.68 Kg

- Localisation of the **center-of-gravity** in the wheel reference:

X_G = 0 mm
Y_G = 43.5 mm
Z_G = -12.65 mm

- **Inertias** applied on the center-of-gravity:

Ixx = Iyy = 5.2 Kgcm²
Izz = 11.9 Kgcm²

- **Space volume** of the wheel :

X : 105.4 mm
Y : 101.3 mm
Z : 70.1 mm

- **Space restriction** (wheel + damping isolator) :

X : 111 mm
Y : 118 mm
Z = 81 mm

- **Mechanical interface** : The interface between reaction wheel and damping isolator is made of four M4 threaded holes (depth 7.5 mm), located around the geometric center O_{ref} separated by 29 mm in Z direction and by 87.5 mm in X direction.

- **Electrical interface** : The reaction wheel is supplied with a diameter 8 cable which has not to debase performances of the damping isolator system.

- **Thermal interface** : The damping isolator system has to assure 3 Watt thermal dissipation between the reaction wheel and the satellite structure.

3. DAMPING ISOLATOR SYSTEM AND EXPECTED PERFORMANCES :

The main functionality of the damping isolator system is to decrease along six degrees of freedom the mechanical levels applied on the reaction wheel from random vibrations and shocks during the launching phase.

Particularly, since the first critical eigen mode has been calculated at 200 Hz, in order to assure a sufficient transmissibility at this frequency, is is necessary that the natural frequency of the damping isolator has to be equal to 75 Hz ±10% with a quality factor lower than 4 and a damping factor equals to 40dB/decade after the cut-off frequency. Moreover, the natural frequency of the isolator can not be lower than 45Hz (first eigen mode of the satellite) and in low frequencies (from 1 to 15 Hz) the transmissibility has to be equal to about 1 to assure a good functionality of the wheel.

To summary, the isolator has to be designed to assure a transmissibility curve including in the following curves(see **Fig II**) :

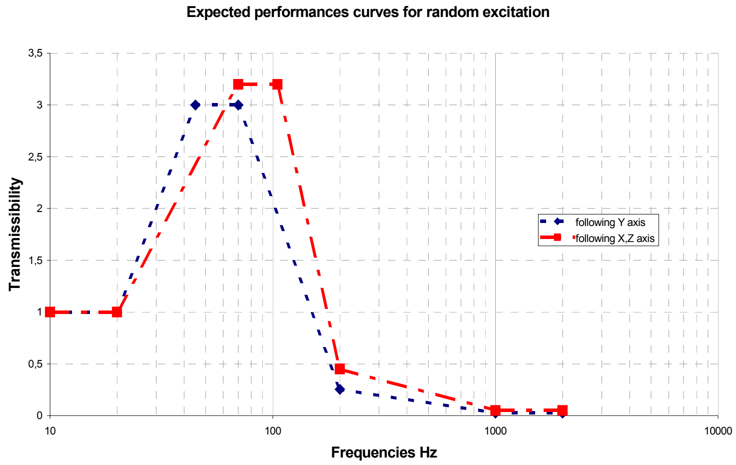

Fig II : Expected performances curves for random excitation

The reaction wheel environnement is composed of sine and random specifications :

- Sine 8g 5-85Hz and 10 g 85-100 Hz following all axis
- Random 20.2 grms following Y AXIS
- Random 19.2 following X, Z axis

4. DESIGN OF A DAMPING INSULATING SYSTEM :

4.1 An isolator system designed by particularities of the reaction wheel:

Since the value of the quality factor has to be lower than 4, the damping isolator will be based on visco elastic parts offering a high damping properties. The number of elastomeric parts has been fixed to four for symmetry reasons.

The first difficulty was merely to locate this visco elastic parts around the equipment. Actually, as shown on the fig **III**, the interval between the center-of-gravity of the equipment and the interface holes is higher than 40 mm following the Y axis. So, if the elastomeric parts are directly located near the wheel feet, coupling between axis will be strong and for an OX or OZ mechanical solicitations, the reaction wheel will be animated by translation and rotation, and the transmissibility will be debased.

