

Development of a Low-Shock Separation Nut Out of the Pyrotechnic Class

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Introduction

About Pyroalliance

Pyroalliance is the European leader and a world-class player in pyrotechnics and mechanisms, delivering innovative and cost-effective solutions tailored to our customers' critical requirements. With more than a half-century of experience as a manufacturer of state-of-the-art pyrotechnic and mechanical equipment, Pyroalliance addresses the requirements of cutting-edge industries, including Aerospace, Defense and Energy. We leverage our proven expertise and innovative mindset to develop products that combine the performance and reliability needed to perform critical functions for our customers' systems.

Facts and figures:

- Counting over 240 collaborators, Pyroalliance is operating from two locations. The headquarters is at Les Mureaux (Region of Paris) and the second site is located in Toulon (Southeast France)
- Pyroalliance is 90% owned by ArianeGroup, the remaining 10% belonging to the company OEA Inc.
- The company has reached 40 million Euros turnover in 2018, representing a 15% growth compared to 2017
- Exporting in more than 15 countries, Pyroalliance is pursuing its international growth

Low-Shock Separation nuts

By adapting the design of its Pyrotechnics Nuts, Pyroalliance overcomes the preconceived notions and changes the game by claiming its products are Ultra Low Shock.

Pyroalliance has been designing and producing Pyrotechnic Nuts as well as Hold and Release Mechanisms for decades. Those are dedicated to maintain satellites on dispensers as well as antennas and booms on satellites. To date, Pyroalliance has delivered more than 6000 of those with a track record of 100% operational success. Indeed pyrotechnic nuts provide major operational benefits thanks to their very high energy density, very high standard of proven reliability, speed of execution (milliseconds scale) and ideal synchronicity when several nuts are to be activated simultaneously (typical situation when satellites are held on a satellite dispenser).

Recent market surveys show that:

- Separation Nuts require a growing capability to reduce levels of shocks on the payloads, what is considered as an attractive feature for sensitive payloads, combined with an ability to ensure synchronicity;
- Despite of their performance, a growing number of actors of the New Space are reluctant to use equipment classified as pyro for operational reasons.

Understanding those challenges, Pyroalliance presents hereafter its recent achievements in those areas.

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Separation Nut Background

Pyroalliance designs, manufactures and delivers separation nuts or complete Hold and Release Mechanisms meeting the requirements of various mission profiles. However, each design is based on the same principles which have cumulated decades of flight heritage .

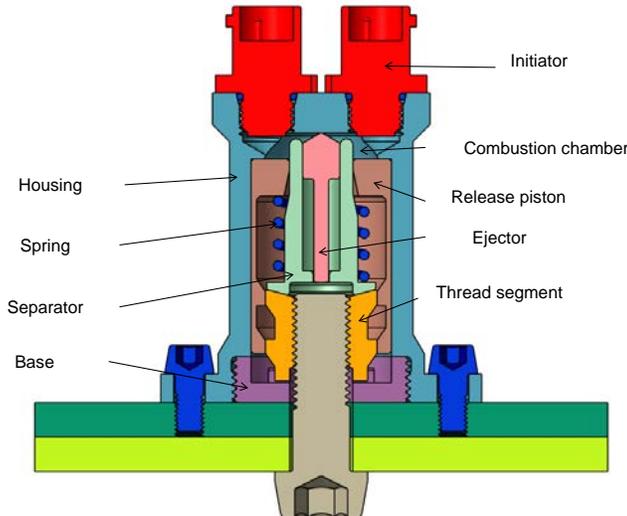


Figure 1. Pyroalliance separation nuts – Principle

Functioning principle: The pyro-initiators make the pressure increase inside the sealed chamber, until the release piston can translate. When shifted, the release piston, due to its inner geometry, allows the radial expansion of the thread segments and, consequently, the release of the screw. At the same time, the ejection pin moves and ensures that the screw cannot remain or move back to its initial location.

Pyroalliance separation nuts are fully resettable on both Pyroalliance sites or customer facilities using cold gas (non pyro gas). The Spring allows resetting the parts in the initial position when actuated by cold gas. Before delivery, 100% of our separation nuts are controlled using cold gas actuation in a test set reflecting the extreme operational conditions of the mission (temperature and pre-load at release).

