Non-Pyrotechnic Multi-Point Release Mechanisms for Spacecraft Release

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Abstract

The Non-Explosive Actuator (NEA) is an electrically initiated Hold-Down Release Mechanism (HDRM) that has the ability to carry a very high tensile preload until commanded to release, with the additional advantage of very low output shock. The NEA has been used for many different spacecraft hold-down applications over the years, but has had limited use as a payload release mechanism due to the limited data regarding its simultaneity capability. The objective of this paper is to expand on this simultaneity database by describing and summarizing Phase I of the NEA Multi-Point Separation Testing that shows that the variation in NEA actuation time can meet certain simultaneity requirements necessary for spacecraft payload separation. The data collected shows NEA's can meet simultaneity requirements of less than 5 ms.

Introduction

NEA Electronics manufactures both pyrotechnic and non-pyrotechnic release mechanisms. NEA Electronics was recently involved in several opportunities that required the release of multiple spacecraft using the multi-point hold down method. All the opportunities pursued elected to use our pyrotechnic separation nuts instead of our low-shock Non-Explosive Actuator (NEA). At the time, the reason stated by potential users for selecting the pyrotechnic device technology over the NEA centered on concerns with the lack of simultaneity data between multiple NEA's used in a time-critical application.

Pyrotechnic devices have been widely used for payload separation in the past, but with the increased need for low-shock mechanisms, especially with smaller constellation payloads, this simultaneity data for NEA release mechanisms will prove very useful to the aerospace mechanism community for alternative low-shock design solutions. This paper is an expansion of the data collected and presented in a poster presentation for ESMATS 2017.

Background

Before diving into the testing, it is best to understand the basics of the NEA design, as well as the details of what constitutes NEA actuation time, including the primary factors that affect the actuation time.

The NEA HDRM is an electrically initiated, one-shot release mechanism that has the ability to carry a very high tensile preload until commanded to release. The preload is applied through a release rod held in place by two separable spool halves which are in turn held together by a tightly wound restraining wire. The restraint wire is held in place by redundant electrical fuse wires; actuation of either circuit allows release, assuring maximum reliability. When sufficient electrical current is applied, the restraint wire unwinds allowing the spool halves to separate, releasing the release rod and the associated preload.

The NEA actuation time is the time from application of current to the start of the release rod exiting from the NEA (i.e., preload drop to zero). This actuation time can be split into two (2) independent segments per Figure 1.

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1) Fuse Wire Burnout time (FWBO): This is the time from application of current to fuse wire burnout. This time is primarily dependent on input current – the higher the input current, the faster the fuse wire burn time.
2) Preload Drop time: Time from fuse wire burnout to when the restraining wire uncoils sufficiently to drop the system preload to zero and allow the release rod to start exiting the NEA.

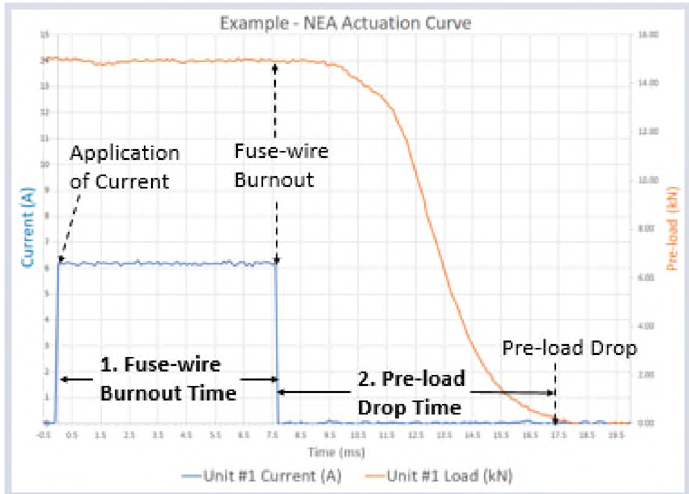

Figure 1. Example of Typical NEA Actuation Time Curve

There were two distinct series of testing performed as part of Phase 1 of the NEA Multi-point Separation Testing. Series I consisted of testing with a 4-point release test plate using a break-link to measure actuation time. Series II consisted of testing performed with units actuated individually using a load cell to measure actuation time.

