NEA® Mini for Low Load Applications – Development and Qualification

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Abstract

EBAD published a paper in the 2018 AMS proceedings [1] describing the development of the NEA® Mini hold-down and release mechanism (HDRM) for low load applications. This design was born from the popularity of small, inexpensive Nichrome burn wire solutions in the small satellite community, coupled with some associated failures of those devices that revealed the opportunity for a more reliable solution. EBAD adapted our GEO NEA® battery bypass switch into an HDRM for small sat applications, built and tested an initial prototype. These devices have the advantages of being small, light, low power, low shock, and high reliability. The 2018 paper described the series of load and shock output tests that validated the HDRM as a potential product for typical low-load release mechanism applications. This paper describes the further development and qualification of the NEA® Mini HDRM for spacecraft and satellite applications.

Introduction

The NEA® Mini (EBAD part number SSD9040) design is an integration of our design expertise with high-reliability bypass switches and high-load/low-shock release mechanisms. The release mechanism in the bypass switch (Figure 1) is similar in operation to our standard release mechanisms and utilizes the same patented fuse wire technology. This combination resulted in the development of a scaled down version of the HDRM that is less than a cubic inch (16 mL) in volume, yet capable of holding a functional load of at least 1110 N (250 lbf) while producing the same low shock characteristics expected of EBAD's NEA® HDRMs.

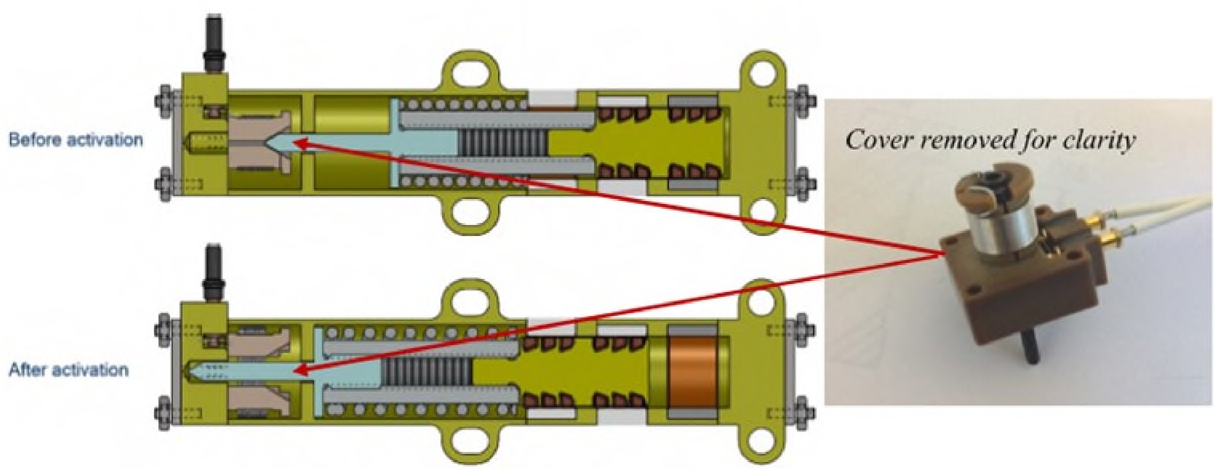

Figure 1. NEA® Switch Components Repurposed for the Mini HDRM

An initial prototype was built with common switch components and a #1 fastener size release rod. This unit was tested for load and shock output characteristics [1] and provided the baseline for further development described in this paper.

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NEA® Mini Design

The design evolved from the initial proof of concept presented at the 2018 AMS to a DVT-level design, then finally to the Qual-level design, with lessons learned at each phase. See Figure 2 for a representation of the DVT and qualification-level designs. The envelope is virtually unchanged between the two.

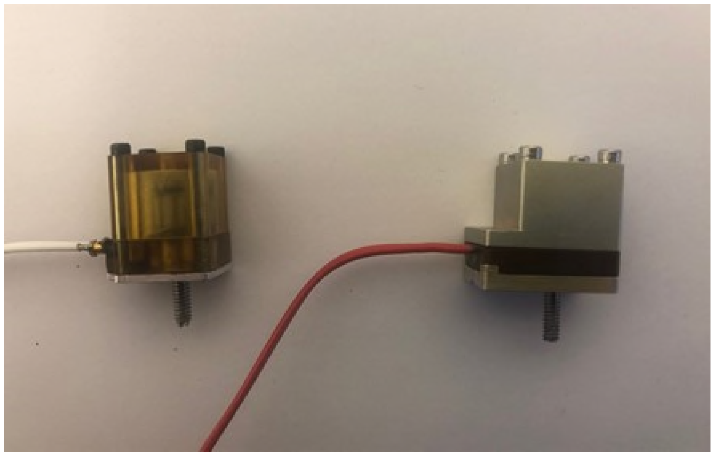

Figure 2. DVT (left) and Qualification NEA® Mini HDRM

At the heart of the Mini design is the split-spool technology used in all EBAD NEA® HDRMs. These HDRMs are electrically initiated, one-shot release mechanisms that have 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 tight winding of restraining wire. The restraining wire is typically held in place by redundant electrical fuse wires, where actuation of either circuit allows release. When sufficient electrical current is applied, the restraining wire unwinds, allowing the spool halves to separate and release the release rod and the associated preload.

