Thin Pack Hold Down and Release Mechanism for Low Load Applications

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Abstract

Ensign-Bickford Aerospace & Defense (EBAD) is a provider of hold down and release mechanisms (HDRMs) to the space industry. Our devices are used in a wide range of load applications. Strong growth in the small satellite (SmallSat) market is driving the need for higher reliability, lower profile release devices. This paper describes the design and development of our third product offering for the SmallSat market, the Thin Pack HDRM (TH50). This new design offers all the advantages of our qualified Micro Latch design in a low profile package of less than 6.4 mm (0.25 in) height for ≤225 N (50 lbf) load cases.

Introduction

The first SmallSats started out using nichrome burn wire technology to perform releases. This technology is very simple and cost effective. Today, SmallSats are being used to perform high value missions and require higher reliability technologies. Well known SmallSat constellations such as Starlink, OneWeb, and Kuiper have driven the market to respond with new products that are not only lower cost, but also have higher reliability. With the increase in the demand for SmallSats, EBAD surveyed our customers and asked “How can we help?”. The industry responded with a common answer: “We need a lower profile, resettable HDRM.”

EBAD’s existing resettable solution, the TiNi™ Micro Latch, leverages our ERM device heritage and has a taller design envelope that users say can cause some integration design challenges. Based on industry feedback, EBAD engineered our new TH50 Thin Pack release device. This new product provides a solution in the ≤225 N (50 lbf) load case in a low profile envelope (<6.4 mm / 0.25 in height). See Figure 1 for both the TiNi Thin Pack and Micro Latch products. This paper describes the design and development of the new Thin Pack device.

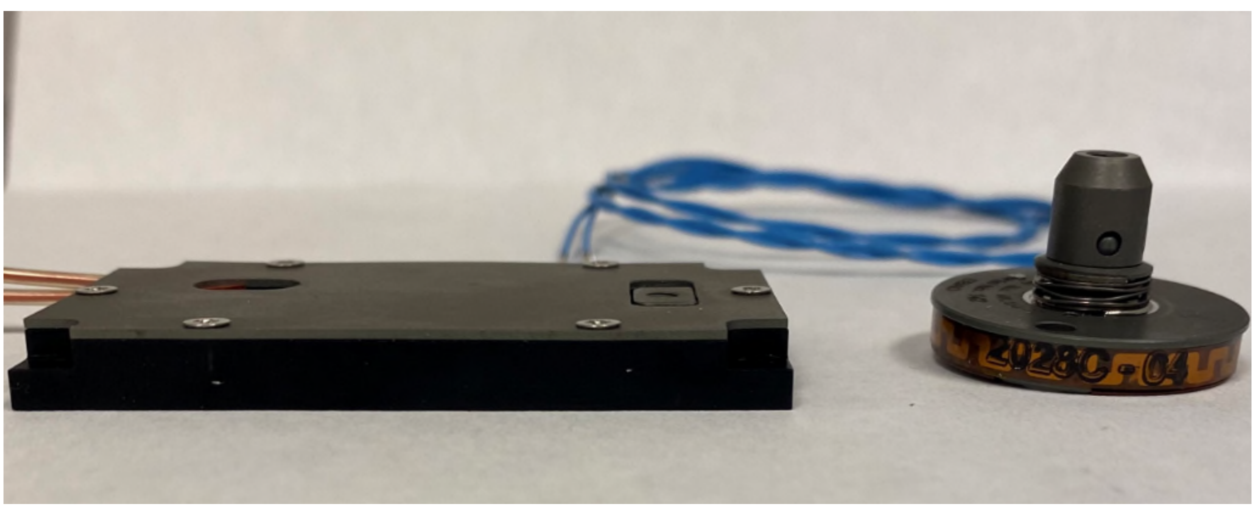

Figure 1. EBAD Thin Pack development unit (TH50, left) and Micro Latch (ML50).

