VERY LOW SHOCK RELEASE PYROMECHANISMS

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INTRODUCTION

Pyromechanisms have long been used in space for launchers and satellites applications, particularly for release or separation purposes, such as bolt cutters, release nuts, pyrovalves, etc…
They offer a great variety of uses, a high potential between the power supplied and the weight on board with, at the same time, a high reliability.

However, they also feature a drawback due to the high dynamics generated by their functioning. Pyroshocks levels may damage adjacent sensible equipments (eg electronic boxes, reaction wheels,…) and require to design damping systems or to remove those equipments from the shock source.

In a mechanism using standard pyrodevices, shock generation comes from three sources:

- Pyrotechnic reaction
- Energy from internal parts in motion
- The release of structural constraints

Devices developed by E. LACROIX have the objectives to avoid the two last ones by:

- Using heat and gas generated by pyrotechnic effects.
- Reducing speed of parts in motion.
- Reducing release speed of mechanical constraints.

In this paper, LACROIX presents two products named “PYROSOFT” and “VIROSOFT “ designed by LACROIX and supported by CNES Toulouse (French Space Agency). R&T contracts.

“ PYROSOFT ”

Release pyro-mechanism

Principle
The conception of a **pyrotechnic system** releasing a mechanism has to deal with two main functions :

- - Achieve a preload tension to allow the hold-down without a gap in the mechanism, while this latter will be undergoing the flight dynamics,
- - Separate the mechanical binding **without any side effect**.

Most pyrotechnic mechanisms designed for separation cannot combine both functions.

In fact, the stacking tension induces a potential energy of strain that is accumulated in the structural and hold-down part.

The actual pyrotechnic systems release the tension in a very short time. The potential energy associated to this very short release time generates an important instantaneous mechanical power therefore inducing shocks.

The dynamics of the shock due to the release are generally predominant over dynamics generated by other sources of shocks.

The solution : PYROSOFT uses the **thermal effects** of a pyrotechnic composition while retaining the pressure effects.
The functioning of PYROSOFT is run in such a way so as to release the preload tension before releasing the real separation function.
The separation therefore runs under a negligible effort, and therefore produces negligible effects.
The pyrotechnic effects are limited to a low temperature increase of the body of the system.

The dynamic effect are neutralized at the source.

Functioning

The "PYROSOFT" concept uses mainly the heat generated by a pyrotechnic reaction (composition highly exothermal) to melt a brazing in less than one second.

This brazing has three functions :

- To ensure the mechanical hold of the effort.
- To damp internal movement (in its liquid phase) by lamination.
- To lock the mechanism in its final position by re-solidification.
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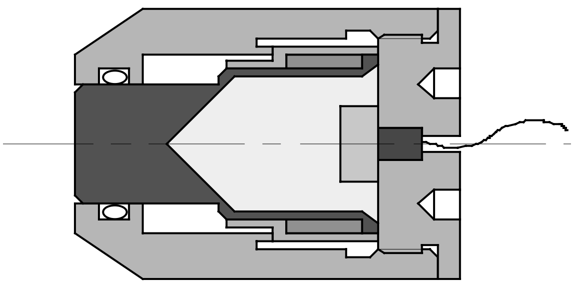
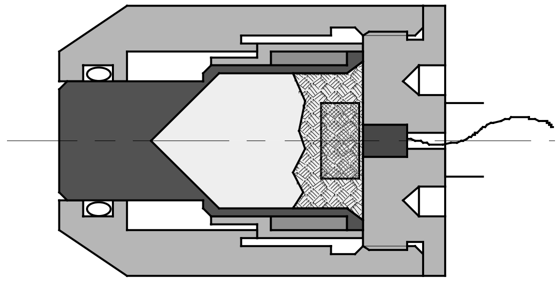
Before Firing