Unlike the vast majority of EBAD's NEA® release mechanisms, the Mini has a single actuation circuit (non-redundant) and is not refurbishable. Based on the low price point of the unit, it is just as cost effective to replace the unit than to refurbish it.

Figure 3 shows the unit that was developed for qualification testing and Figure 4 illustrates its interface dimensions. The prototype test results were very promising in terms of load, functionality, and emitted shock. EBAD implemented several changes in the qualification model design that improved its performance. Chief among the design updates was to increase the functional load capacity of the initial prototype from 445 N (100 lbf) to a minimum of 1110 N (250 lbf) by incorporating metal spools, a primary component that holds the load in the device.

To maintain the increased load without yield or creep throughout environments, the unit base was upgraded from plastic to aluminum. Additionally, to increase load margin on the release rod, as well as make the unit easier to assemble and install, the release rod was increased from a #1 size fastener thread to a #4-40.

The change from a #1 size fastener to a #4-40 was based on a lesson learned from various manufacturing issues and prototype tests. The original design utilized a #1 thread in an attempt to machine it from a standard #1 size fastener, in order to reduce cost and lead times. However, this led to various challenges. Both internal and external machine shops had difficulties working with a #1 size thread on high strength material while holding tight tolerances on a relatively long component. It also meant that all test hardware would need to have a corresponding #1 thread, and would need to be made from high strength material, with tight tolerances. We learned in test that small errors in the setup utilizing a #1 thread could lead to significant load drops, or high stress points. Changing to a #4-40 thread eliminated most of these issues. A #4-40 thread was much easier to machine, and since the stress was lower, the material did not have to be as high strength, and tolerances could be loosened. Paying a bit of a premium for custom 4-40 threaded rod led to a reduction in cost of other associated components and much more robust design. It also made the testing process easier, saving additional labor.

Changing the base and spools from plastic to aluminum created a potential ground path between the actuation circuit wires and the unit housing through these and other metal components in the assembly. To address this concern, the bases and the spools are coated with high dielectric space-qualified coatings. The coatings provide a measured insulation resistance consistently above 50 MΩ.

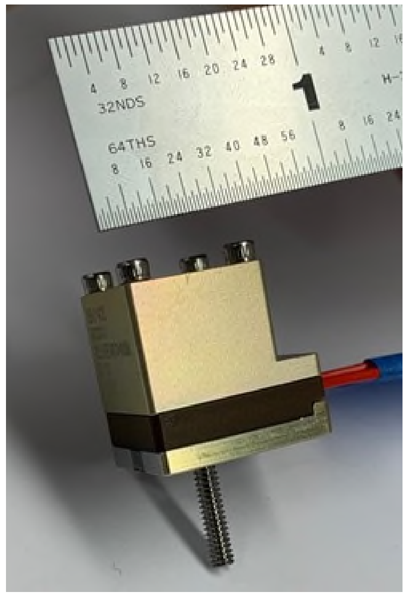

Figure 3. Qualification-level Mini HDRM

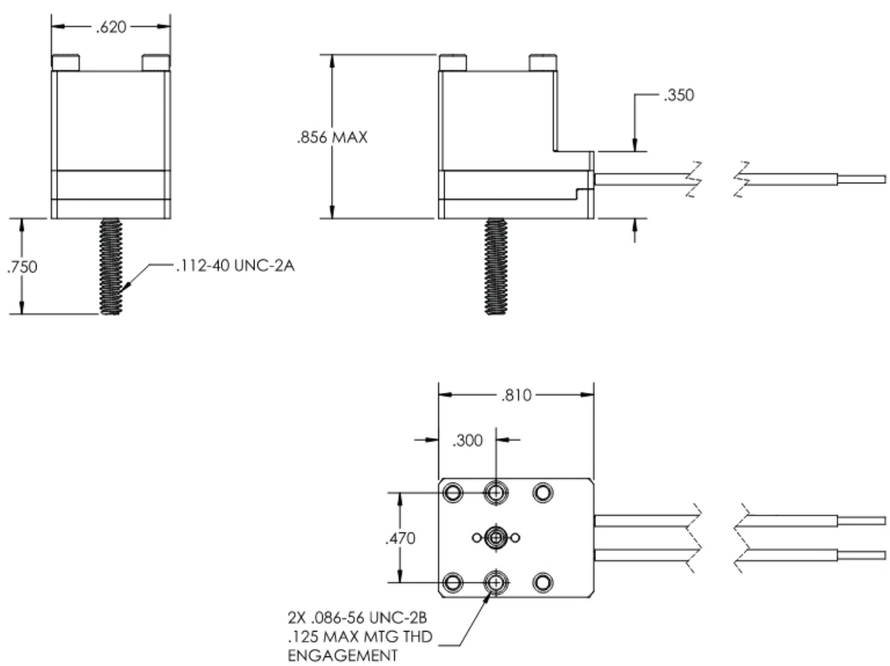

Figure 4. Mini HDRM Interface dimensions

NEA® Mini Testing

The DVT and Qualification test sequence is shown in Table 1. This sequence is common for NEA® HDRMs of all sizes. The DVT phase of testing was completed in 2021 and internal Qualification testing was performed in 1Q2022. The test levels selected were based on worst-case intended use cases and parameters previously used for similar NEA® HDRMs of larger size but similar material components.