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Thin Pack Background

EBAD's Thin Pack uses our qualified Shape Memory Alloy (SMA) technology, which makes it field-resettable like all of our other TiNi devices and shares the same high reliability. The Thin Pack helps SmallSat designers improve space utilization and reduces integration costs for solar arrays, antenna reflectors, instruments, doors, sensors, and booms.

SMAs refer to a group of materials that have the ability to return to a predetermined shape when heated, illustrated in Figure 2 [1]. The shape memory effect is caused by a temperature dependent crystal structure. When an SMA is below its phase transformation temperature, it possesses a low yield-strength crystallography referred to as Martensite. While in this state, the material can be deformed into other shapes with relatively little force. The new shape is retained, provided the material is kept below its transformation temperature. When heated above this temperature, the material reverts to its parent structure, known as Austenite, causing it to return to its original shape.

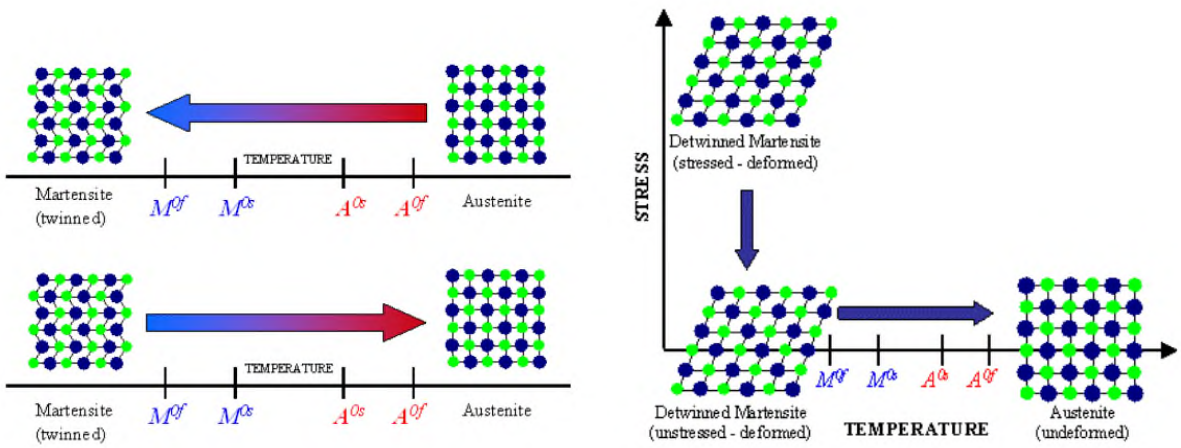

Figure 2. Shape Memory Alloy Phase Transformation [1]

The most widely used shape memory material is an alloy of Nickel and Titanium called Nitinol. This alloy is commercially available and has the following characteristics:

- Excellent mechanical properties
- Capable of long fatigue life
- May be joule heated
- High corrosion resistance

In actuator applications, it is capable of up to 4% strain and 345 MPa (50,000 psi) recovery stress, resulting in approximately 1 joule/g of work output. Nitinol is readily available in the form of wire, rod, and bar stock, with a transformation temperature in the range of -100°C to +100°C.

As with some other TiNi™ devices, such as ejectors and pin pullers, the Thin Pack utilizes the SMA wire as a trigger to actuate the unit. The Thin Pack interfaces with the load to be released via a #4-40 threaded release nut. The nut is held captive by a slider, which is retained by a rolling trigger. The Nitinol wire is attached on each end to a switch contact and routed through a bell crank that holds the position of the trigger. When sufficient current is applied to the external lead wires, the Nitinol wire is heated and shrinks, shifting the trigger and releasing the slider. This motion frees the release nut, allowing the payload to separate from the Thin Pack body.

Thin Pack Design

The interface dimensions of the Thin Pack are shown in Figure 3. The design's low profile makes it able to fit into small envelopes, particularly in applications with very low height requirements. It is manufactured using the same space-rated materials as all of our other space-qualified products. Commercially-available components were used as much as possible to help keep the price point of the device in line with other devices on the market. The Thin Pack generates no debris during its actuation, so it is compliant to applications where FOD is prohibited. When a nominal 1.8 A current is applied, the device actuates in approximately 50 ms. It is also equipped with a safety switch that automatically opens upon release and stops current flow through the SMA wire. This feature prevents excess current from damaging the SMA wire.

