NON EXPLOSIVE LOW SHOCK REUSABLE 20 kN HOLD-DOWN RELEASE ACTUATOR

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ABSTRACT

SENER has developed a Non Explosive Hold-Down Release Actuator: NEHRA (Patented). The mechanism is based on a segmented nut kept in position by a preloaded mechanism. The preloaded mechanism is clamped with a latch than can be triggered by a wire of Shape Memory Alloy (SMA).

A demonstrator model has been manufactured, assembled and functionally tested. The size developed is for a high strength M8 bolt (with an ultimate load about 40 000 N, and a nominal preload of 20 000 N).

1. INTRODUCTION

The present spacecraft architectures require that the appendages are stowed for launch, and released and deployed in orbit for operation.

Those appendages require hold-down and release mechanisms able to provide adequate strength and stiffness to survive the launch mechanical environment, having release functions to allow the appendage deployment.

The separation nut is one of the hold-down and release mechanism types more used, because it is simple, reliable and easy to use compared with others like pyro-cutters, thermal-knifes, etc..

During the last years different methods have been developed for the separation of the nut segments.

Typically the nut segments are released by the action of gas generated by a pyrotechnic, but this system induces high shocks and it has hazard operations requiring strict handling procedures.

In addition the pyrotechnic charge must be replaced after each use, and the one to be flight hardware is never functionally tested. These aspects lead to expensive test campaigns.

The mechanism described herein is the result of an internal development programme at SENER. The main objectives of the programme have been to obtain a low cost, general purpose complete hold-down and release system, with high load capability, negligible induced shocks, reusable many cycles after a simple reset without need of consumables.

2. DESIGN REQUIREMENTS

The NEHRA has been designed with the following requirements:

- High load capability
  - M8 high strength bolt
  - Preload: 20 000 N ±10%
  - Yield load: 40 000 N
  - Ultimate load: 43 000 N
- Activation
  - Electrical current
  - Compatible with pyro power sources/ heater lines
  - Electrically redundant
  - Activation time about 1 sec
- Actuation
  - Negligible induced shocks
  - Non-explosive actuation.
  - Smooth bolt preload release
  - Actuation time about 10 msec
- Resettable
  - Manually in seconds after activation
  - No consumables
- Number of operations without maintenance > 50
- Hold-down compact design
- Low cost
- Mass < 400 grams
- Maximum power consumption: ≤ 20 W
- Temperature range (qualification):
  - Pre-operational: from –50 ºC to +75 ºC
  - Operational: from –40 ºC to +75 ºC
- Sine qualification level:

In any orthogonal axis [2 oct/min]	
5–20 Hz	11 mm (0-p)
20-100 Hz	20 g

- Random qualification level:

In any orthogonal axis [2.5 min]	
20–100 Hz	+ 10 dB/oct
100–200 Hz	2.49 g^2/Hz
200–2000 Hz	- 16 dB/oct
Overall Level	20.52 g_{RMS} (61.58 g 3σ)

3. DESIN CONCEPT

The proposed hold-down and release mechanism is based in the separation of a segmented nut.

A new system has been developed to accomplish the two required functions: maintain the segments in position for hold-down and displace the segments radially (at least the pitch of the nut thread) for the release.

The system is based on the diameter difference of an helical torsion spring between its released and loaded configurations. The spring should be designed to withstand the radial load induced by the bolt preload and the required diameter change. One of the spring ends should be fixed to the housing, and the other should be connected to a trigger system. The trigger is actuated by a Shape Memory Alloy wire.

4. DESIGN AND PERFORMANCES

The mechanism provides a segmented nut for a high strength M8x1 bolt. The structures to be separated can be easily clamped by this system with a nominal preload of 20 000 N.

An helical torsion spring is placed around the segmented nut. This spring has one leg fixed to the mechanism housing and the other one is fixed to a rotation wheel (see Figure 1).

The spring is hand preloaded by rotation of the wheel 180 degrees, reducing its diameter about 2.8 mm. In this configuration the spring geometrically restrain the nut segments and the nut is closed.

The spring is maintained in the loaded configuration by a latch mechanism acting on the rotation wheel.