Table 1. Mini Qualification Test Sequence.

Sequence	Test Type	Unit 1	Unit 2	Unit 3	Unit 4
1	Visual & Dimensional Inspection	X	X	X	X
2	Mass Evaluation	X	X	X	X
3	Circuit Resistance	X	X	X	X
4	Dielectric Strength	X	X	X	X
5	Insulation Resistance	X	X	X	X
6	Proof Load	X	X	X	X
7	Preload	X	X	X	X
8	Functional Test	X	X	X	X
9	Unit Rebuild	X	X	X	X
10	Circuit Resistance	X	X	X	X
11	Dielectric Strength	X	X	X	X
12	Insulation Resistance	X	X	X	X
13	No-Fire Testing	X	X	X	X
14	Proof Load	X	X	X	X
15	Circuit Resistance	X	X	X	X
16	Preload for Environments	X	X	X	X
17	Random Vibration	X	X	X	X
18	Input Shock	X	X	X	X
19	Thermal Cycling	X	X	X	X
20	Functional Testing - Cold	---	---	X	---
21	Functional Testing - Hot	---	---	---	X
22	Output Shock	X	X	---	---

<u>Initial Tests</u>

Test sequence numbers 1 through 6 are intended to confirm compliance to design requirements and workmanship standards to proceed along to the full functional test sequence. The four test units passed all of these tests and moved on to be functioned.

The units were proof-loaded to 1335 N (300 lbf), then preloaded to a test plate to 1110 N (250 lbf). The setup is shown in Figure 5. All units were actuated successfully and rebuilt for the remaining test sequence. Note that this is a one time use device. The parts were refurbished to save time in qualification. Dielectric coatings need to be replaced after actuation. This process would be cost prohibitive for production devices.

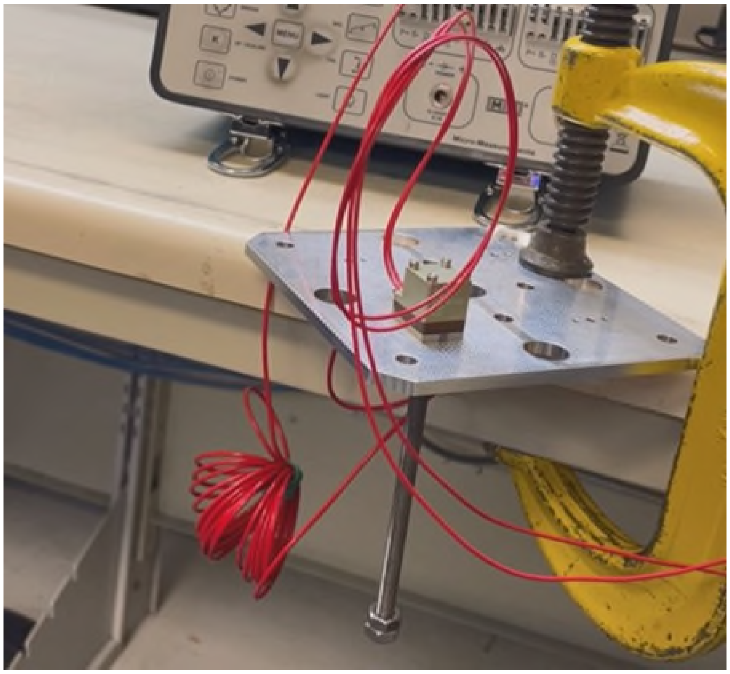

Figure 5. Mini HDRM Initial Actuation Setup

<u>Random Vibration</u>

After rebuild, the test units were preloaded to 1110 N (250 lbf) on a vibration test plate, as shown in Figure 6. The test parameters are shown in Figure 7. No mechanical issues, visible damage, or degradation were observed, with minimal preload change in-line with other NEA® HDRMs. The units were left installed on the test plate and moved on to input shock testing.