Series I – Four-Point Release Testing

Series I - Test Setup and Plan

Series I testing consisted of two sub-series of tests where preload and firing current were adjusted. Each sub-series test consists of data from each of the 4 NEA's actuated during that test, for a total of 28 data points (see Table 1)

Table 1. Series I Test Plan

		Firing Current	Target Preload
Sub-Series I.1	Test I.1.1	3.0 Amps	11.6 kN (2,600 lbf)
	Test I.1.2	4.5 Amps	11.6 kN (2,600 lbf)
	Test I.1.3	4.5 Amps	11.6 kN (2,600 lbf)
	Test I.1.4	7.0 Amps	11.6 kN (2,600 lbf)
Sub-Series I.2	Test I.2.1	7.0 Amps	17.8 kN (4,000 lbf)
	Test I.2.2	7.0 Amps	17.8 kN (4,000 lbf)
	Test I.2.3	7.0 Amps	17.8 kN (4,000 lbf)
4 actuation data points are collected for each test			

This initial series of tests were conducted using an NEA model SSD9102J, an M6-sized HDRM with an integral 60-degree cup/cone interface and retraction spring. Four NEA's were affixed to the corners of two 610-mm (24-inch) square aluminum plates; each plate being 19-mm (0.75-inch) thick and weighing approximately 177 N (40 lbf). The aluminum plates were suspended in a frame so that the plates were parallel to the ground. Application of the actuation current activates the NEA's and allows the bottom plate to fall and separate from the top plate with gravity providing the separation force (see Figure 2).

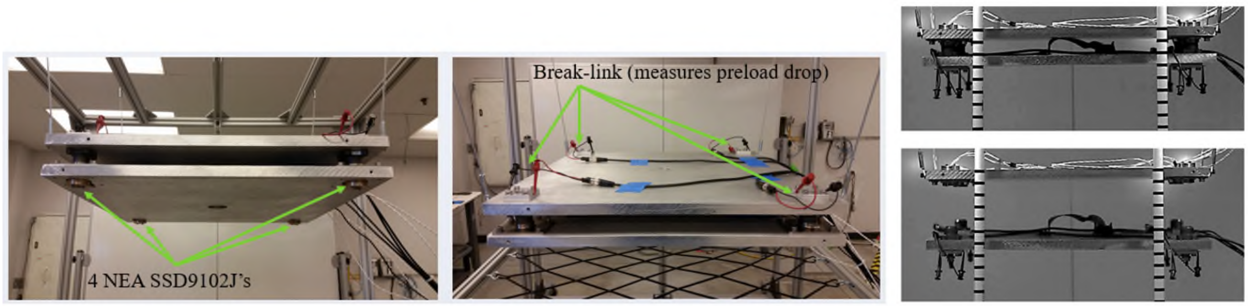

Figure 2. Test Setup

A multi-channel Synergy Data Acquisition System was used to capture Fuse Wire Burnout time and Preload Drop Time. Because load cells could not be installed directly into the NEA assembly for this configuration, a "break link" was used to estimate the Preload Drop Time. This break link consists of a piece of lead fixed in proximity to the release rod exit path – once the preload dropped and the release rod begins to move, it breaks the "break link" and a signal is shown on the data acquisition system.

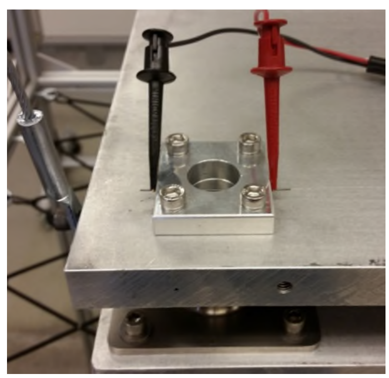

Figure 3. Break Link Setup

<u>Series I - Test Results</u>
Figure 4 and Figure 5 shows that overall actuation time is primarily influenced by the input firing current. As the current increases, the actuation time decreases significantly (Figure 4). It also reveals that preload does not significantly influence actuation time as shown with the significant overlap in individual actuation time data points (Figure 5).

Figure 6 shows that the reason input current is the primary influence on Actuation Time is because of its effect on Fuse Wire Burnout Time – higher input current reduces the magnitude and variation in Fuse Wire Burnout Time. Figure 6 also shows Preload Drop Time is independent of input current.

Figure 7 summarizes the effects of input current to the Simultaneity Range of each test - the range of actuation time for each test between the 4 NEA's was determined and sorted by input current. This data shows the simultaneity between 4 NEA actuated together improves significantly with increasing input current, with a max simultaneity range of 5.1 ms.