Piston locked to fixed elements



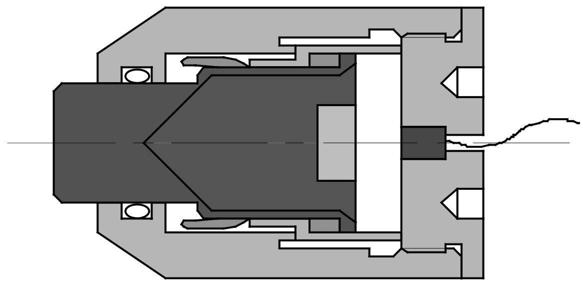
Firing

Melting of the Low Melting Point Alloy – LPMA



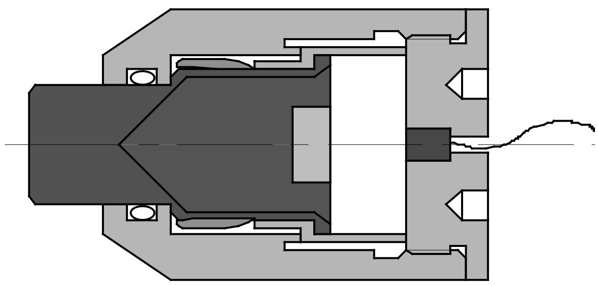
Motion

Piston is unlocked and moved under gas pressure.
Speed is controlled by the LMPA flow



After Firing

Piston is re-locked on cooling

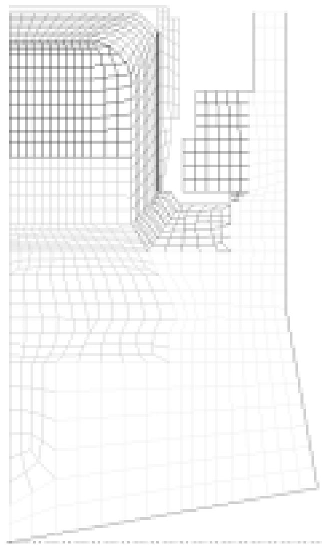


Main characteristics

MODEL	12-392V
Nominal load ***Load with margins***	12 000 N 18 800 N
Weight	125 g with 2 NSI
Operation duration	1 s
Shock level	< 100 g at 1 kHz
Operating temperature	-110°C /+110°C
Random Vibrations	50,9 g RMS
Acceleration	+/- 25g
Reliability	> 0,9999
Shelf Life	10 years
Initiation	NSI or 1-TAP
Max relaxation stroke	1 mm

Thermal study

A data-processing model of the thermal behaviour has been developed from the PYROSOFT type 12-392-V.
The transmission modes of the heat taken into account are conduction, radiation and convection for the study cases in test (ground conditions).



All the parts are modelized in 3D axisymetric elements (axisymetric solid) and also the air zone under the chamber and around the piston for the complete model.

The powers given by the combustion of the pyrotechnic composition are applied, for each area, to the solid elements.

The following method is applied :

1. From the system geometry, the volume of each composition area is calculated. Based on density data, the composition mass corresponding to each area is deduced.
2. Following the calorific potential of the area, the energy released by the mass is calculated.

3. Based on the combustion velocity, the power generated by the combustion to apply, in time, to each area. (Pmax Power gap from T to T + dT) is evaluated.

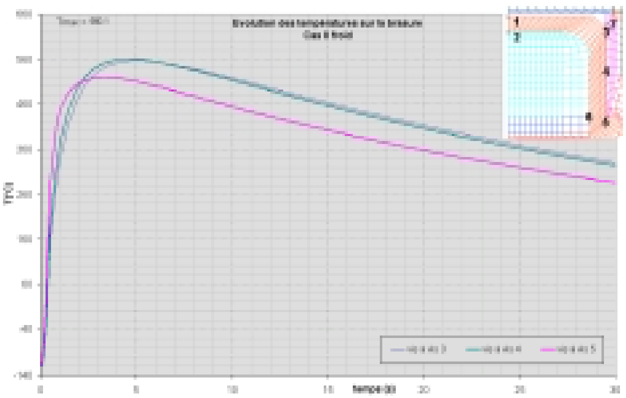
Whatever the calculation case, the transitory cycle applied is the same :

- Initial conditions T0 : the whole at room temperature,
- Combustion of the composition mass from T0 up to T0+Δt
- Calculation cycle : from T0 to T0 + 30s.

The room temperature in the model is said to be at:

- +20 °C : reference calculation,
- +120 °C : sensitivity to hot conditions,
- -120 °C : sensitivity to cold conditions.

Example of temperature evolution of the brazing (–120°C)



The temperatures available for the resetting correspond to the values recorded on tests with thermocouples.

