FAST ACTING NON-PYROTECHNIC 10kN SEPARATION NUT

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ABSTRACT

A release mechanism based on a segmented nut and a Shape Memory Alloy (SMA) wire trigger was designed and qualified based on general requirements for the Teledesic program. Basic design issues and a description of the device are presented. Highlights of test results and typical operational response of the device are discussed.

1. INTRODUCTION

Separation nuts are a standard method used to release spacecraft deployable components. The segmented-nut design is simple, straightforward, and relatively easy to use. The nut segments are held together for retention of a bolt and then allowed to release through a mechanical action that is triggered on command. Assembly of the interface is relatively easy: the bolt is threaded into the enclosed nut and tightened to the proper preload. Release is achieved by providing an electrical signal to initiate the mechanical release action.

Typically separation nuts are released through the action of gas generated through detonation of a pyrotechnic charge. The safe and effective use of a pyrotechnic mechanism is based on some very strict handling protocol.

Another characteristic of a pyrotechnic device, possibly having a greater impact on mission success, is the shock generated during operation. With today's current trend toward smaller spacecraft, sensitive instruments must be located closer to release mechanisms on smaller lighter structures. These instruments must be able to withstand the shock created during release events prior to fulfillment of their spacecraft mission. Striving for shock survivability near a pyrotechnic device can create significant impacts on instrument design and testing.

Once fired, a pyrotechnic charge cannot be re-used. Because the pyrotechnic charge must be replaced after each use, there are issues with replacement of components after testing of a system has been completed. A new, un-tested component, as well as de-mating and mating of the electrical connectors, can lead to reliability issues.

The above issues create difficulties in designing and operating spacecraft. Often increased mass and increased costs are result.

The device described in this paper, the Starsys Research Qwknut 2000, is aimed at maintaining the ease of use of a separation nut while solving several of the inconvenient problems associated with traditional separation nuts. Several of the important design features are:

- Typical separation nut ease-of-use
- Pyro-pulse compatibility (electrical initiation signal)
- No pyro shock
- Resettability / reusability
- High reliability mechanism

2. OPERATIONAL ISSUES

2.1 Fast Operation

Several separation nuts are often used together in a hold down/release system. In many cases simultaneous release of each point is required to release components at the same time. In these cases a separation nut must release very quickly; typical release times required are between .01 and .05 seconds.

2.2 Pyro-pulse Operation

Most spacecraft and launch vehicles are equipped with electronics capable of firing a pyrotechnic device. To minimize impacts to control electronics the non-pyrotechnic device should utilize a similar initiation signal. A typical pulse is 3 to 5 Amperes for a duration of approximately .05 sec.

2.3 Low Shock

A key issue for the device is that it not create a large shock during release. A very distinct requirement was that the device must not be based on a pyrotechnic charge for release.

2.4 Re-useability

To maximize the effectiveness, simplicity, and reliability of the device, resettability or re-useability are important. In-situ reset means that no components are replaced and no electrical connections are broken. Both of these improvements allow for repeated testing of flight components and eliminate the risks associated with assembly and disassembly of flight hardware.

2.5 Safety

The device must be safe for operation. Operators and hardware should not be at risk during handling, storage, or operation of the device. The device should not be susceptible to random operation based on stray electrical signals such as electro-static discharge (ESD) or electromagnetic interference (EMI). If the device is not based on an explosive charge, the safety and handling of explosives is not required.

3. DESIGN ISSUES

The basic design problem was to create a device that could utilize a very low energy signal to release a relatively large load of 10kN while addressing the above issues. The overall device comprised several basic components:

- The “prime mover” which converts electrical energy to mechanical
- The mechanical components that provide the force reduction from the 10kN load down to the low-energy/low-force release trigger.
- The release elements consisting of nut segments and bolt.
- The latching elements

3.1 Prime Mover

Several fast acting, re-useable components can be (and have been) used to convert electrical energy to mechanical work. Among these are piezo-electric components, motors, solenoids, and shape memory alloy (SMA) components. Of these components SMA in the form of wire has the best combination of features for this type of device. For this design a wire .2 mm in diameter and 50 mm long was chosen. This yielded a force of 7.3 Newtons over a distance of 1.5 mm.