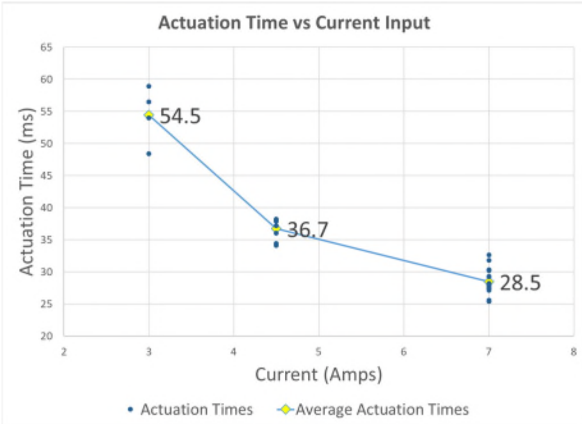

Figure 4. Actuation Time vs Current

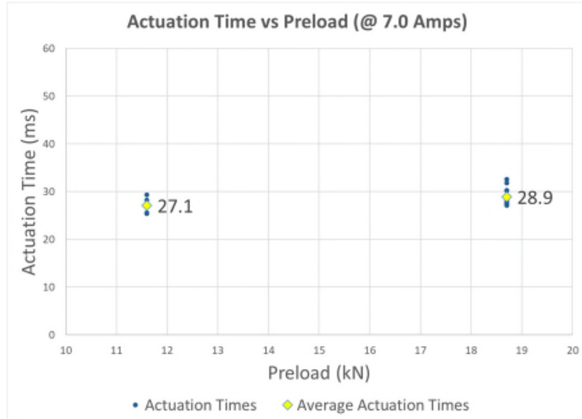

Figure 5. Actuation Time vs Preload

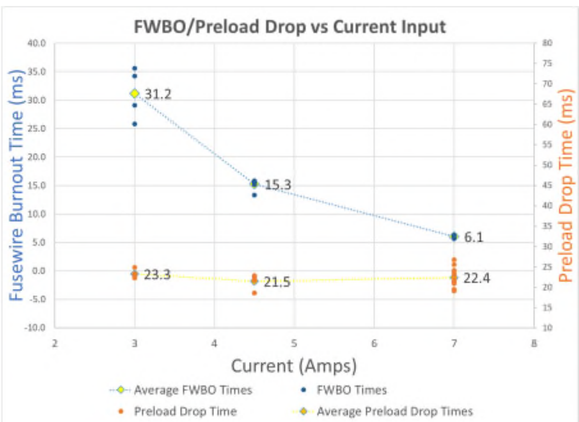

Figure 6. FWBO/Preload Drop vs Current

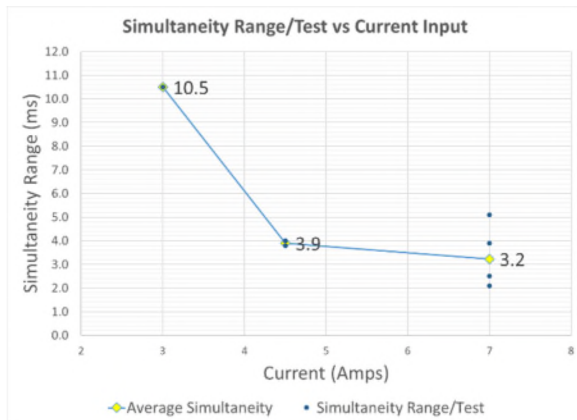

Figure 7. Simultaneity Range/Test vs Current

Series I testing was an excellent start to better understanding the simultaneous capability of our mechanism, but the lack of direct preload data and concern that some of the variance could be caused by the test setup led our team to the next series of testing.

Series II – Individual Release Testing

<u>Series II – Test Setup and Plan</u>

Similar actuation testing parameters were used as in Series I, but the units were tested individually and with a load cell in-line. This allowed us to understand the true preload drop time of the NEA, compare it to the break-link data above, and isolate the internal NEA dynamics from the effects of the 4-point test plate setup. The team also decided to add some additional factors to understand if the units behaved consistently across different assembly operators and over several build lots. Table 2 summarizes the test plan for Series II. Figure 8 provides a schematic of the test setup used.