The temperature obtained on the level of the thermocouples after are the following :

Calculated temperature : **554,1 °C**
Measured temperature : **540 °C**

Interest of the thermal study

- study the thermal sensitivity between –120°C and + 120°C
- Optimize the pyrotechnic payload
- Optimize the thermal flow in the chamber.

Conclusion

The resetting allowed to obtain satisfying maximal temperature levels.
On the other hand, we observe great differences in terms of time of response : the thermocouple response is probably slow when facing the speed of the temperature rise. (combustion in about 200 ms). The experience also shows debrazing times of about 1 second, what the model predicts, while the measure by TC would give a 3s time !

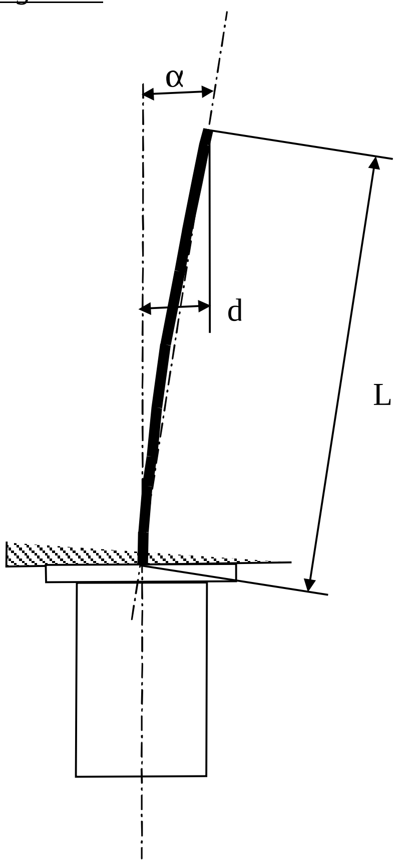
The sensitivity study led by this model allowed to evaluate the impact of the foreseen configuration modifications on the distribution of the heat in the model and on the levels of temperature and thus allowed to define the best compromise.

Mechanical study

Dimensioning

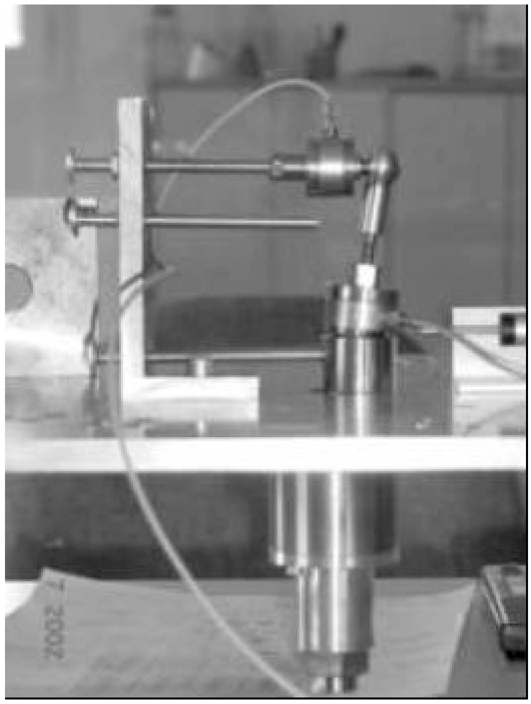
A data-processing model with finite elements allowed to create a structural model for the different parts and allowed their slight evolution in regard to the initial design, to respect the specifications of this type of mechanism ((chamfers and bending radius in the zones of constraint concentration).

Misalignment



The capability of the device to accept the mechanical misalignment was tested so as to validate the reliable operation of the product in this configuration.

A maximum acceptable misalignment "α" for a Ø6 mm bolt of 70 mm length in 15-5PH stainless steel is of 2mm and of 2,2 mm with a TA6V bolt (The motorization margins are compliant with the (European Cooperation for Space Standardisation) ECSS E30 part 3- Mechanism recommendations.