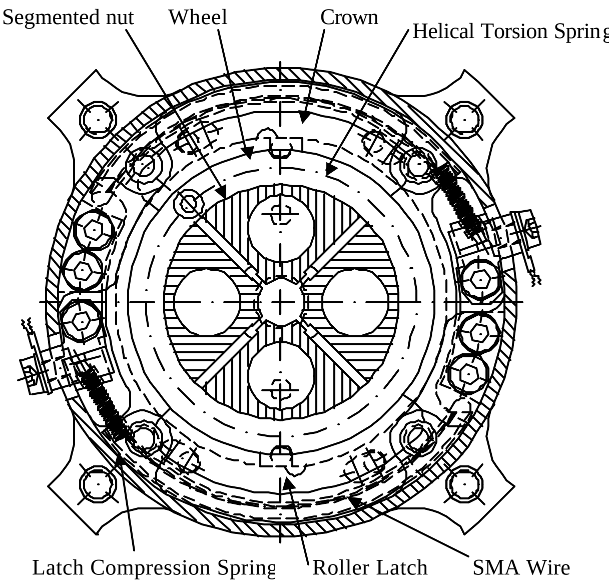

Figure 1. NEHRA. Main Parts

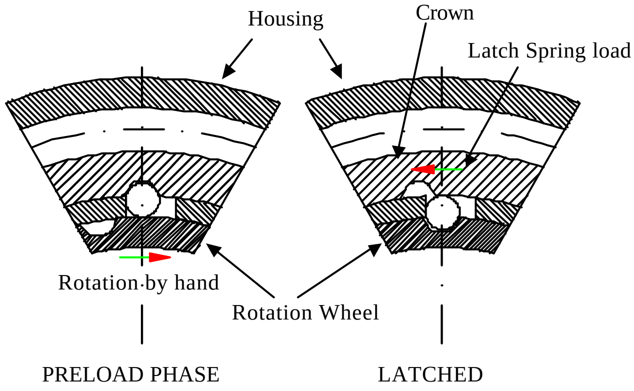

Figure 2. NEHRA Latching Mechanism

The latch mechanism is based on two rollers that block the rotation wheel. During the torsion spring preload the rollers are continuously pushed against the wheel, by a crown powered with a couple of compression springs. When the torsion spring is preloaded 180º, the rollers engage in the wheel and become blocked by the crown. In this stage the latch only can be released by the displacement of the crown against the latch compression springs (see Figure 2).

When the nut is closed and the bolt is preloaded, the spring coils support the radial load generated in the nut segments.

The trigger operation for the bolt release is performed by the actuation of a SMA wire. This activation of the NEHRA is fully redundant, as it is provided with two Shape Memory Alloy wires electrically connected to completely different electrical circuits. Any of them is able to trigger the bolt release.

Each SMA wire has their tips fixed to insulated contacts at the housing. The wire is disposed in a loop over a crown and is slightly preloaded to avoid any lose of the wire actuation stroke. This preload is given by the latch compression spring that actuates between the housing and the crown.

The Shape Memory Alloy wires have a diameter of 0.38 mm and a length of 151 mm. When the SMA wire is heated up above 90ºC by electrical current, the wire contracts about 3.5% of its length rotating the crown and releasing the latch.

The wire can provide up to 40 N force over the crown, with a 2.6 mm stroke, to overcome the latch compression spring and the friction of the trigger system.

The trigger activation is compatible with heater electrical lines, pyro activation lines, etc (the only difference would be the activation time). It can operate in a range between 1.5 and 5 Amperes. The activation time is about 1 sec for intensity currents of 2.75 Amperes in air.

Once the crown has been displaced the rollers are pushed out of the wheel notch by the 0.8 Nm torque that the helical torsion spring provides.

Being the latch released, the helical torsion spring returns to its unloaded configuration, rotating the wheel 180 deg and increasing 2.8 mm its diameter. This actuation takes about 20 milliseconds.

The segments of the nut are displaced as the spring diameter increase. This radial displacement implies also a lose of preload on the bolt, as the segments are disposed in an inclined plane, allowing a smooth bolt preload release. The bolt preload release time measured in the functional test has been 10 milliseconds.

As a result the mechanism induced shock is minimized in the two shock sources: the actuation is non explosive, and the bolt stress is smoothly released.