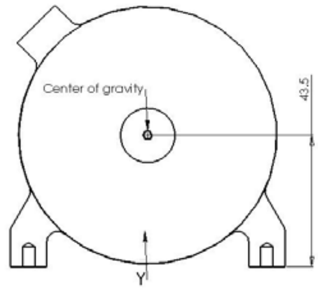

Fig III : Localisation of the center of gravity following Y axis

The optimum solution is to locate elastomeric parts at the same level as the center of gravity following the Y axis, so than the center of gravity and the geometric center of damping isolator system are the same. The original idea (see Fig **IV**) is to clamp the wheel at a metallic frame (inside frame) tanks to the four interface holes, the elastomeric parts are positioned in the top of the frame to align center of mass and geometric center, then an other metallic frame (outside frame) links elastomeric parts and satellite structure thanks to 4 M6 holes.

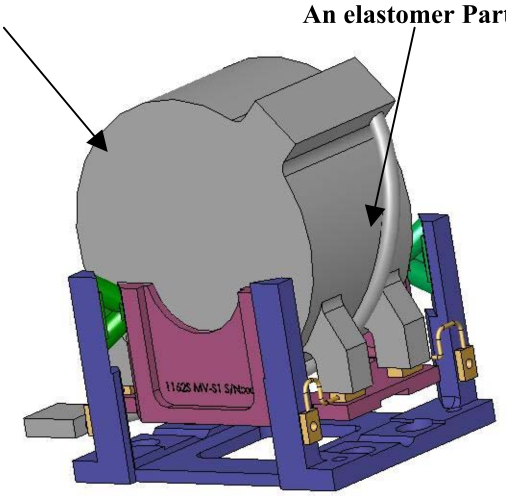

Fig IV : the damping isolator system and its reaction wheel

Mainly, the damping isolator is made up of three main parts :

- The inside frame : (built in Aluminium) The reaction wheel ie clamped by its four "feet" to the inside frame thanks to countersunk screws (diameter 4 mm) in order to limit space volume.

- The outside frame : (built in Aluminium) The outside frame links the reaction wheel and micro satellite structure tanks to four screws (diameter 6 mm)

- Viscoelastic parts : (built in SMACTANE elastomer) : These four parts provide the damping and decoupling role between the satellite structure and the equipment.

4.2 Metallic frames and their dynamical properties:

In order not to debase the damping performances of the isolator, the first eigen mode of the two metallic frames has to be higher than 1000 Hz, and they have not to be bent during qualification tests.

The **fig V** and the **fig VI** shows the chosen design taking into consideration the volume restriction.

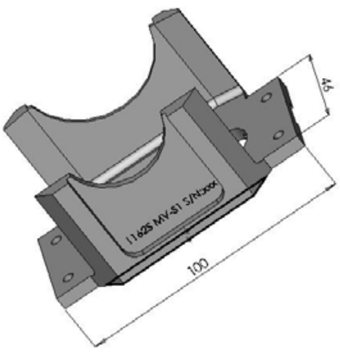

Fig V : The inside frame

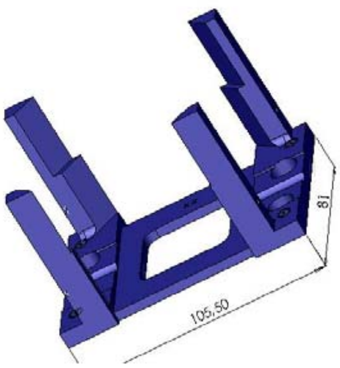

Fig VI: The outside frame

A FEM analysis shows that the first eigen mode of the inside frame is about 1335 Hz and the first eigen mode of the outside frame is about 1540 Hz. Concerning Solid Von-Mises stresses, they are lower than 70 MPa when qualification levels are applied (elasticity limit of used aluminium 7075 = 235 MPa). As a rule, with a minimized weight and optimised space volume, the stiffness obtained is sufficient not to decrease damping performances.

4.3 The elastomeric parts :

The geometry of the elastomeric parts was drawn one's inspiration from an existing damping isolator system used to protect hard disk in military applications. As shown on **fig VII**, each individual elastomeric part is made of two elastomeric battens separated with an angle of 70 degrees.

Fig VII : elastomeric part

Four individual elements are positioned around the frames with a 45 ° angle between principal axis and individual element axis to cope with equi frequency properties of the damping system isolator.