The Thin Pack is designed to have a minimum number of moving parts. This was a significant design challenge for a resettable device, as resettability inherently means the unit will have more parts. The Thin Pack also does not require disassembly or have replaceable or consumable parts in order to be reset. These factors increase the device's reliability substantially when compared to other devices on the market with a similar form factor.

The Thin Pack is designed to be reset without the need for a special tool. After actuation, the Thin Pack can be reset by threading a #2-56 screw or inserting a gage pin into the device. The Thin Pack is rated for at least 50 actuations, giving the user plenty of test cycles during development.

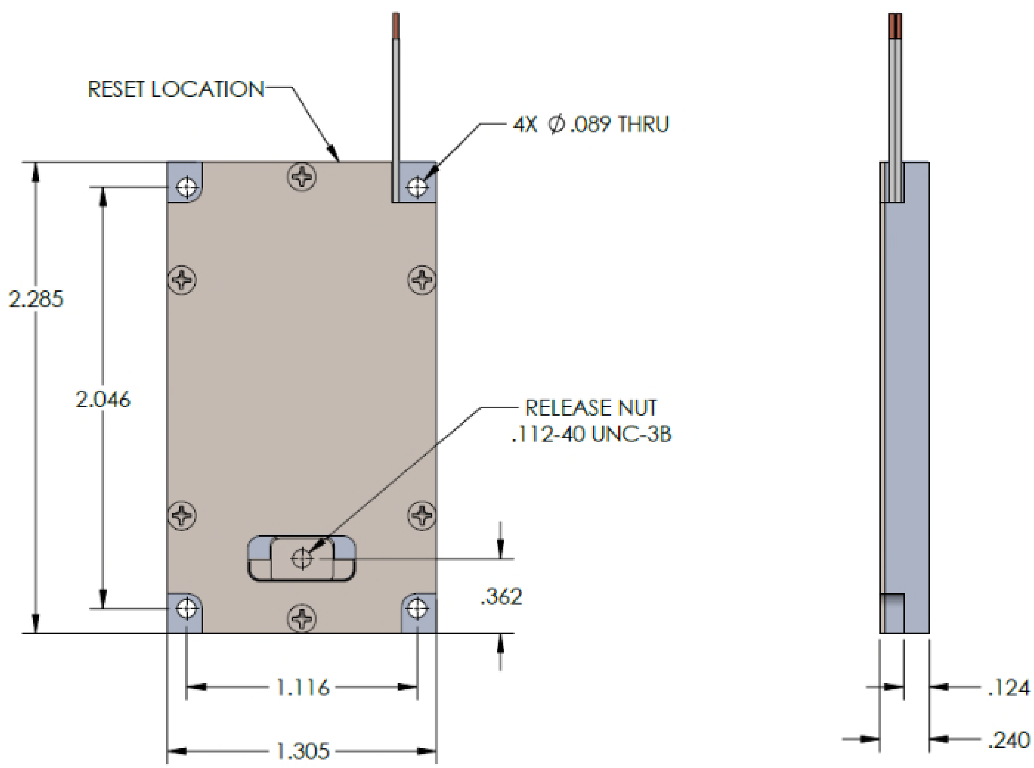

Figure 3. EBAD Thin Pack (TH50) Interface Dimensions

Design Challenges

The device's small size (see Figure 4 for reference) presented several design challenges to the team. Constrained to less than half the footprint of a credit card and thinner than a deck of playing cards, the device packs a number of space-grade components into a tiny body. With the small scale of the components, part tolerancing and assembly were continually reviewed.

The small size of the internal components presented the team with several assembly and handling challenges. The assembly process was developed in conjunction with the manufacturing team, with input from engineers and operators. Special handling fixtures and tooling were designed to aid in assembling the tiny components of this device, with a focus on ergonomics.