The proposed hold down actuator is fully reusable during all test campaign. It is provided with a very easy reset without changing any piece of the item. So, there is no need of consumables purchasing. The resetting consists on to preload the helical torsion spring up to the latch up position, and it can be manually performed. For that purpose the rotating wheel provides two holes for a dedicated wrench (see Figure 5)

Even, the NEHRA housing can be used as Hold-Down Structure, if the specific application allows it, saving mass and adding compactness. The NEHRA could include for a proper separation performance a VESPEL spherical pad between NEHRA M8 structure and the piece attached to the deployable appendage. This last piece would be provided with a spherical shape in the contact surface with the VESPEL pad.

Present available NEHRA envelope is ∅ 70 mm x 38 mm height, having a mass of 400 gr. Future enhancements can reduce its mass up to about 280 gr.

Complementing the NEHRA, a bolt catcher is available. A spring is disposed below the bolt head in order to remove the bolt from the separation area. Additionally, this spring maintains the bolt against a cap once the NEHRA has been activated and the bolt release has been performed (see Figure 4).

5. TEST

The NEHRA test campaign includes the following activities:

- Functional Test at Ambient:
  - Friction Measurement of movable parts
  - Measurement of spring characteristics
  - Preload application
  - Trigger function, activation time
  - Preload release function, load release time
  - Helical spring deployment angle versus time

Figure 3. NEHRA. Development Model

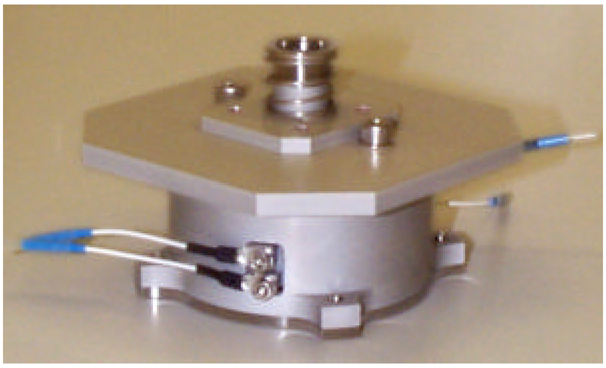

Figure 4. NEHRA. M8 Bolt and Ejection Spring

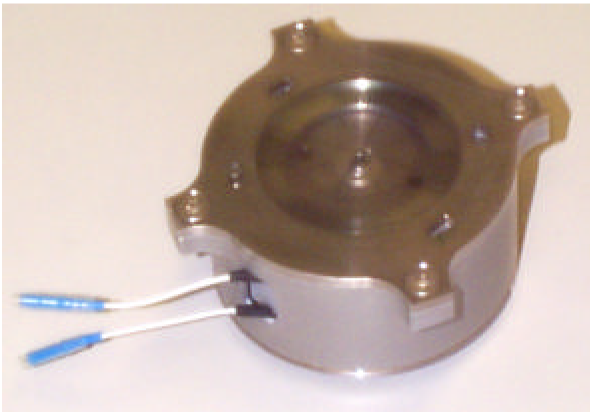

Figure 5. NEHRA. View of the Rotation Wheel.

- Functional Test in Thermal Vacuum conditions:
  - Non Operating Cycle. Environment Survival
  - Operation at Cold Condition (-40ºC)
- Sine and Random vibrations. Induced shock measurement
- Thermal Vacuum Cycling with functional test at Hot and Cold operating conditions.

Functional Test at Ambient

Functional test was performed successfully. All NEHRA actuators, Shape Memory Alloy wire, Latch Springs, and Helical Torsion Spring have demonstrated adequate torque/force margins with respect to the resistive sources.

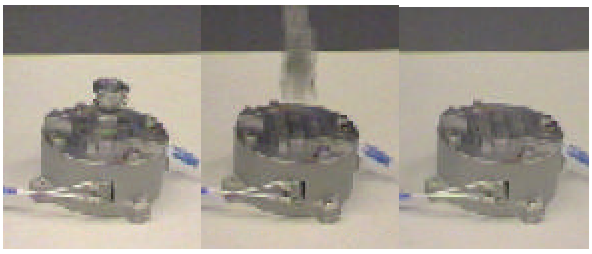

Figure 6. Functional Test. Video Sequence

The following figures show some of the most significant results of the functional test performed.