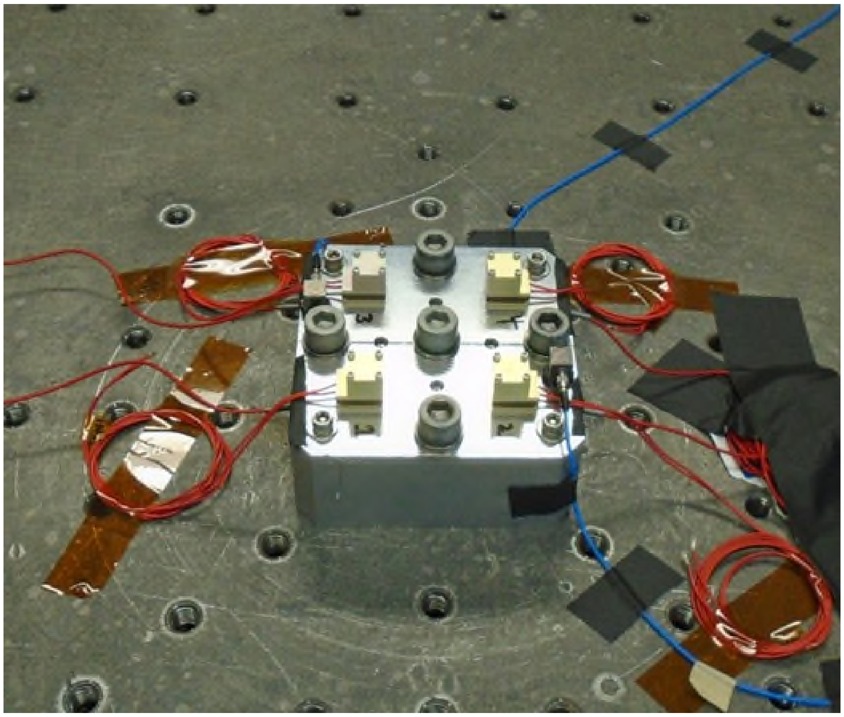

Figure 6. Mini HDRM Random Vibration Test Setup

Direction	Frequency (Hz)	PSD (G^2/Hz)	GRMS
X,Y, & Z	20	0.8	50.9
	50	2	
	600	2	
	2000	0.6	
Test Duration: 6 minutes/Axis			

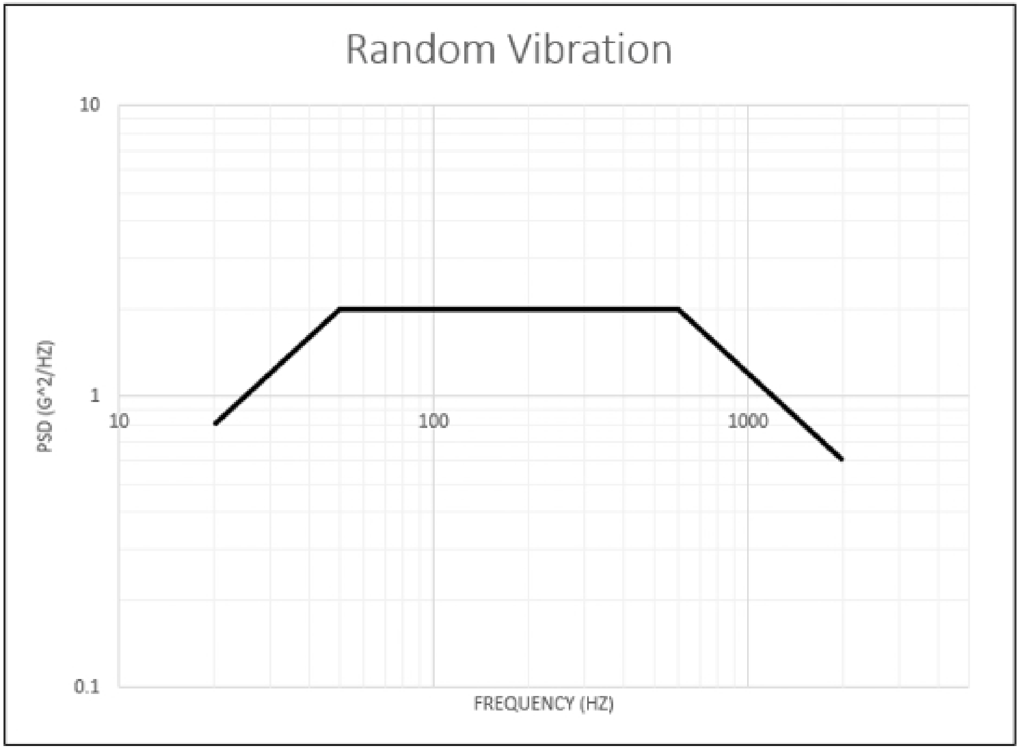

Figure 7. Mini HDRM Random Vibration Test Parameters

Input Shock

The units remained preloaded from the vibration test setup and were installed onto the drop tower for input shock testing. No mechanical issues, visible damage, or degradation were observed, with minimal preload change in-line with other NEA® HDRMs. The units were left installed on the test plate and moved on to thermal vacuum cycling. The input shock test setup and parameters can be seen in Figure 8 and Figure 9, respectively.