Vibrations

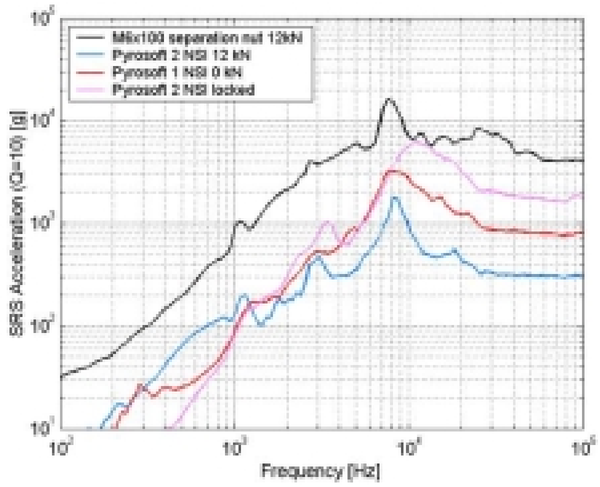
The Sine and Random vibration tests of (50,9g RMS qualification level – 6 min/axis – 3axis) were performed on a device with a 12000N preload in the bolt.

These tests showed neither damage of mechanical elements nor damage of the device pyrotechnic charge.

The initial tension of 12 000N did not change during the vibration sequences.

Shock measurements

Shock measurements on CNES/ESA tests bench in CNES Toulouse were made to evaluate the shocks induced by the functioning of the device. This “standard” test bench consists in a 1 mx1 m x 5 mm aluminium plate with an instrumentation of 32 shock sensors. Pyrodevices of different models and manufacturers have been characterised by CNES (bolt cutters, release nuts, cable cutters).



On this plate are shown the SRS (Shock Response Spectrum) of the shocks recorded at 10 cm of the source. The shock reduction of Pyrosoft compared to a classical Separation Nut is important (14 dB)..
The two devices were fired in the same configuration eg 2 NASA Standard Initiators (NSI)fired simultaneously with a 12 kN bolt tension.
The others Pyrosoft test configuration(1 NSI -tension 0 N) and (2 NSI lock shut) demonstrate that the shock source is mainly the effect of the initiators functioning and not the mechanical effect of the bolt release.

Conclusion

The activities performed in the frame of the R&T CNES contract have shown that the PYROSOFT design is compliant with the space environment requirements. The most critical points have been overcome :

- Pyrotechnic composition
- Handling of the thermal transition
- Structural margins of the mechanism
- Behaviour under vibrations
- Shocks induced while functioning

The aim of the activities in progress is to fulfil the CNES requirements : demonstration of the reliability and compliance with the qualification.

The development of derivate versions is in progress with the support of ESA.

“ VIROSOFT ”

The feasibility of this concept has been performed under CNES Toulouse R&T contract.

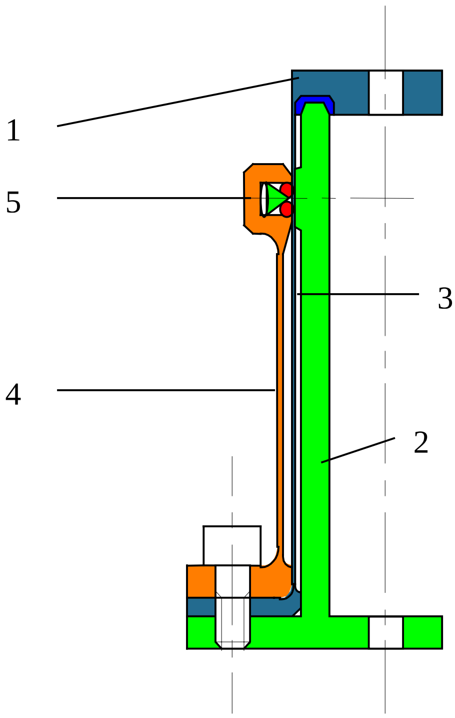
Separation Device for Satellite Adapters

Some separation devices for launcher /satellite adapters are based on expanding detonating tubes which break weakened sections of the adapter. This technology is widespread for launchers inter-stage separation systems. Shocks are produced by the cutting of the separation flange and are transmitted to the satellite structure.

In order to limit the shock, the aim of VIROSOFT is to dissociate link and release functions.