However, in the case of the reaction wheel, a such configuration is not possible because of space volume restriction. A compromise is to be found between space obstruction and equi frequency properties.

Concerning the stiffness of the damping system, it can be adjusted by modifying length and cross section of the battens and modifying the hardness of the elastomeric material.

Choice of elastomer material:

To assure a quality factor lower than 4, the visco elastic material chosen is the *SMACTANE®*, an elastomer showing high damping and space environment compatibility properties.

In the other hand, the **fig VIII** shows that the center of gravity is not on the same level following the Z axis. That's why if the four elastomeric parts are identical, coupling between axis will be strong due to this non symmetrical geometry. To prevent this effect, a simple solution is to introduce a dissymmetry in elastomeric parts.

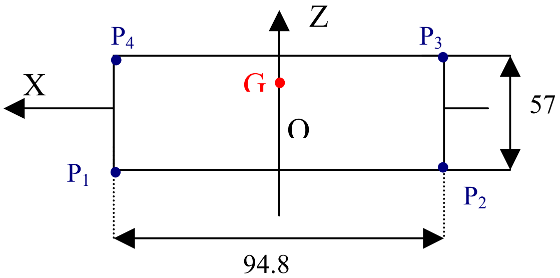

Fig VIII : LOCALISATION OF THE CENTER OF GRAVITY FOLLOWING Z axis

Thus, the four parts are not built in the same elastomer, the polymer is the same but the hardness is different. As shown on **Fig VIII**, the two parts near the center of mass are built in a high hardness (**SMACTANE®** 60 for P3 and P4) and the others are built in a low hardness (**SMACTANE®** for P1 and P2), and so the stiffness of the elastomeric parts located near the center of mass are higher than the others parts.

Using two different hardnesses, the response in transmissibility for an OY solicitation is similar to the response of a system with a single degree of freedom, that is not obtained by the using of four identical parts.

The difficulty was to adjust exactly the elastomer hardness to prevent coupling phenomenon, thus, several compounding was elaborate to find the best results with **SMACTANE®** 47 and **SMACTANE®** 60.

4.4 Which solution to assure thermal conductivity ?

The thermal coefficient of **SMACTANE®** (and it is the case for the others rubbers) is about 0.17 W/mK and is low enough not to dispel the reaction wheel heat. It is necessary to install thermal braids between the inside and the outside frame of the damping isolator system. But this braids have not to disturb the vibration behaviour of the isolator, that's why it is necessary to design them in order to have a low stiffness and to have a sufficient thermal dissipation.

Four braids are used for symmetry reasons and they have shaped as shown **fig IX**. They have been clamped on the outside frame thanks to M3 screws and under the feet of the wheel thanks to M4 screws used to bound the wheel on the inside frame (see **fig IX**)

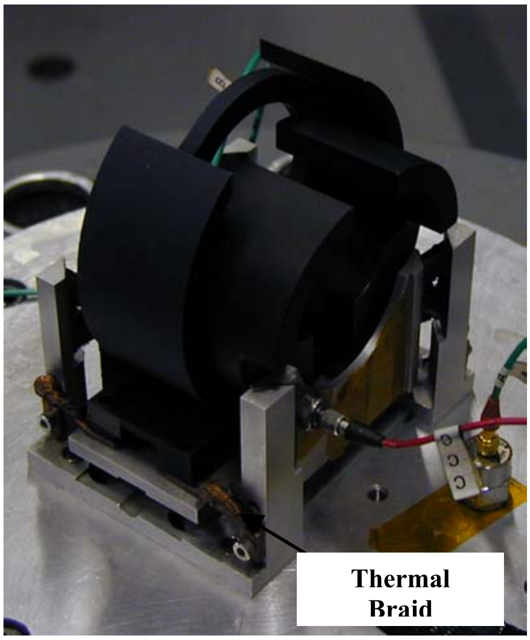

Fig IX : localisation of thermal braids

Sinus tests have been carried out to show the efficiency of the damping system isolator despite the user of the four thermal braids. Only a mass addition effect appears as shown, the solution can then be adopted.