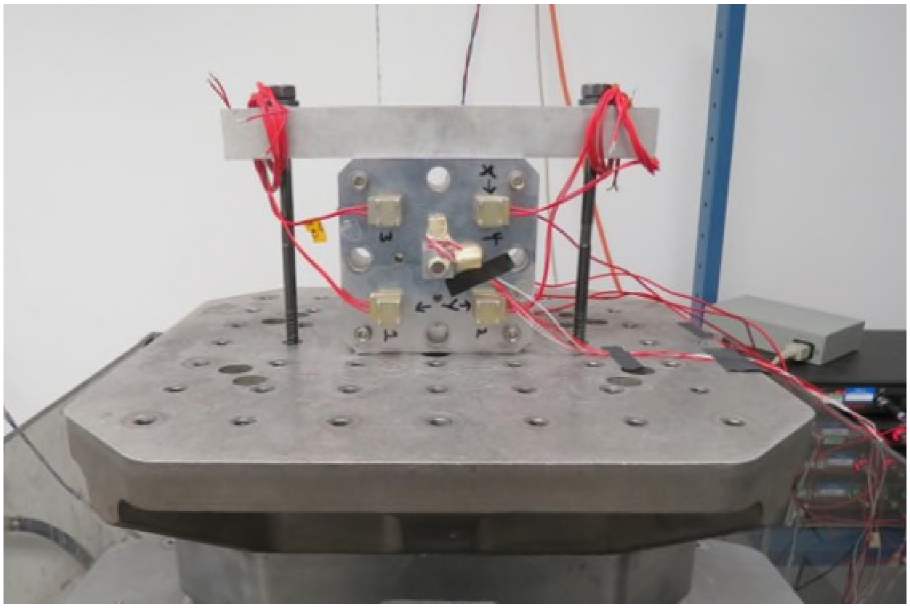

Figure 8. Mini HDRM Input Shock Test Setup

Frequency (Hz)	Shock (G)
100	100
700	1000
2000	2500
10000	2500
Shocks/ Axis =1	
Shock Spectrum Q=10	

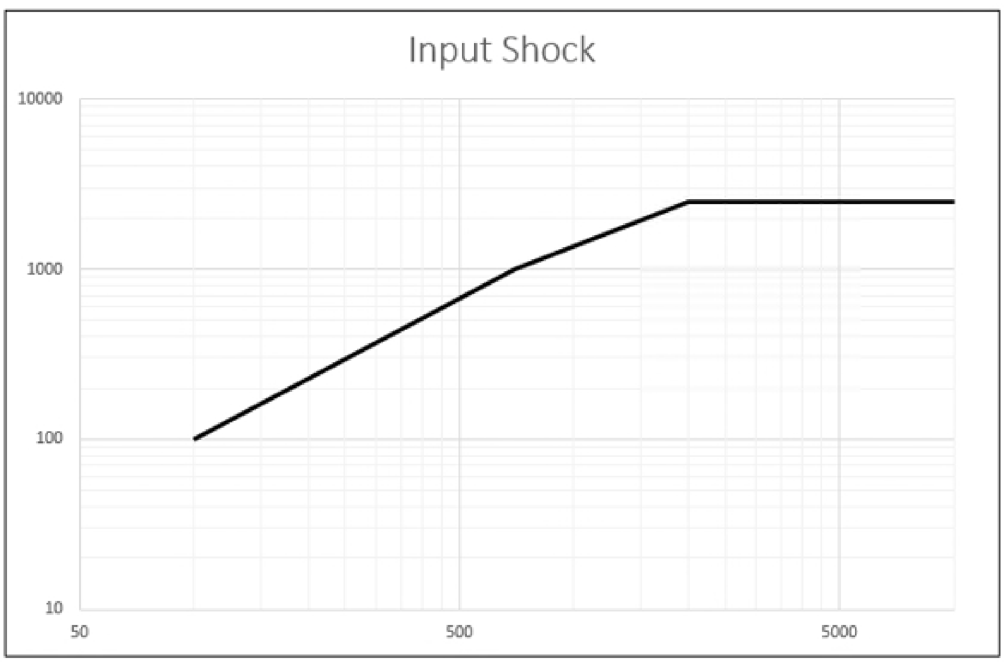

Figure 9. Mini HDRM Input Shock Test Parameters

Thermal Vacuum (TVAC) Cycling

The pre-loaded units remained on their test plate and were moved from shock input testing to TVAC cycling. They were subjected to 10.5 cycles in a thermal vacuum environment (<1.33E-3 Pa) from -135°C to 135°C. The TVAC cycling test setup and thermal cycle plot can be seen in Figure 10 and Figure *11*, respectively.

