Development of a Self-latching Hold-down RElease Kinematic (SHREK)

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Abstract

SHREK (Self-latching Hold-down Release Kinematic), is an innovative shape memory actuated hold down and release device, aimed to latch and release solar panels. It is specifically conceived to fit the small satellite market requirements, as well as overcome some recurring shortcomings of existing similar devices. This paper describes SHREK's unique design characteristics and preliminary test results.

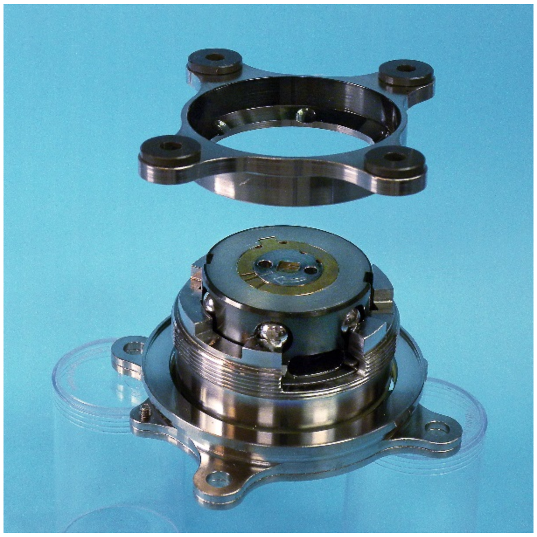

Figure 1. SHREK

Introduction

Small (mini and micro) satellites represent a rapidly expanding market, which extends the access to space to a number of comparatively small organizations. Its commercial nature brings in requirements that, at no detriment of technical performance, are focused on operability and cost. For this market, AEREA has devised a mechanism for latching and releasing deployables while pursuing the following goals:

- Commercially attractive
- ITAR free
- Automatic manual latching (self-latching)
- Simple manual release
- Remote release with shape memory alloy technology
- Full control over the applied preload
- Ground and flight operable without parts replacement
- On-site ground reset operations without parts replacement
- 50 remote actuations without degraded performance (operating time and shock)
- Functional temperature range: -56°C to +70°C (-56°C to 100°C desirable)
- Disconnection shock: < 300 g's [negligible shock desirable]
- Preload force: up to 5 kN

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- Panel mass: up to 10 kg
- Mechanism mass < 0.5 kg [0.3 kg desirable]
- Nominal power consumption: 15 W
- Actuation time: < 60 s
- Envelope: diameter < 100 mm, height < 40 mm

SHREK Description

The following is based on an application where the solar panel is hinged to the satellite on one side and held by the SHREK mechanism on the opposite side.

<u>Mating principle</u>
The mechanism is composed of a Panel module and a Satellite module. The Panel module is a lightweight metallic ring permanently connected to the internal surface of the panel. The Satellite module is a metallic cylinder 35-mm long and 85 mm in diameter, mechanically and electrically connected to the external surface of the satellite. The two modules are axially mated by interposition of an array of spheres (ball lock concept). The spheres are housed in the Satellite module, where they can be radially displaced in either one of two positions: retracted (Unlatched status) or extracted (Latched status). The position of the spheres is determined by the rotation of a Spool, internal and coaxial to the Satellite module. The Spool has radial pockets which, when aligned with the spheres, allow the spheres to retract.