4.5 Which's solution for electrical interface ?

The reaction wheel is supplied with a cable diameter 8, preliminary tests have shown that the stiffness of this cable is low enough not to debase the damping isolator behaviour. The point was to locate the cable in the system ?

A solution is to pass the cable between wheel's feet and between the frames, then the cable is fixed by sticking it on to the gutter machined on the outside frame.

Fig **X** shows the complete damping isolator system with thermal braids and fixed cable. Qualification test can then be carried out on this complete model.

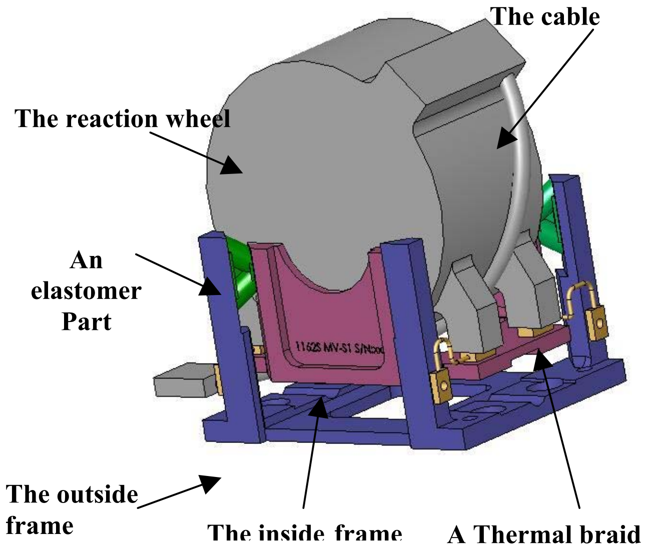

Fig X : The damping isolator system and its reaction wheel

5. QUALIFICATION TEST RESULTS :

Qualification tests have been realised using a mechanical model and not using a flight model wheel. The test model and flight model wheel show exactly the same weight, the same localisation of the center of gravity and similar inertia (see).

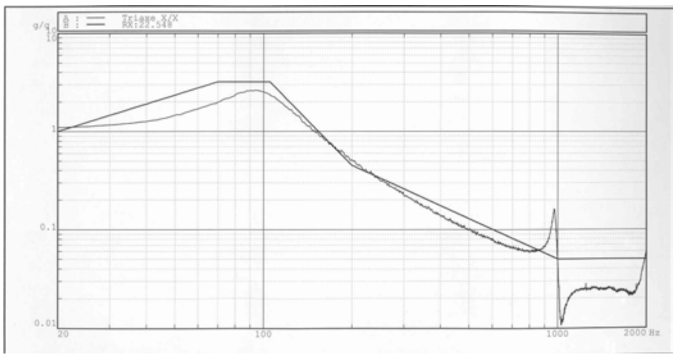

Fig XI : Transmissibility following X axis (factory acceptance test at 25°C)

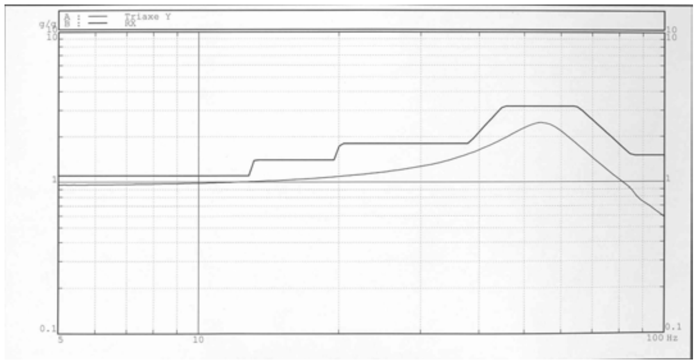

Fig XII : Transmissibility following Y axis (factory acceptance test at 25°C)

5.1 Factory acceptance test at 25°C :

Curves **XI**, **XII** give the transmissibility response obtained during factory acceptance test at 25°C.

Following the Y axis, the eigen mode is about 55 Hz with a quality factor equal to 2.5. Only one degree of freedom is excited despite a non alignment concerning the center of mass wheel : using **SMACTANE® 47**and **SMACTANE® 60** parts has been successful. For a frequency equals to 200 Hz (first eigen mode of the reaction wheel), the transmissibility is lower than 0.20, only 1/5 of mechanical vibratory constraints are applied on the reaction wheel.