3.2 Force Reduction / Release Elements.

This device utilizes a roller-bearing type geometry to achieve force reduction and to maximize mechanical efficiency. When the tensile preload is applied to the bolt, the threads react against the nut segments in the release device. The contact angle of the threads creates both radial and axial loads against the segments. The axial loads are reacted into the base plate of the mechanism and into the spacecraft structure. In the latched position the redial loads are reacted into the rollers and into the notched outer race. In this position, all loads are carried through the structure and do not act through the SMA wire. Rotation of the race allows the rollers to drop into the notches. The radial load path is no longer intact and the nut segments are free to move outward. Figure 1 shows the basic configuration of the segments, the rollers, and the outer race. A roller retainer (not shown) maintains the roller spacing

In addition to providing the low friction of rollers, another advantage of the roller geometry is the effective “force reduction” that it creates. The force reduction is achieved through the effective coefficient of friction in the roller bearing. For a preload of 10,000 Newtons, the net radial load is 722 N per roller. With an effective coefficient of friction of .016, the net force to move each roller is 11.5 N. At a race radius of 12.5 mm (.0125 m) the total torque to rotate the race is 1.2 N-m. Actual measurements of this resisting torque show that approximately 0.6 N-m are required to rotate the outer race with a 10,000 N preload.

3.3 Latch Elements

While the torque to release the mechanism has been reduced to a relatively low level, it still is not low enough to rotate directly using the SMA wire. Rather than attempt to drive the release directly with the SMA wire, the approach of using the SMA to trigger a self-driving release latch is used.

The outer race is biased toward the open position using springs, and a latch is incorporated to retain the outer race in the closed position until the SMA is triggered. The latch consists primarily of two toggles, a latch arm, and two notches in the flywheel. The toggles are mounted in two pockets on opposite sides of the mechanism housing that allow the toggles to rotate. When in the latched position, the notches in the flywheel align with the toggles. The latch arm is aligned to capture and hold the toggles inward to engage with the notches. In this position the rotational load from the springs is converted to a radial load through the toggles and a tangential load into the mechanism housing. The load reduction in this stage occurs through the reaction angles of the toggles and the effective coefficient of friction between the toggles and the latch arm. Friction at this interface is controlled through a hard coating with an impregnated, dry-film lubricant. A spring retains the latch arm in the latched position prior to triggering. The total torque required to rotate the latch arm and initiate release is approx. 0.1 N-m.

Release of the mechanism consists of rotating the latch arm with the SMA trigger wires until the toggles are no longer constrained radially. Once the latch arm has rotated clear, the toggles move outward and the outer race rotates toward the released position as described above. Figure 2 shows a cross section showing the basic latch components.

4. OVERALL DESIGN FEATURES

Figure 3 is a photograph of the Qwknut and the bolt retractor/catcher in the configuration that has been qualified.

The mechanism release side consists of:

- SMA wire triggers – the mechanism is triggered by redundant SMA wires as described above
- Rotary release latch – The triggers rotate the latch arm to initiate outer race rotation
- The outer race/segmented nut assembly described above
- Automatic shutoff – ground test switches automatically shut off current to the SMA wires upon release
- Reset features – all latch components are reset by manually rotating the outer race back to its latched position

The bolt retractor/catcher consists of:

- Housing – the housing retains the bolt once released
- Load cell – a load cell is included in the retractor side to accurately set the preload
- Retractor spring – a spring assures the bolt is retracted clear of the release mechanism housing

5. TEST RESULT SUMMARY

During the development and qualification of the release mechanism, a large number of functional and environmental tests were performed. A qualification test series was performed consisting of typical spacecraft environmental tests and interspersed functional tests to monitor performance. During development testing similar environmental tests were performed along with a number of tests to assess mechanism performance and verify forces and margins within the mechanism. While presentation and discussion of all of the development and qualification test results are beyond the scope of this paper, significant results that relate to the basic operational capabilities follow.

5.1 Typical Operational Response

Figure 4 is an example of data from a typical room temperature operation. The two data traces represent the axial preload (measured by a load cell) and the current applied to the SMA wire. Nominal preload during qualification tests was 13,350 N. The tests were performed at constant voltage with the initial current set at 3.5 Amps.