Table 2. Series II Test Plan

	Firing Current	Preload	Assembly Technician (A or B)
Test II.1	7.0 Amps	11.6 kN (2,600 lbf)	A
Test II.2	7.0 Amps	17.8 kN (4,000 lbf)	A
Test II.3	7.0 Amps	17.8 kN (4,000 lbf)	A
Test II.4	7.0 Amps	17.8 kN (4,000 lbf)	B
Each test series represents a different build lot			
8 actuation data points are collected for each test series above			

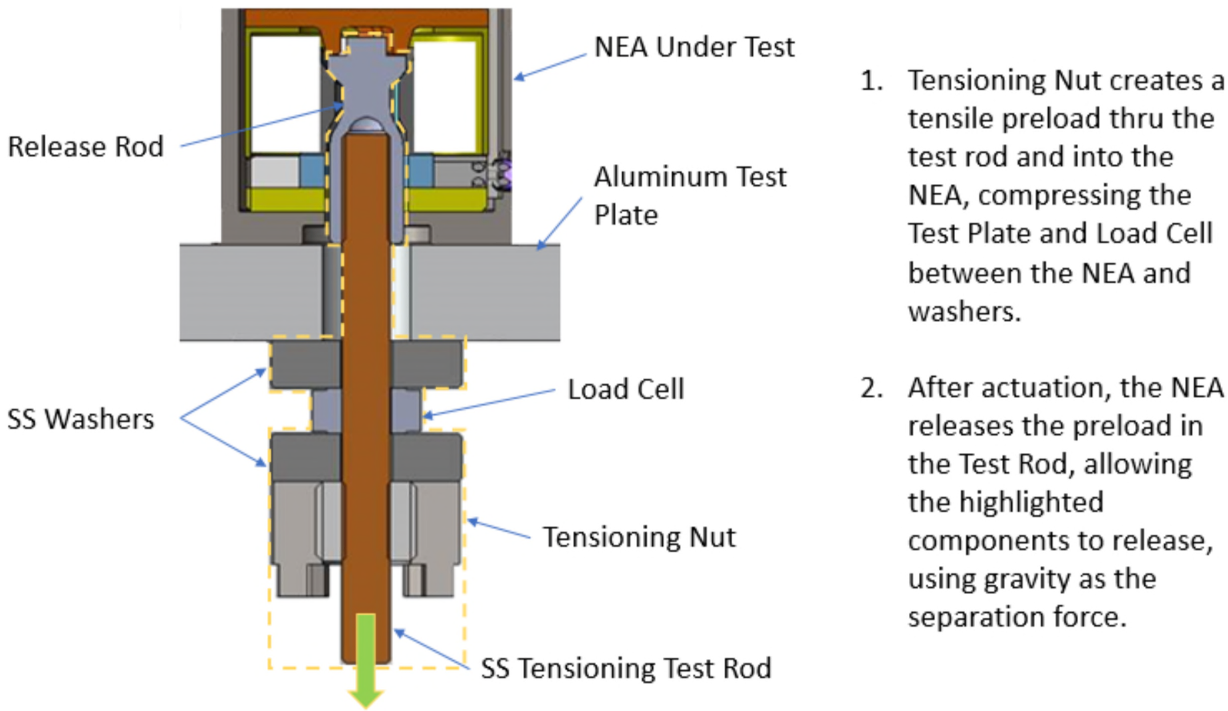

Figure 8 - Series II Test Setup Schematic

<u>Series II - Test Results</u>

All testing under Series II used the same input current since the factors affected by the input current were already understood from Series I testing. Figure 9 shows that the actuation time is still primarily unaffected by the preload, similar to Series I testing.

Comparing the Series I and Series II data, there are a few key insights to highlight. The first is the difference between the break-link signal (Series I) and the preload drop time (Series II) – see Figure 10. On average, the preload drop time was 9.8 ms faster than the break-link signal. This is expected since sufficient movement of the release rod after preload release is required to fracture the break-link assembly. This extra movement, and the act of breaking the lead, adds variation which leads to the second key difference in the data.