The Thin Pack is designed to have 2X margin on the force to release the payload nut. The device's release and reset energy is supplied via springs. The design of the springs compensates for sliding friction between internal components during release and reset. Initial development testing on a prototype test rig showed the frictional forces were higher than expected, impacting the 2X design requirement. Increasing spring size within the device would have grown the package size, which was not desirable. Therefore, the team opted to address the friction issue with smoother surface finish and coatings to reduce friction between moving components.

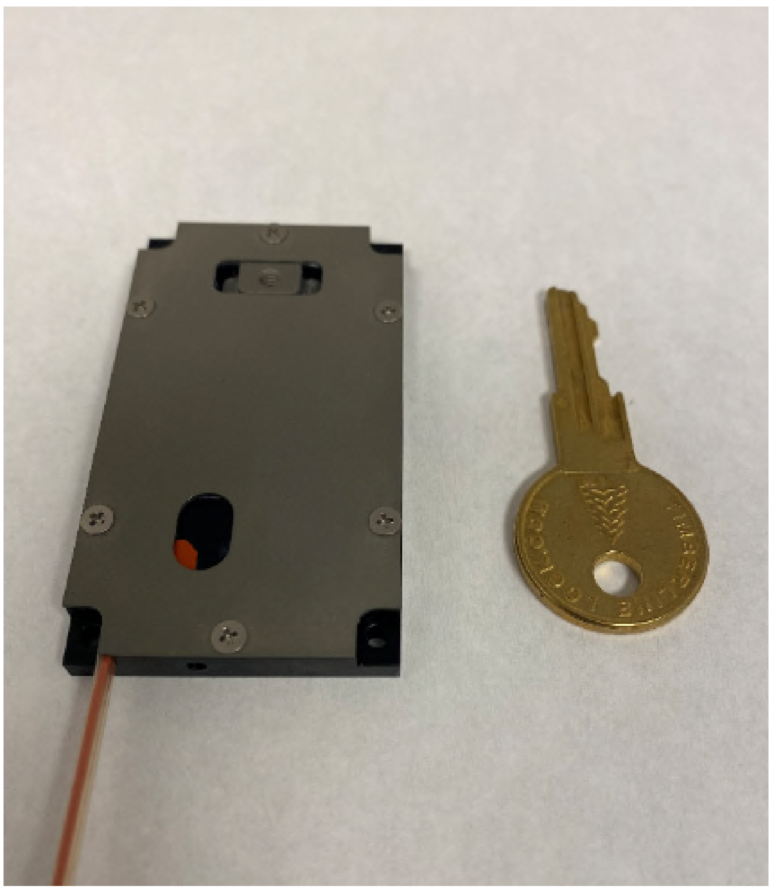

Figure 4. EBAD Thin Pack (TH50)

Prototype Testing

A prototype unit, shown in Figure 5, was built as a proof-of-concept device to demonstrate functionality and characterize baseline performance. The team was given a tight development timeline of nine months. A prototype device was fabricated using internal machining capability and quick-turn prototype shops. Testing of this initial iteration of the Thin Pack started with characterization with respect to basic design goals and expected use cases, consisting of:

1. Proof load test
2. Release test under full load
3. Force to release (actuation margin)
4. Self actuation limit for thermal environment
5. Vibration survivability

Figure 5. EBAD Thin Pack Prototype Unit.

A Mark-10 force tester was used to apply loads for the proof load, release test, and force-to-release tests. The proof load and release test setup can be seen in Figure 6, and the force-to-release test setup is shown in Figure 7. The unit was proof-load tested to 445 N (100 lbf) and release tested to 290 N (65 lbf). It was subjected to random vibration at the planned development test level of 26.0 G_{rms} in each of three orthogonal directions. No issues arose from these tests.

Since SMA devices are temperature-limited based on their transformation temperature, the Thin Pack was placed in a thermal chamber to determine its self-actuation limit. The temperature was gradually increased until the unit self-actuated. This action occurred at approximately 81°C, which is consistent with devices of similar materials and construction.