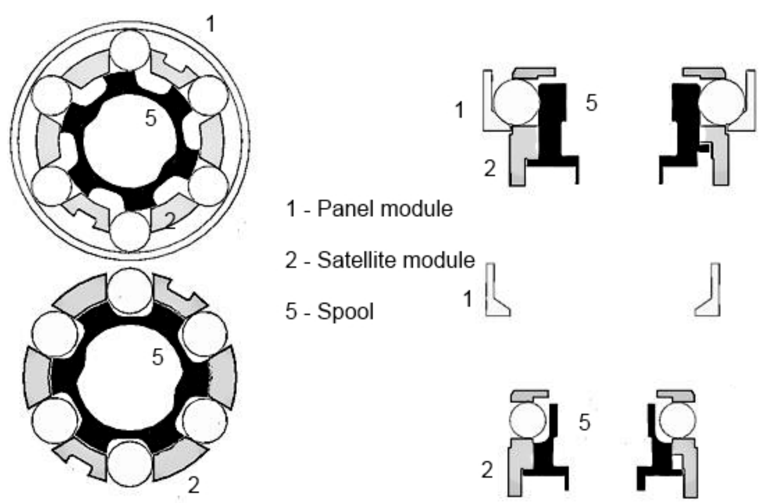

Figure 2. Mating concept (Top=Latched – Bottom=Unlatched)

<u>Self-latching</u> (reference Figure 3)
This is a unique feature of SHREK, operable by manually pushing the panel against the satellite, and its goal is to simplify installation, integration and ground testing of the mechanism.

The Spool is permanently biased, by a Torsion spring (10), to rotate toward the latched position. The torsion applied to the Spool is reacted by the spheres. The radial components of such reactions permanently push the spheres toward the extracted (Latched) position. In the Unlatched condition, the spheres are kept into the Spool (5) pockets by an external, coaxial, spring-loaded Active sleeve (9) which physically blocks the spheres' passages.

For latching, the Panel module (1) is pushed against the Active sleeve (9), which consequently slides axially toward the base of the mechanism, against the force exerted by the Kick-Off spring (7). At the bottom end of the Active sleeve movement, where the Kick-Off spring reaches its maximum compression, radial motion of the spheres is possible. In this position, the torsion spring rotates the Spool. The rotation of the Spool results in the expulsion of the spheres from their pockets due to the pocket having an angled side that produces a radial force on the sphere. When the Spool reaches its Latched status, the spheres remain locked between the inside walls of the Panel module and the external surface of the Spool.

<u>Preload</u> (reference Figure 3)
The Kick-Off springs force (V), applied to the Panel module through the Active sleeve, is re-introduced through the spheres vertically, into the Satellite module (V), and radially into the Spool (H). Such action removes any residual play between the mated parts. Furthermore, during the unlatching sequence, the Kick-Off force, which is applied all along the demating stroke, provides an additional deployment aid, intended to insure absence of disengagement uncertainties.

The preload introduced by the Kick-Off spring (0.5 kN) is considered adequate for stiff, light panels. Should that be insufficient to ensure continuous contact between Panel and Satellite modules at any point of the operational envelope, the provision of an optional Ring nut (6) to be screwed onto the Active sleeve (9) in order to create further separation force has been provided.

The downward rotation of the Ring nut (6) translates in an upward axial motion of the Active sleeve against the Panel module. With this feature, an additional preload of up to 5 kN can be achieved. The control of the preload is obtained by putting a calibrated preload wave spring (8) between the Ring nut and the Satellite module.

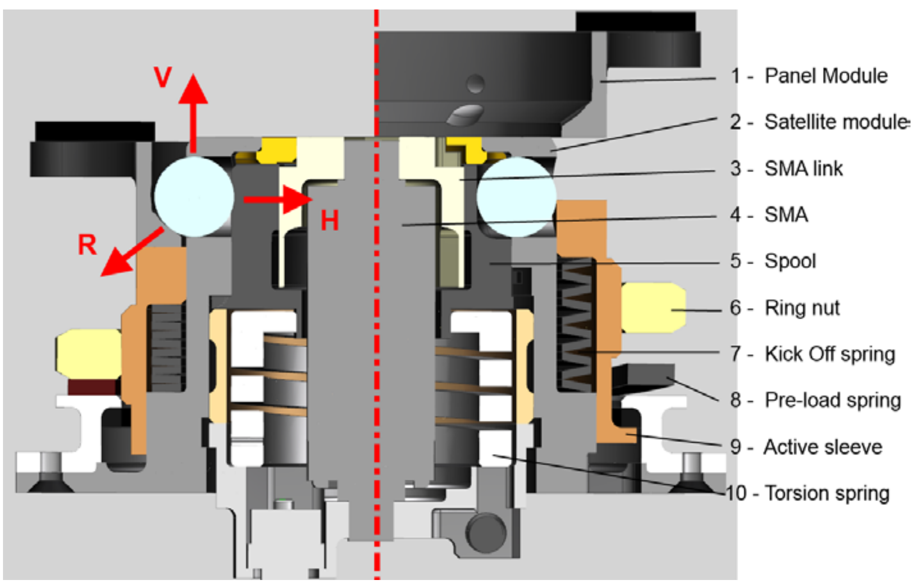

Figure 3. SHREK section (Left=Latched – Right=Released)