The heritage design has the following main advantages:

- Outstanding reliability figures ($>1 - 5 \times 10^{-5}$) despite extreme operational conditions; the simple design made of only a few parts and the motorization margins driven by the pyrotechnics are the key features enabling such level of reliability
- Extremely low actuation time / actuation time standard deviation: the actuation time of Pyroalliance separation nuts remains below 2 ms cumulating both contributions of pyrotechnic and mechanical actuations. Then, the actuation time standard deviation is well below 1 ms which is particularly suited for multi-point release.

On top of those advantages, Pyroalliance recently started to implement some adaptations to this heritage design in order to meet new emerging market requirements. They aim at :

- Reducing the level of shock induced on the holding structures during the release
- Performing the necessary steps to make the device Out of Class (non pyro).

Pyroalliance is currently working on implementing those adaptations while preserving all assets of the heritage design.

Pyroalliance achievements

First analysis

When analyzing the separation nut heritage design, Pyroalliance made the assessment that there were three main contributors to the induced shock:

- Pyrotechnic shock due to the initiator actuation
- Strain energy stored in the screw during the preload and freed during the release
- Kinetic energy stored in the release piston during the release and further distributed during following shocks of the piston with other mechanical parts.

Table 1 summarizes the different contributors of the shock and quantifies their respective impact. The considered design is the heritage M10 separation nut (screw diameter: 10 mm / 0.39 inch).

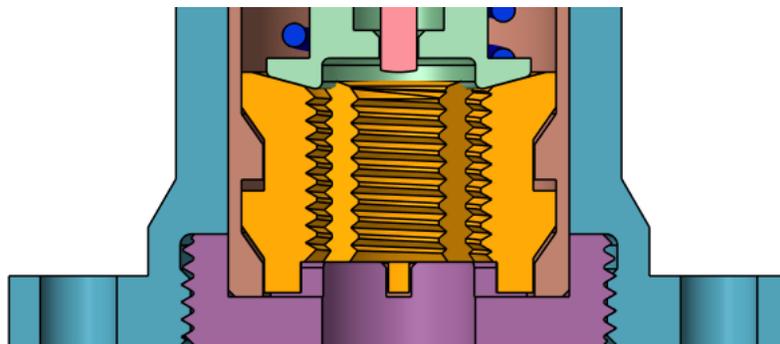
Table 1. Shock contributors assesement – M10 separation nut heritage design

| Shock source | Nature | Shock contribution* |
|------------------------------|-------------|--|
| Initiator actuation | Pyrotechnic | 10% (tested with NASA Standard Initiator / Space Standard Initiator) |
| Screw release of the preload | Mechanical | 5% (preload: 20 kN ; screw length: 100 mm ; screw material: stainless steel) |
| Impact of the release piston | Mechanical | 85% |

**Note: Several tests / analysis have been performed in order to quantify the impact of each contributor.*

Pyroalliance found out that the shock was mainly caused by the impact of the release piston at the end of his stroke once the threaded segments are expanded.

As an example, the sketch on Figure 2 presents the characteristic of the piston collision using the M10 separation nut. The velocity of the piston at the time of the impact has been captured using a high-speed camera.



Impact characteristics

- Release piston mass: 50g
- Release piston velocity: 30 m/s
- Kinetic energy: 22.5 J

Figure 2. M10 separation nut – Collision characteristics

Addition of a damping system

Based on those findings, Pyroalliance designed a specific damping system made of a dedicated damping material and located after the release at the end of the release piston stroke. This system allows performing a progressive braking of the release piston without degrading the reliability of the global system.

Furthermore, this damping system is fully compliant with respect to LEO space requirements:

- Outgassing compliant with NASA / ESA Standards
- Tested on the temperature range [-60°C;+80°C] without any performance degradation
- Compatible with a 10 years storage duration without any performance degradation (tested through accelerated aging).

Pyroalliance has performed several tests with the addition of the damping system. The shock configuration is composed of an aluminum plate of 1m×1m×5mm receiving the separation nut test assembly. Four accelerometers are distributed on a 100-mm-diameter circle around the separation nut.