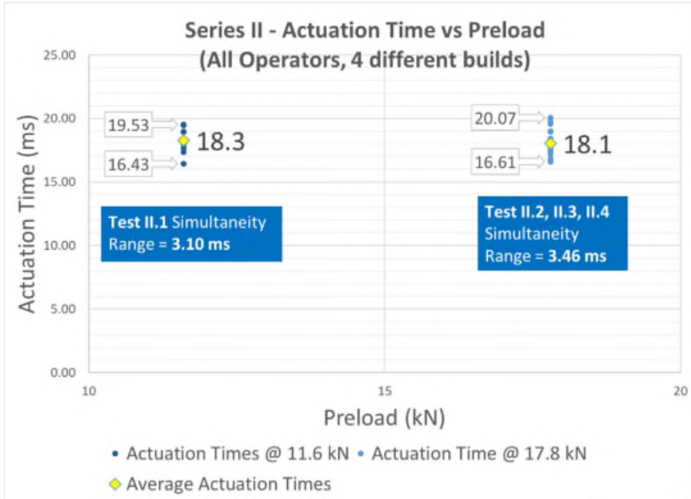

Figure 9. Series II Actuation Time vs Preload

The second significant difference between Series I and II, is the reduction in actuation time variation of 37%, from 5.50 ms to 3.46 ms (Figure 11 shows all data compared at 17.8 kN). This reduction in variation can be attributed to the elimination of variables in the test setup. The test setup in Series II is much more simplified, focusing primarily on the NEA capability itself. Now that the NEA variance in actuation time is understood – which has shown that it can meet a 5-ms simultaneity requirement – the next phase of testing can be centered around building a more flight-like test setup to validate the system.

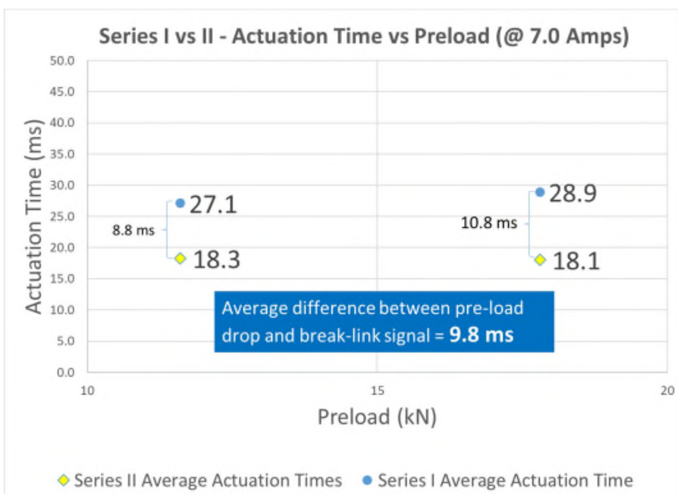

Figure 10. Series I (break-link) vs Series II (load cell) Actuation Time

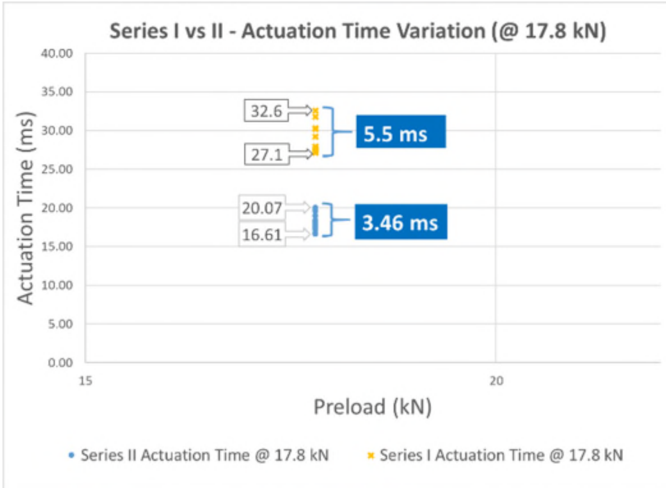

Figure 11. Series I (break-link) vs Series II (load cell) Actuation Time Variation

Conclusions & Lessons Learned

Phase 1 of the NEA Multi-point Separation Testing completed shows the NEA's actuation time capability can meet a simultaneity requirement of 5 ms or less, even across different build lots and different assembly technicians.

Although several lessons were learned during the scope of this testing, the ones of most interest and importance is the dependence of input current on actuation time simultaneity (higher current improves the simultaneity behavior because of reduced fuse wire burn-time variation) and conversely, the independence of preload on simultaneity.

NEA Multi-point Separation Testing Phase 2 has also begun. During this phase, NEA plans to incorporate a more flight-like setup thru cooperation with potential customers, and create a reliable analytical model predicting spacecraft trajectory and tip-off using this empirical data. This data will be ready later this year.