<u>Manual release</u> (reference Figure 3)
On the ground, the Spool can be manually rotated to the Unlatched position through a dedicated operating point accessible from the side of the Mechanism. The Spool rotation ends at a predetermined mechanical stop, where the Spool pockets are aligned with the spheres. In that position, the radial component (H) of the overall force (V), exchanged between Panel and Satellite, drives the spheres into the Satellite module. With the spheres out of the way, the modules are disengaged. The Active sleeve, under the action of the Kick Off spring, slides upward along the Satellite module, forcing the Panel module away and blocking the spheres into their pockets.

<u>Remote release</u> (reference Figure 3)
A NiTiNOL bar, enveloped by two redundant heaters, is axially integrated into the Satellite module. The bar is installed in a torsionally deformed martensitic phase with the mechanism in the latched condition.

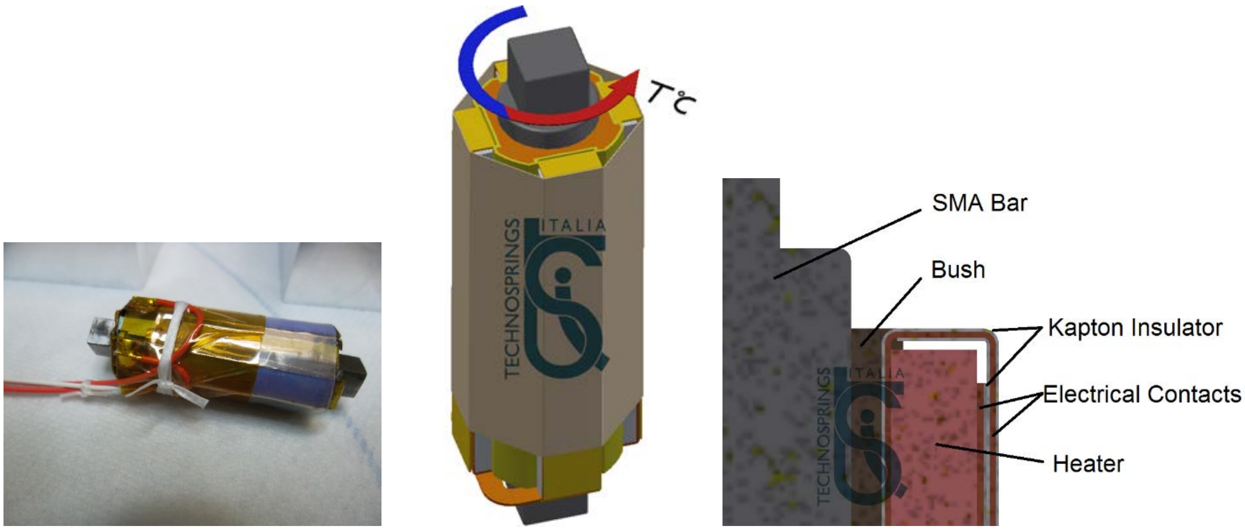

Figure 4. SMA bar with heater

The bar has one extremity firmly mated to the Satellite module, while the opposite end is connected to the Spool through the SMA link (3). When heated at a temperature above the austenitic phase transformation, the bar rotates, recovering its original un-deformed shape. The bar rotation, transferred to the Spool by the SMA link, puts the mechanism into the Unlatched status, thus releasing the Panel module.