Several distinct features characterize the current trace. It starts out at a value dictated by the wire resistance and applied voltage (3.5 Amps, nominal). As the wire heats the resistance increases, causing the current to drop. The wire begins to transform to its high temperature phase, the resistance drops (the higher temperature phase has lower resistivity) and the current can be seen to rise. When the outer race has rotated far enough for release, two in-line switches cut power to the wire. Full rotation corresponds to the point at which the load in the bolt and the current both drop to zero, as seen in both traces.

5.2 Temperature Effects

The phase change in the SMA wire is a thermal process. The time to function is, therefore, dependent on the environmental start temperature and the power input to the wire. Figure 5 shows a family of typical response time curves developed from thermal test results. Because the speed of the heating is so high and losses low (through the ends of the wire), there is little difference between vacuum test results and air test results. The shape and spacing of the curves emphasize the relationship between power, environmental temperature, and release time.

The temperature range represented in this figure represents the currently qualified temperatures. The temperatures chosen for this series of tests were based on general requirements and are relatively conservative. The current range does not represent the full capability of the design, and minor design revisions could allow for a greater operational temperature range of –65°C to +90°.

5.3 Shock

The device is not based on an explosive charge, so the shock associated with detonation is not present. As with any high force release device, the release of the strain energy from the preload must be considered. In several tests instrumented with accelerometers, the maximum shock measured in an aluminum fixture near the device was 60 g.

6. CONCLUSIONS

The Qwknut reliably achieves the desired operational goals:

- Separation nut ease-of-use
- Non-pyrotechnic operation
- Pyro-pulse compatible
- High-speed release
- Resettable
- Safe handling and operation

7. FLIGHT HISTORY

The Qwknut is scheduled to fly as the primary release device for a small spacecraft, Falconsat, in September, 1999.

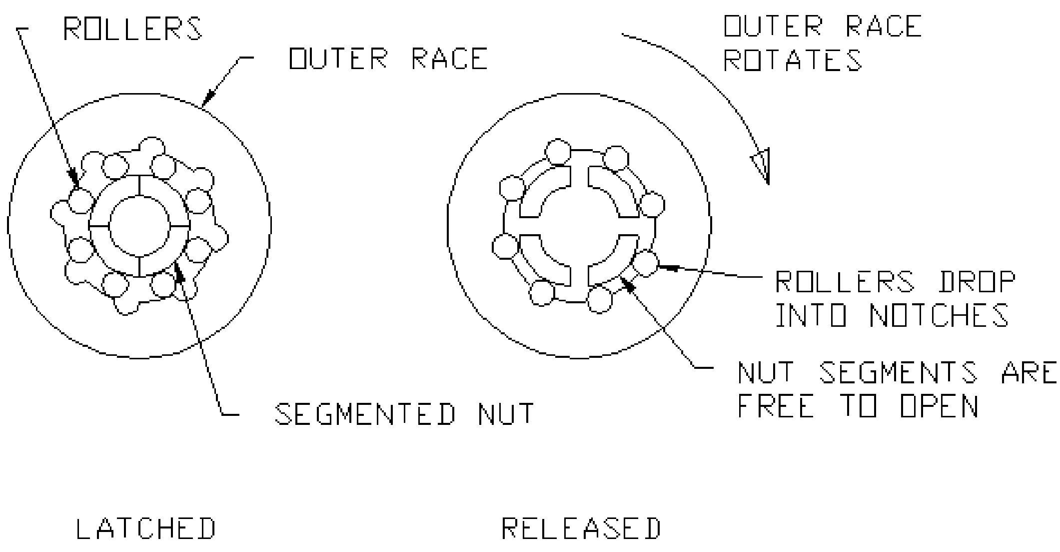

Figure 1. Flywheel, roller, and segmented nut operation.