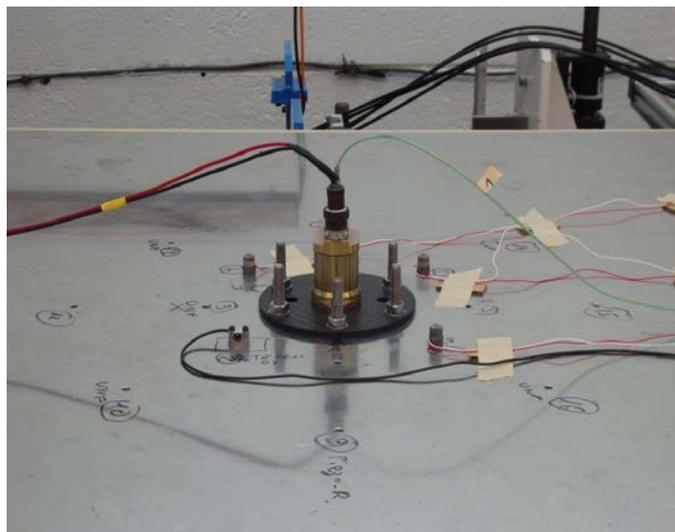


Figure 3. Shock test configuration – M10 separation nut

The results are presented on the Figure 4.

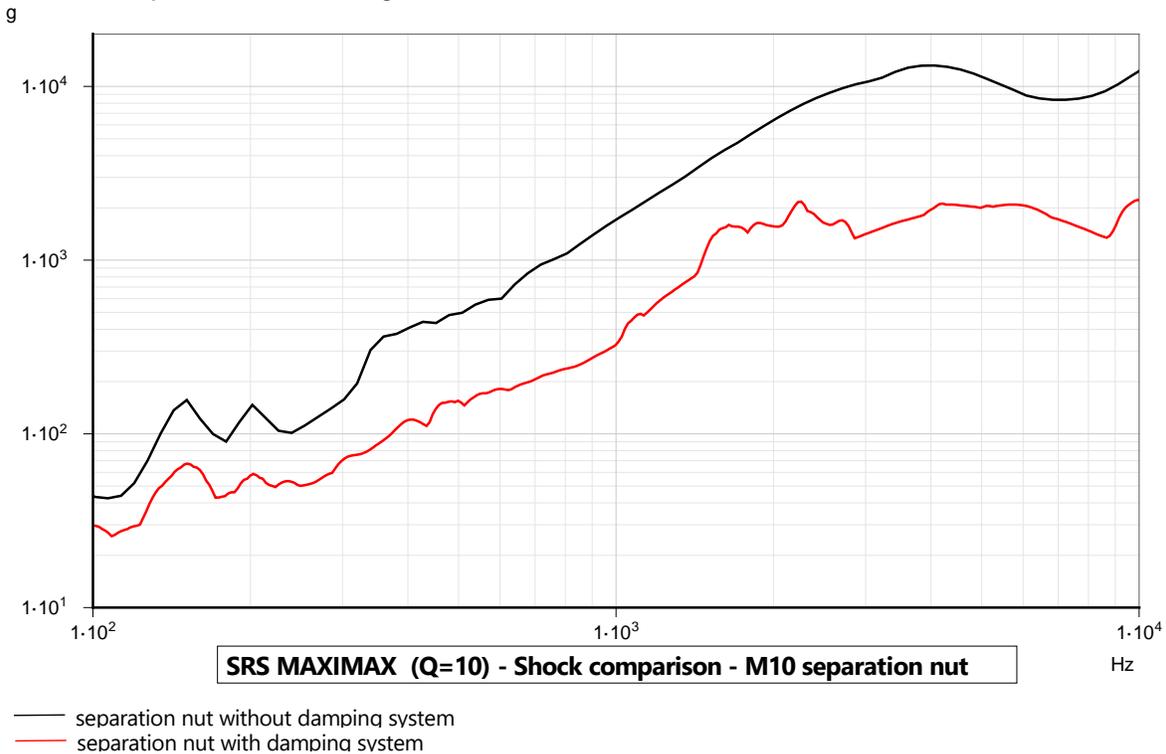


Figure 4. Shock Response Spectrum - Addition of the damping system

These results have been measured on Pyroalliance own shock test lab configuration. A comparison of the shock with / without damping system has been performed in the exact same configuration considering several units. The induced shock has been reduced by a factor 4 on the frequency band [1000 Hz; 10000Hz]. Furthermore, the damping system brings similarly better results on the entire frequency range.