Using a test rig representative of the prototype design, the force to release was measured to be 22 N (5 lbf). This is the amount of force it took to shift the internal bell crank and release the payload nut, and accounts for the component interaction and friction within the device. When compared to the full force capability of the SMA wire, this gives an indication of the actuation margin in the system. The pull strength of SMA wire size used results in approximately 70% margin based on the prototype fixture test.

EBAD expects that the force to release can be reduced by minimizing the friction in the device through smoother surface finish, low-friction coatings, and the continued use of grease, which reflects the construction of the development units. This configuration will be assessed on a similar test rig, with the goal of demonstrating higher actuation margins. EBAD expects force-to-release margins in excess of 100% (compliant to the 2X design requirement) for this configuration based on similar historical data.

The prototype successfully completed all tests, indicating that the base design functionally met the design goals.

Figure 6. EBAD Thin Pack proof load and release characterization test setup.

Figure 7. EBAD Thin Pack force to release test setup.

Development Testing

Based on lessons learned from the build and test of the prototype unit, the design was updated for the development units. This included the component coatings, adding a damper to reduce actuation shock, and providing internal strain relief of the lead wires.

EBAD built and performed preliminary tests on five (5) development units. These tests consisted of electrical checks, proof loading, actuations, and output shock. A full set of development tests is planned for these units. The tests are described in the following sections.

Electrical Tests and Proof Load

Electrical tests were performed based on typical release device parameters and SMA characteristics. They are meant to confirm workmanship and compliance to the design. The tests, requirements, and test results (Pass/Fail) for the units are shown in Table 1.

Table 1. Thin Pack Development Unit Electrical Tests

Test	**Requirement**	**Test Result**
Circuit Resistance	5 to 6 Ω	Passed
Insulation Resistance	100 MΩ minimum, shorted lead wires to lid (@500 ± 50 V_{DC} for 15 seconds minimum)	Passed
No-fire Current	75 mA to 85 mA for 5 minutes	Passed

Proof load testing was performed using a Mark-10 force tester shown in Figure 6. All units held the proof load of 445 N (100 lbf).

Actuations

The units were successfully actuated and reset five times each. The planned cycle life for the Thin Pack is 50 actuations, which is consistent with TiNi™ devices that operate in a similar fashion. This requirement will be validated as part of the full development plan.

Output Shock

An output shock test was performed to characterize the shock emitted from the Thin Pack when actuated. As mentioned, a damper was incorporated into the development unit design to reduce this shock. The test utilized a typical 19 mm x 610 mm x 610 mm (0.75 in x 24 in x 24 in) plate with accelerometers installed 127 mm (5 in) away from the test unit, as shown in Figure 8. Output shock results were very consistent across all five units (<50g max up to 10,000 Hz), with a typical SRS plot shown in Figure 9.