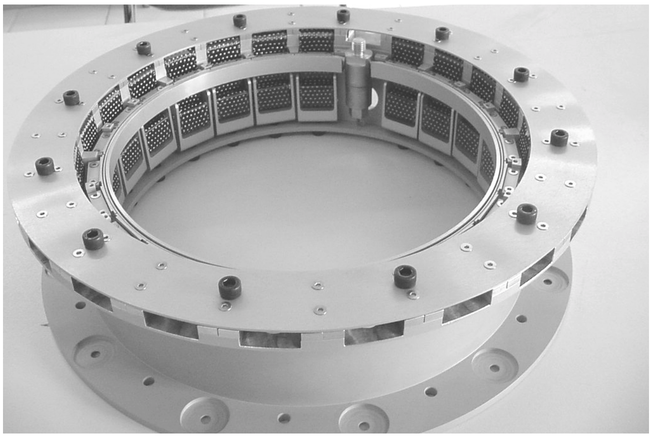
Principle

- Upper : composite material ring
- Lower : light alloy half-flange pre-stressed in compression
- Composite bands operating in tension
- Flange supporting pyrotechnic cutter
- Cutter blade moved by an expansion tube combined with a gas generator



Design

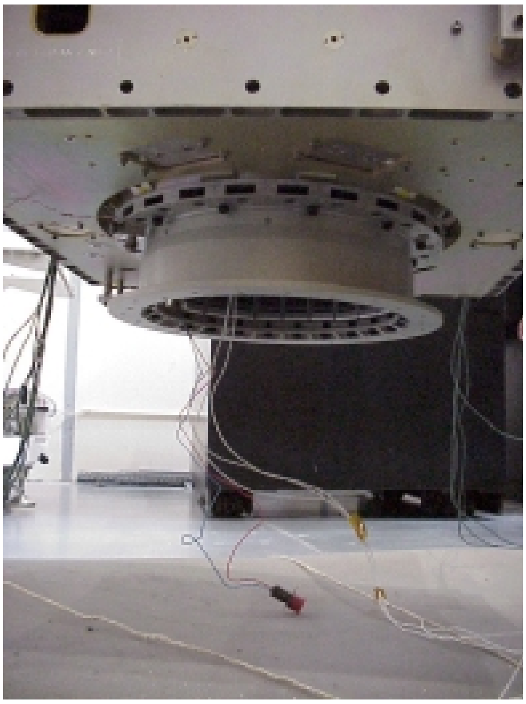
VIROSOFT is designed to withstand the two parts of the adapter by the mean of carbon straps in tension. For satellite release, the expansion of a tube pressurized by a gas generator moves cutters which cut the carbon straps.



Dimensioning and development of the different elements have been achieved with processing models and validated with tests taking into account structural-margins.

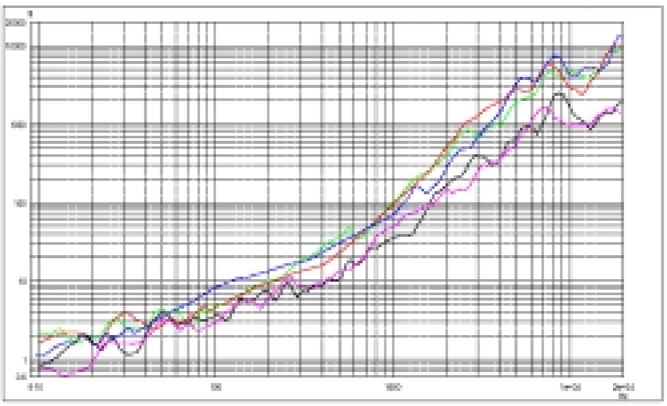
- *Composite bands:* dimensioning with static and dynamic margins.
- *Expansion tube and gas generator :* design and dimensioning validated with functioning tests; hermeticity before and after firing checked by helium leakage tests.
- *Cutter blades* : design and dimensioning validated with functioning tests.

CNES Toulouse TESTS



Two tests have been performed by CNES on a the CNES microsatellite structural model.

SRS (Shock Response spectrum) of the shocks recorded at the adapter/spacecraft interface (satellite side).



Vibrations tests

The Virosoft adapter fitted to a 125 kg micro-satellite mock-up has been installed on a the LACROIX vibration facility.

Quasi Static Load (7.5g longitudinal axis and 6.5g radial axis) have been applied by sine vibration in the 20Hz – 25 Hz range . No anomalies and damages have been recorded.

Conclusion

Compared to the expanding detonating tube separation systems, the energy required for cutting straps is lower.

VIROSOFT tests on a CNES micro-satellite have shown a shock level reduction from 3 dB up to 6 dB in the frequency range of 1 kHz to 10 kHz referred to an equivalent detonating separation system. The structural behaviour of Virosoft has been evaluated with success.

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