SMA Monolateral spool control

Figure 5 shows the peculiarity of the monolateral constraint between the SMA bar and the Spool, allowing the Spool to rotate without being affected or affecting the SMA bar in the martensitic phase. Conversely, the rotation of the SMA bar in the austenitic phase induces the rotation of the Spool.

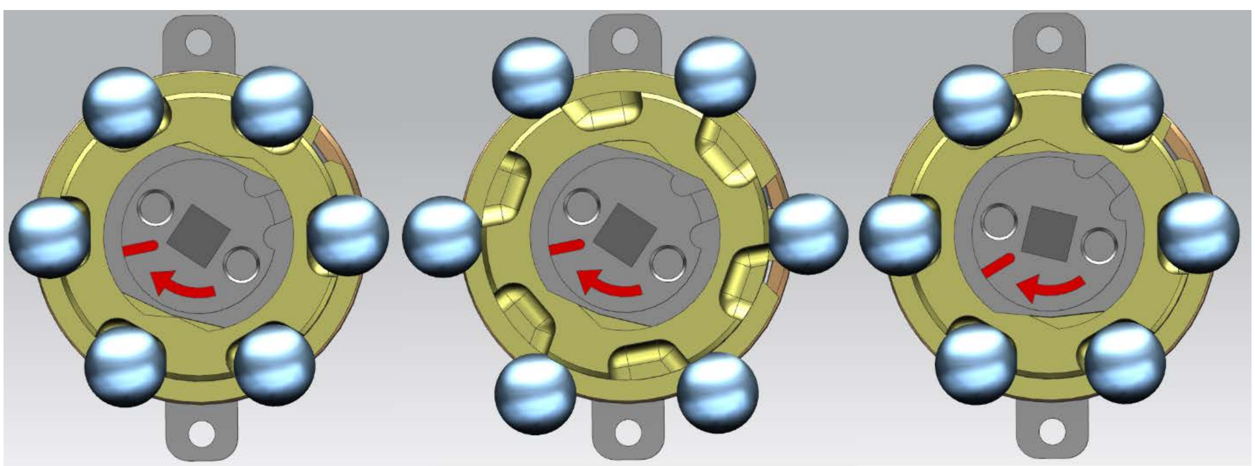

Figure 5. Spool control

The central picture of Figure 5 shows the SHREK in closed status. The picture on the left shows the Spool manually rotated in Released status with the SMA bar unaffected by the Spool rotation. The picture on the right shows how the rotation of the SMA bar is transferred to the Spool (remote actuation).

Reset after remote actuation

Once the SMA bar is cooled below the martensitic phase temperature, and the mechanism is in the Released condition, the bar can be re-deformed through the operating point located on the top of the

Satellite module (pin wrench interface visible in Figure. 5). Up to 50 reset operations without performance degradation are possible.

Assessment of Results

Operability features evaluation

Self-latching, manual Unlatching, Remote actuation and Reset functions have matched the expectations. The additional preloading concept needs to be further improved. The thread pitch is to be enlarged to make it less likely to bind. Smooth manual release requires the Ring nut to be fully screwed down. The use of a relatively large wrench is not seen as appropriate in close vicinity of solar panels. The wave spring effectively allows seeing the applied preload at a glance. Conversely, that spring was revealed to be the single most significant source of shock.

The NiTiNOL bar proved it had more than adequate behavior. In particular, it was ascertained that the actuating time is independent of the preload applied, a good indication of the adequacy of the motorization margin. During development, different alloy compositions and alloy training procedures were tried. It was realized that the functional properties, in terms of torque generation for a given torsion strain, were inversely proportional to the transition temperature. This means that rising the austenitic transition temperature reduces the motorization margin. The selected solution has a transition at about 80°C in 55 seconds. Vacuum tests will probably induce further, hopefully little, adjustments.