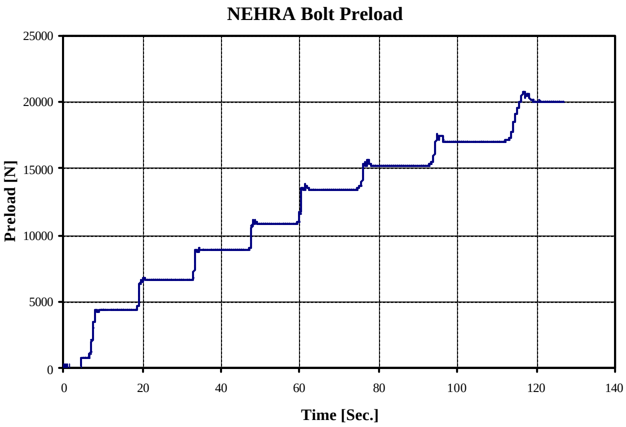

Figure 7. Bolt Preload up to 20 000 N

A M8x1 high strength bolt have been preloaded on the NEHRA Development Model. No lose of preload have been detect.

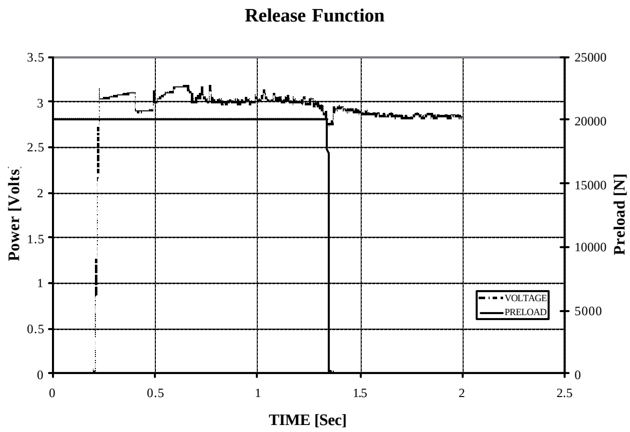

Figure 8. Release Function

Figure 8 shows the activation time required for the trigger function performed by the SMA wire from the power switch on to the release function. This is about 1 sec at 2.75 Amperes in air.

Figure 9 shows the typical wheel deployment function time (spring unwind). The spring is fully unloaded in about 20 milliseconds.

Figure 10 is a detail of the preload release. The bolt preload is released in about 10 milliseconds.

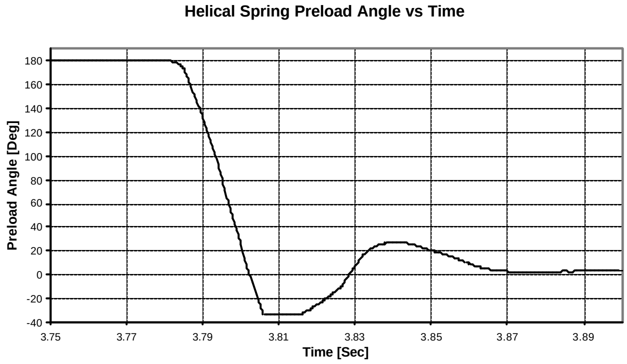

Figure 9. Wheel Rotation Angle at Release

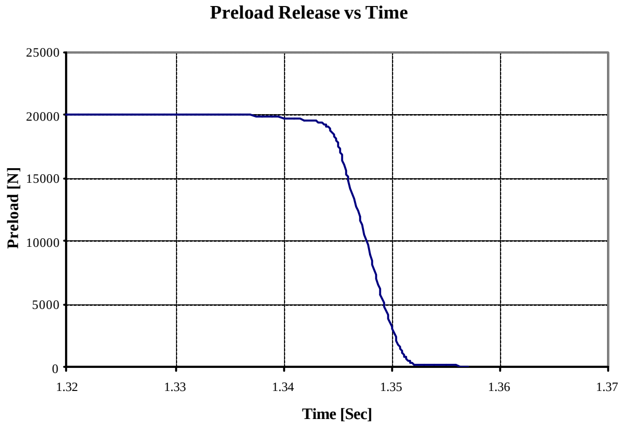

Figure 10. Bolt Load Release.

Really this release mechanism provides much less shock than pyrotechnics as it takes about 10 milliseconds to perform the release of the bolt, against the < 0.2 milliseconds of a pyrotechnics.

Even more, as the release of the preload is based on the progressive release of the coils of the spring, it provides less shock that other non pyrotechnic release devices that release in ≈1 millisecond.

As per Figure 11 the shock torque induced by the helical torsion spring during the release, measured at NEHRA interface is below 1 Nm.