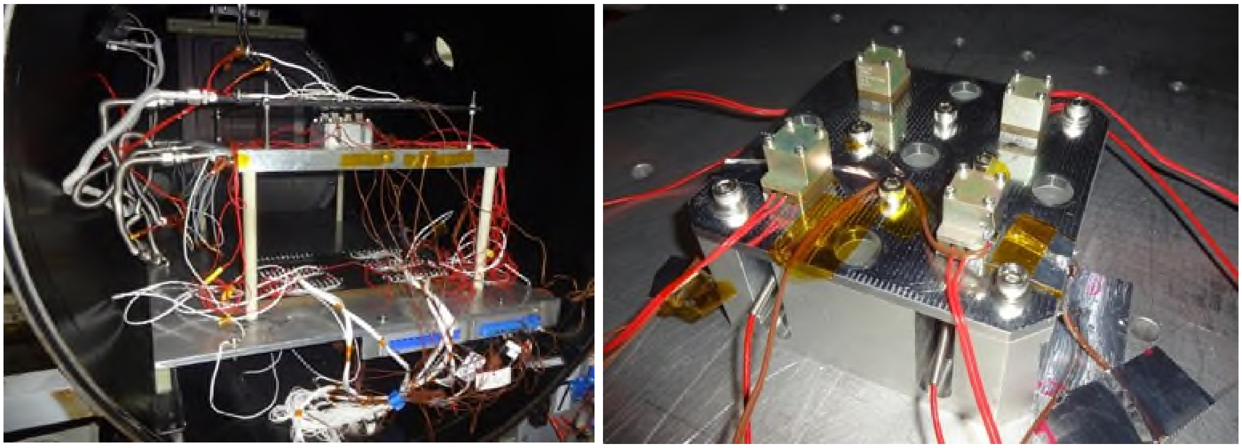

Figure 10. Mini HDRM TVAC Test Setup

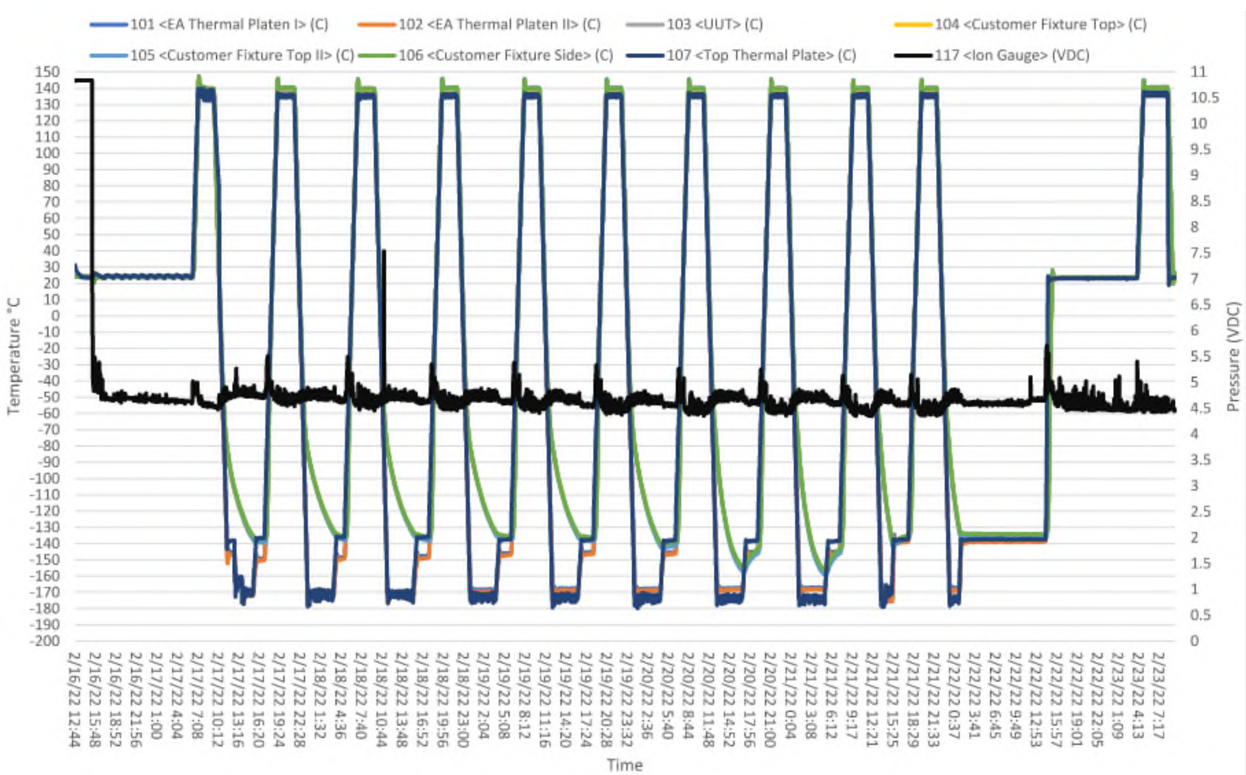

Figure 11. Mini HDRM TVAC Cycling Plot

The units experienced an out-of-tolerance extreme temperature on two cold cycles, where they reached as low as -159°C. This was deemed acceptable for the purpose of this testing, in which the units would be actuated following the TVAC cycling. There was no apparent impact to the units due to the thermal cycling or the out-of-tolerance test condition.