Tests have also been performed on a spacecraft mockup at customer level. The accelerometers were located on the spacecraft side close to the cup / cone interface. The results measured by the customer were the following:

- 4000 g_{SRS} @2000Hz with the heritage design (without damping);
- 1000 g_{SRS} @2000Hz with the addition of the damping system.

The shock reduction by a factor 4 measured on the shock test lab configuration has therefore also been verified with the same ratio at customer level.

Pyroalliance is pursuing this effort to improve the damping system and reduce the shock induced by the separation nuts with a target of 500 g_{SRS} @2000Hz on a spacecraft configuration.

Out of classification European procedure

In the context of aerospace industry, Pyroalliance is turning toward technologies which contain pyrotechnics and its condensed power while being as safe as other non pyrotechnic devices.

In order to be classified as non-dangerous good regarding the law (c.f French transport regulation law: *Recommandations relatives au transport des marchandises dangereuses ST/SG/AC.10/1/Rev.20*), Pyroalliance will conduct several tests to demonstrate that an unpackaged separation nut equipped with pyro-initiators satisfies the 6 criteria in Table 2.

Table 2. European criteria – non dangerous goods transport regulation

| Criterion | Content | Status | Sensor type | |
|----------------------------------|---------------------|--|--|------------------------|
| Property when functioning | | | | |
| 1 | Surface temperature | When actuated, external surfaces of the product shall not reach a temperature higher than 65°C (149°F). A transient 200°C (392°F) peak remains acceptable. | Checked (measured through tests) | Thermocouple |
| 2 | Integrity | Neither rupture nor movement of any parts of the item, or the item itself, should occur beyond a 1-meter range in any direction. If the integrity can be affected by the fire exposure, tests under fire can be requested. | To be checked under fire exposure | High speed Camera |
| 3 | Low noise | No audible effect above 135 dB at one meter from the item in any direction. | To be checked | Sonometer |
| 4 | Arc and flames | No electric arc, no flame should occur able to inflame material such as a sheet of paper whose density is $80 \pm 10 \text{ g/m}^2$ in contact with the item. | To be checked | High speed camera |
| 5 | Fumes | No production of fumes, emanations or dust should occur which would reduce the visibility by 50% in a 1-meter-cube chamber. The luxmeter is located at 1 meter from a constant light. | To be checked | Luxmeter |
| Others | | | | |
| 6 | Inviolability | To make the item safe to manipulate even in case of untimely firing, the design shall ensure that the pyrotechnic initiators can not be unscrewed from the separation nut, as a warrant of inviolability and safety for operators and users. | Compliance of design options to be confirmed by regulation authorities | Conception requirement |

Note 1: If no fumes are observed during tests performed for previous criteria, criterion 5) can be exempted.

Note 2: The regulation authorities can determine that a packaged item is more dangerous than an unpackaged one and can request tests with packaging.

Pyroalliance is in the process of verifying all of those 6 criteria until mid-2020 in order to submit the file and request the EU out of class certification. Finally, Pyroalliance objective will be to transpose the EU out of class certification to US regulation of goods by contacting US DoT.

Conclusion

While preserving all assets of the heritage design of its separation nuts (very high reliability and extremely fast actuation time), Pyroalliance is currently working and quickly progressing on bringing new advantages to its products:

- With the addition of a new damping system, Pyroalliance has already reduced the level of induced shock by a factor 4 compared to its heritage design. As a next step, Pyroalliance is now targeting to reach a shock below 500 g_{SRS} @2000Hz measured on a small spacecraft configuration
- Besides Pyroalliance aims at delivering separation nuts out of the pyrotechnic classification (EU / US regulation laws) by mid-2020.