Functional Test at Thermal Vacuum Cold Conditions

The mechanism has been tested in thermal vacuum conditions $p < 10^{-5}$ mbar demonstrating survival to the maximum non operating temperature of 75ºC and successful performance at –43ºC.

Furthermore, after 8 cycles in thermal vacuum between –50ºC and +85ºC the mechanism has been successfully operated in ambient.

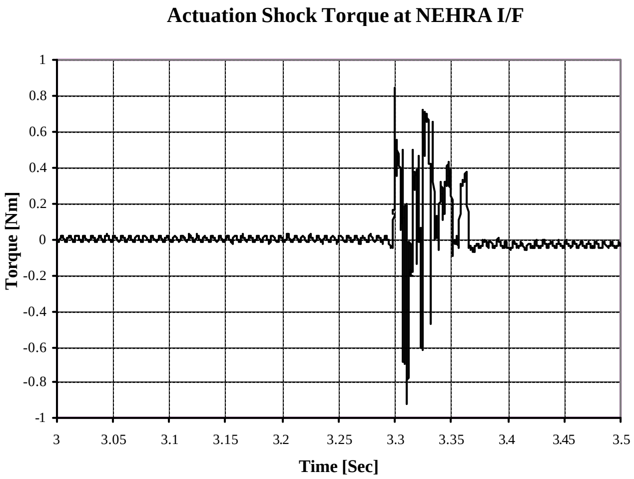

Figure 11. Actuation Shock Torque

6. COMPARISON WITH OTHER HRM

Up to now, the most extended hold-down and release mechanisms used in space have been based in pyrotechnics. Although significant improvements have been performed to mitigate the induced shock, these devices still produce high accelerations at high frequencies that can be extremely dangerous for the integrity of delicate equipment. These accelerations have two main causes. The first one is the explosion itself; the second is the sudden deformation energy released by the hold down preloaded parts. Pyrotechnic systems are not reusable and have an intrinsic risk during their manipulation, storage or operation. Pyrotechnic systems have not the capacity of being functionally tested before flight, and to achieve a confidence in their operation, statistical data or test by lot on randomly selected units is necessary.

An alternative to pyrotechnic systems is the use of motorised hold down and release mechanisms. Those mechanisms are usually complex, heavy and costly.

Mechanisms with a fusible wire, based on providing the sufficient heating energy to a wire that maintains the mechanism preload up to fuse it (or at least weaken it up to rupture), requires to substitute the fuse.

Paraffin actuators are voluminous, and very slow in their performance, with high energy consumption.

Mechanisms with a shape memory alloy piece acting directly in the release by breaking the joining bolt or by changing the geometry of the element maintaining the joint, require a big amount of energy. If the system is based on the rupture of a piece it can originate particles that could endanger the operation of delicate equipment.

Thermal Knifes can release the load smoothly with negligible shock, but their load capability is quite limited, require consumables, a significant actuation time and energy, and the hold-down preload shall be verified carefully.

Other non explosive hold down and release mechanisms based on mechanical nut separation, perform the release of the segments quite fast (in about 1 millisecond). This fast action induces a release shock that might be not acceptable in some applications.

The objective of the proposed mechanism is to solve the problems of pyrotechnic devices and the inconveniences of the existing non-explosive actuators fulfilling the following characteristics:

- Non pyrotechnic device (no explosion)
- High load capability, with easy preloading operation.
- Progressive release
- Conceptual simplicity and easy operational handling to provide high reliability
- Reusable without any consumable
- Easy rearming, assembled and electrically connected
- Redundant activation system based in redundant electrical circuit
- Compatible with mechanism manual activation
- Non safety critical
- Using non life limited components
- Cost effective

7. CONCLUSION

NEHRA concept is based on the diameter difference of an helical torsion spring between its unloaded and loaded configurations.

This concept applied to a segmented nut has the additional advantage of a smooth preload release.

The mechanism is triggered by a SMA actuation, requiring an acceptable amount of energy. The SMA can be chosen according to the thermal range required by the application. The activation time can be adjusted by the intensity current of the power line.

NEHRA is a good and economic substitute to pyrotechnics as it is very adequate for those applications where low shock appendage release is mandatory. Even more the mechanism can be used as the proper hold-down structure.

The results obtained from the tests show that this mechanism is a promising Hold Down and Release Actuator.