Following the X and Z axis, results are similar : eigen mode is about 90 Hz, with a quality factor near to 2.7. At 200 Hz, transmissibility is to 0.47. This 2 eigen modes are higher than Y eigen mode, and so the transmissibility is higher too. Equi frequency are not absolutely obtained since the location of elastomeric parts are not equi axis symmetric because of space obstruction. That is the best compromise obtained between equi frequency properties and space obstructions.

5.2 Qualification tests and temperature factor:

Qualification tests have been carried out at 05°C and 30°C. **Fig XIII** gives main characteristics of the damping isolator system for this 2 temperatures. For each solicited axis, notice that the eigen mode increases and the quality factor decreases as soon as the temperature decreases. A Ratio equal to about 1.6 exists between the eigen mode at 05°C and the eigen mode at 30°C.

SMACTANE® has excellent damping properties at ambient temperature, but its dependence on temperature is strong and it is important in a such development to know exactly the temperature range of use. If this temperature range is large, so it is necessary to use another rubber family steady properties in temperature like silicon for example, a rubber based on silicon family whose damping properties stay good in large temperature range (-100°C / + 150°C).

Moreover, **SMACTANE®** also depends on applied level. **Fig XIV** shows the transmissibility obtained for qualification levels and for factory acceptance levels (factory acceptance levels = qualification levels –3dB).
This phenomena is due to the dependence on **SMACTANE®** temperature conditions, but also to the non linear mechanical properties existing for all elastomers.

		sinus 10g 5°C	***sinus 10g 30°C***
OX	**fr Hz**	97	61
	Q	2,16	4,6
OY	**fr Hz**	62	39
	Q	1,85	3,4
OZ	**fr Hz**	92	58
	Q	2,18	4,44

Fig XIII : Depended on temperrature

		Factory acceptance levels	***Qualification levels***
OX	**fr Hz**	92	73
	Q	2.43	3.18
OY	**fr Hz**	52	47
	Q	2.33	2.98
OZ	**fr Hz**	93	75
	Q	2.16	2.93

Fig XIV : Depended on mechanical applied levels

6.3 Torque transmissibility :

The torque transmissibility (around Z axis) of the reaction wheel equipped with the damping isolator system has been plotted using a Kistler reaction table and a shaker injecting a load on the wheel equivalent to a torque of 0.6 mNm. The related curve is plotted on **fig XV**.

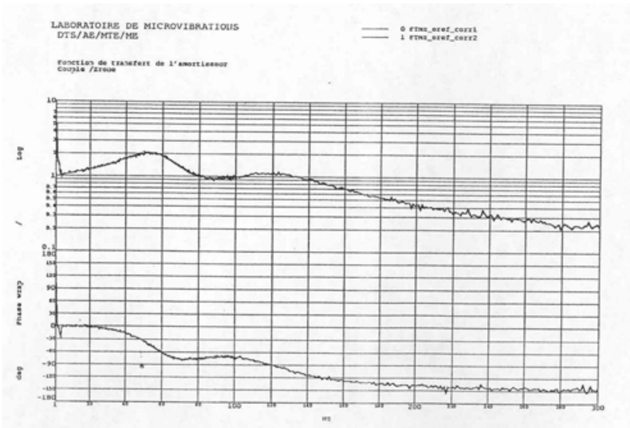

Fig XV : Torque transmissibility

From 1 Hz to 10 Hz, gain is near to one this is necessary to guarantee a good functionality of the reaction wheel.

6. CONCLUSION AND NEW WAYS :

The compatibility of an elastomer material with limited space environment has enabled the development of a damping isolator system which looks forward limiting the vibrations transmission through the onboard equipment 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 : about 0.220 Kg
- Volumeless : The elastomer 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.

During its development, a new solution was found to comply concerning the elastomer with thermal dissipation (CNES R&T). The idea is to add aluminium particles inside the elastomer compounding. Thus, the thermal coefficient of a such material becomes equal to 0.34 W/mK (0.17 W/mK without aluminium particles) with damping properties equals to **SMACTANE®** damping properties This is a good alternative solution for viscoelastic material using and space thermal constraints.

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