Shock Response Spectrum

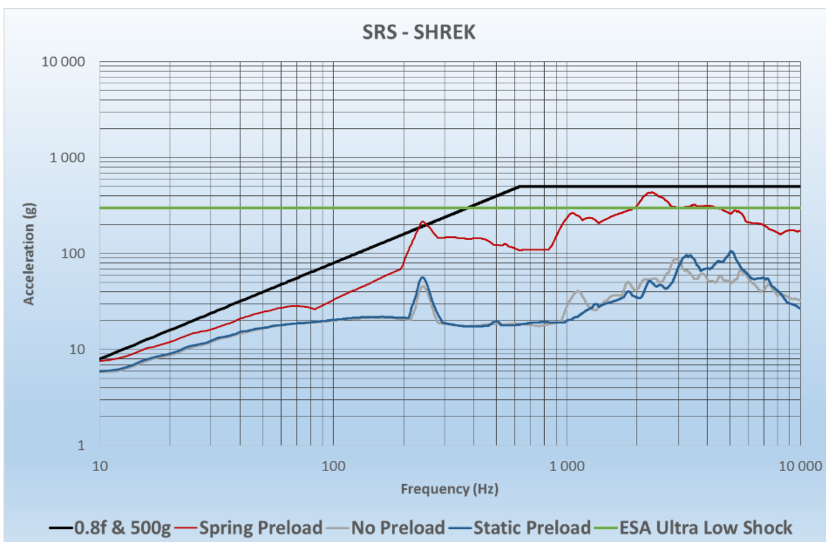

Figure 6. Preliminary Shock test results

Within the SHREK mechanism, there are four sources of shock:

- The Spool hitting its mechanical stop under the drive of the torsion spring.
- The spheres hitting the bottom of the Spool pockets driven by the action of the Kick Off spring
- The Active sleeve reaching its mechanical stop driven by the action of the Kick Off spring.
- The release of the energy stored in the preload spring.

Care has been taken to physically separate as much as possible the events associated with shock generation. This has worked well with the first three sources.

From the SRS curves shown in Figure 6, reflecting the Release Shocks in different configurations, it can be seen that the wave spring increases the Shock level, rising it marginally beyond the Ultra-Low Shock acceleration threshold. Replacing such a spring with a standard washer brings back the shock level below

100 g. With the removal of the wave spring, a different method to measure the applied preload needs to be conceived. Integrated strain gauges are under evaluation.

Motorization
SHREK concept is based on sliding elements, thus friction plays an important role in performance and motorization factors. Several element tests were performed to support the selection of the materials, the treatments, the roughness and geometry of the contacting surfaces as well as the number and size of the locking bodies.

The torque required to open the mechanism, with a friction coefficient of 0.15 and a preload of 5 kN, is expected to peak at 8 Nm during the initial 5-8 degrees of Spool rotation. After that, the mechanism is expected to become self-propelling with a null driving torque at about 10 degrees and a positive one after that. Actual tests performed in air have shown a max torque of 5 Nm peaking at the same expected rotation point.

The SMA bar is dimensioned with a torque capability of not less than 12 Nm at the beginning of the shape recover and not less than 8 Nm after 20 degrees rotation. Actual motorization factor will be measured in vacuum conditions.

Tests
So far, three SHREK prototypes have been manufactured and successfully subjected to Vibration (Sine and Random), Shock, High Temperature and functional endurance tests in air. Thermal Vacuum testing is planned in the first quarter of 2016. Opportunities for an in-orbit demonstration are being actively pursued.

Affordability
At a mass of less than 0.4 kg, SHREK is composed of 15 parts, obtained with standard machining processes, a SMA bar with associated heater, plus standard parts. Its assembly takes roughly 20 minutes and the use of two simple special tools. Its manual operation needs one simple, to make and use, special tool. A 30% cost reduction over the average comparative existing mechanisms is expected.

Conclusions

The SHREK mechanism is maturing as a small, simple and reliable mechanism for a specific field of application (solar panels of small satellites). Its unique features, simplicity and economic affordability should grant its adoption on a large scale.

The outstanding future tasks are:

- performance measurement in vacuum environment (actuation time, motorization and life)
- alternative method of preload measurement (strain gauges integration)
- obtain flight experience with an in-orbit demonstration.

The first two tasks are planned to be achieved during first half of 2016.

References

- Patent Pending “Shrek - Domanda di brevetto italiano n. 102015000010459”