Two units were actuated at Cold temperature (-135°C) and two at Hot temperature (135°C). Both fired successfully. See Table 2 for conditions and actuation times.

Table 2. Mini TVAC Actuations.

Serial Number	Temperature (°C)	Firing Current (A)	Actuation Time (ms)
1	135	3.0	32
2	135	3.0	26
3	-135	3.0	38
4	-135	3.0	40

<u>Output Shock</u>

Two test units were actuated and the resulting output shock was measured. See Figure 12 for the test setup parameters and Figure 13 for a photo of the setup. Figure 14 shows the test result data. Each unit had an output shock <250g for the full measurement range of 10,000 Hz.

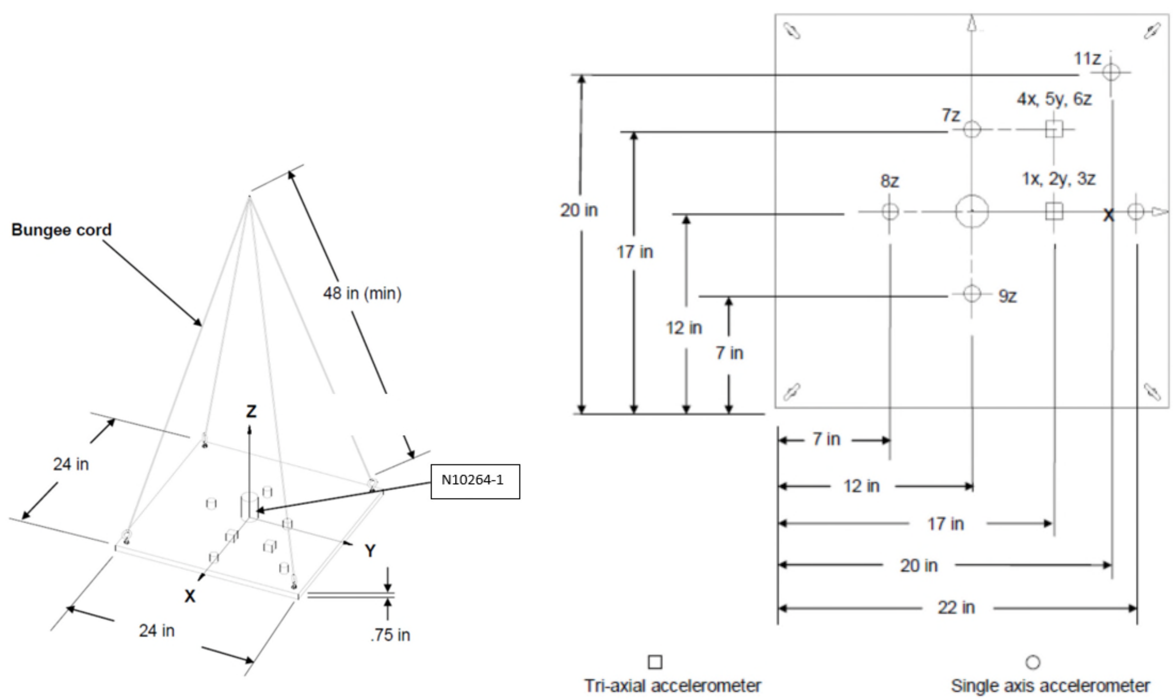

Figure 12. Mini HDRM Output Shock Test Setup Parameters

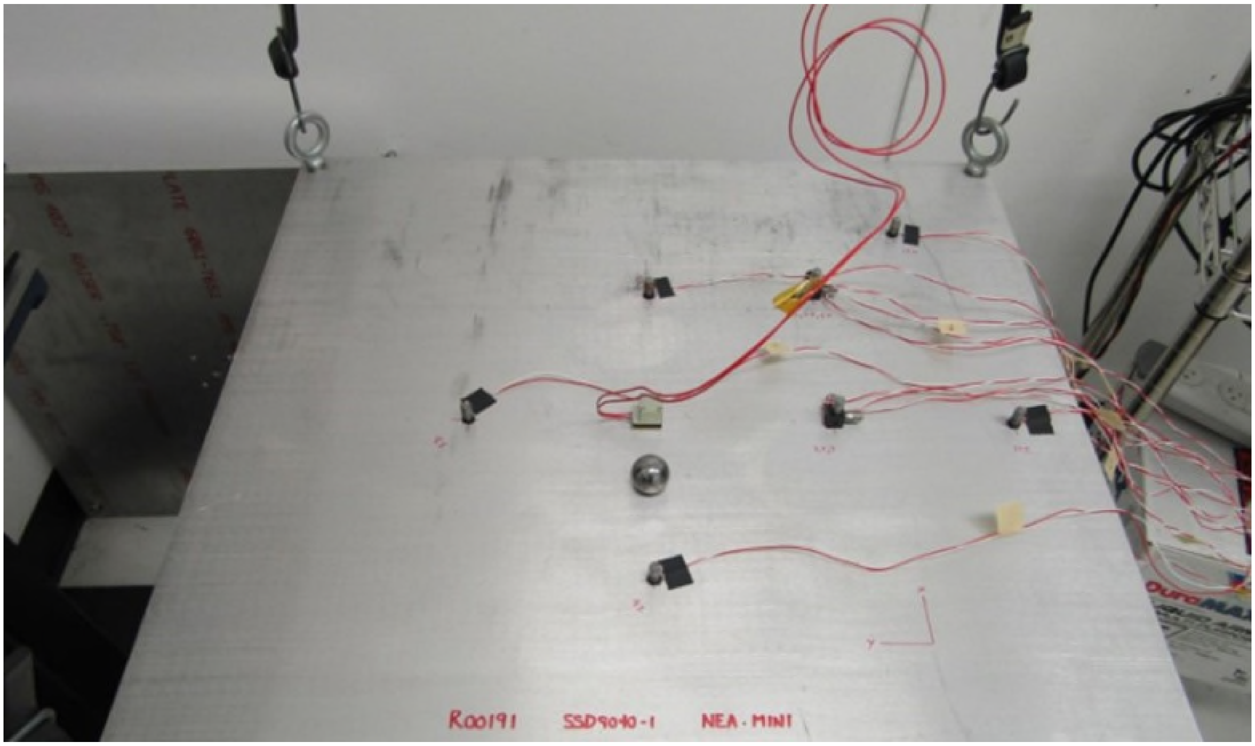

Figure 13. Mini HDRM Output Shock Test Setup Photo

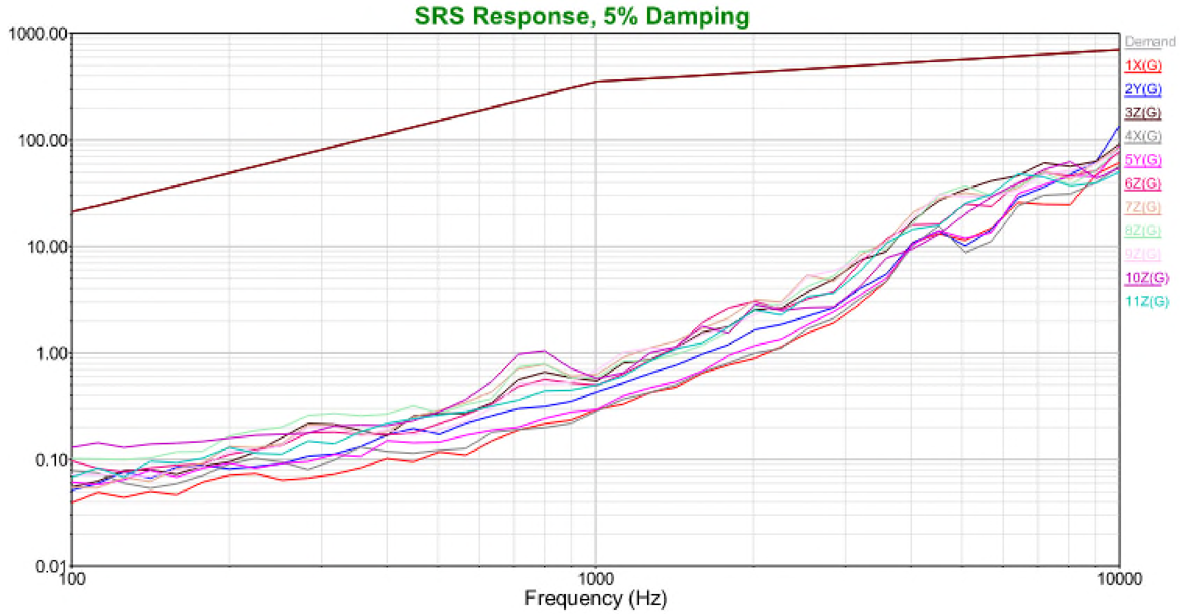

Figure 14. Mini HDRM Output Shock Test Results

Conclusions and Lessons Learned

The design, build, and test of the NEA® Mini HDRMs resulted in a number of lessons learned, as listed below.

1. Functional loads of at least 250 lbf are achievable with the updated Mini design.
2. Shock Output of the mechanism is well below expectations and industry standards.
3. The Mini devices successfully operate in extreme heat and cold space environments.
4. Miniature size mechanisms in general present manufacturing and test challenges that require special tooling and fixturing.
5. Very small fasteners (#1) present issues in machining, assembly, and test. The release rod was therefore upsized to a #4-40.
6. Upgrading to metallic parts from plastic increased the load and thermal capabilities of the device with minimal impact to cost.
7. Upgrading to metallic parts introduced a ground path that needed to be mitigated.
8. Units with no ground path mitigation function as designed.

References

1. Sudick, John and Geoff Kaczynski. "Development of the NEA® Mini for Low Load Applications." *Proceedings of the 44th Aerospace Mechanisms Symposium*, May 16-18, 2018, pp. 233-238.