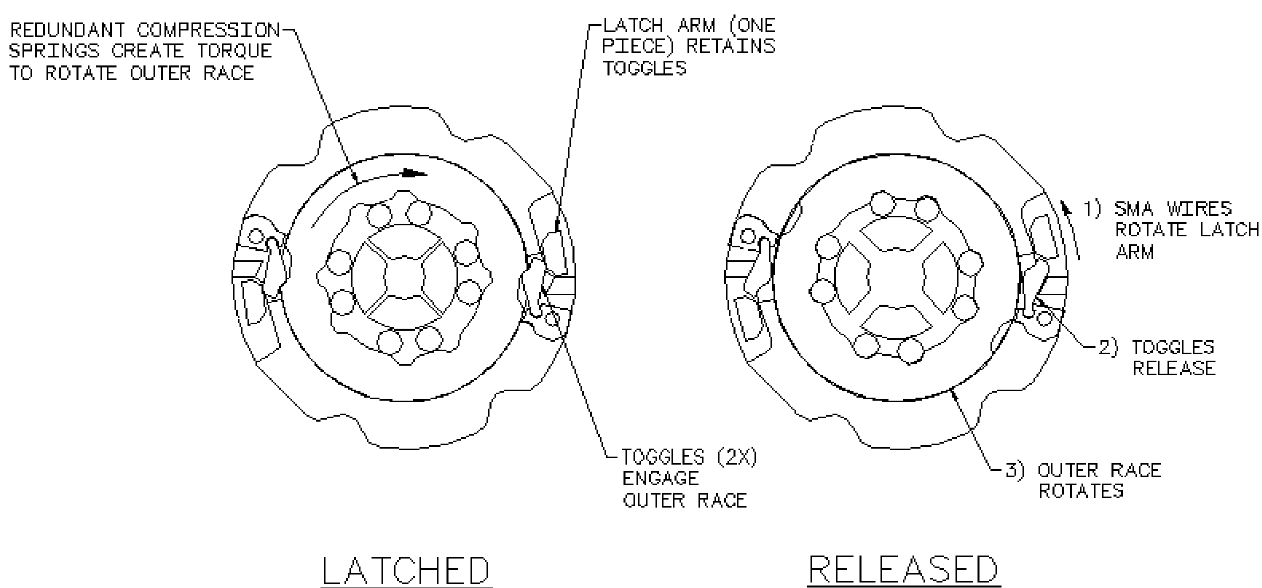

Figure 2. Latch geometry and operation.

Figure 3. Photograph of the Qwknut (on left) and bolt retractor (on right) attached to test fixture

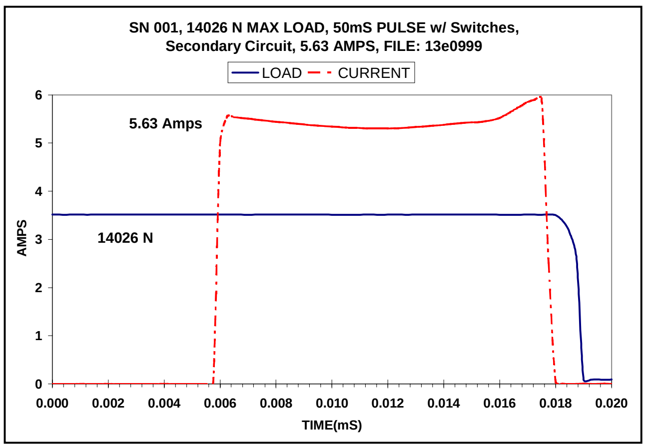

Figure 4. Typical functional response. A current pulse is applied to the wire. Release is indicated by the bolt load decreasing to zero.

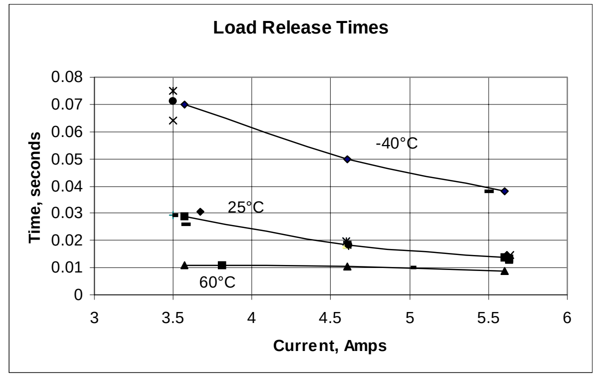

Figure 5. Three sets of release time data for three temperatues. The times correspond to the time between current start and load release. The curves represent averages of actual data.