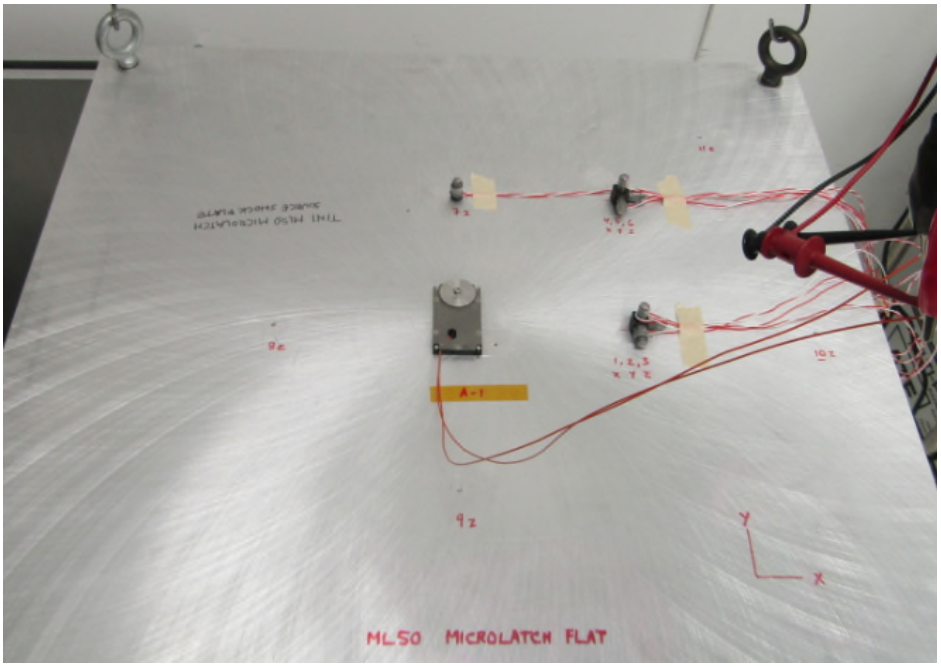

Figure 8. EBAD Thin Pack Output Shock Test Setup.

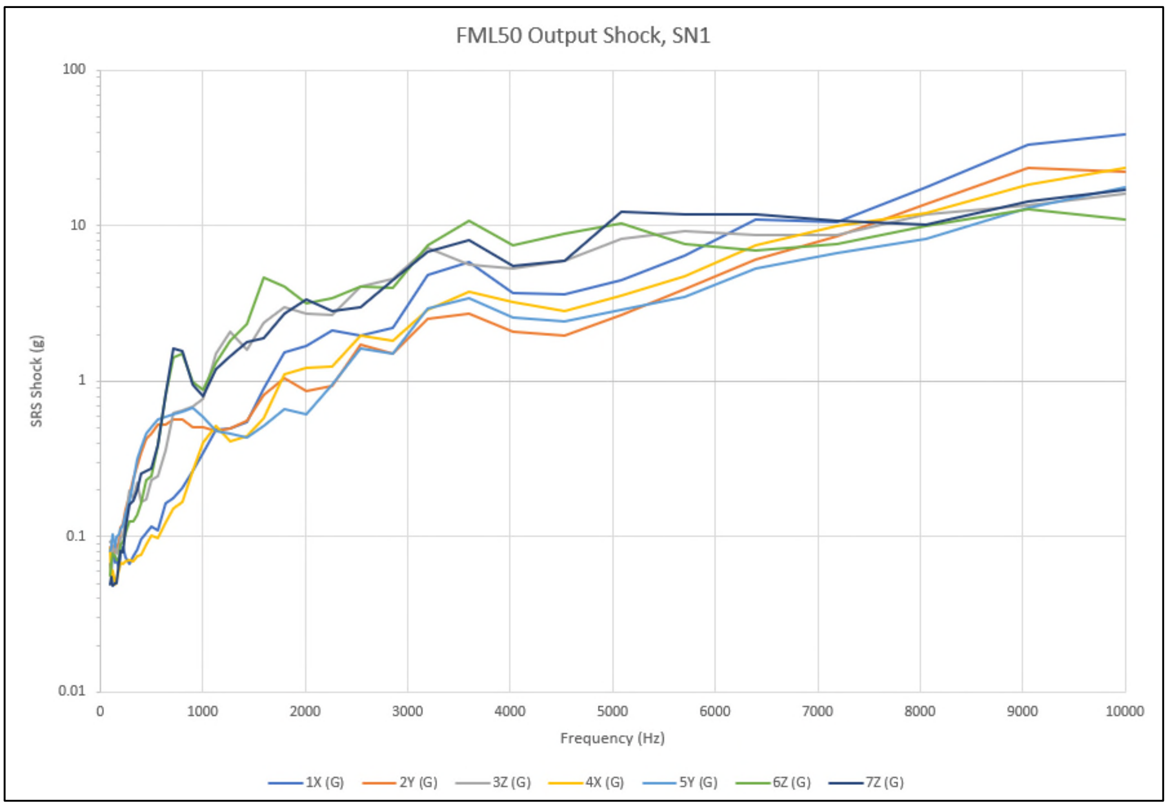

Figure 9. EBAD Thin Pack Output Shock Test Results.

Full Development Testing

After assessing the preliminary test results and design enhancement opportunities, EBAD will take the Thin Packs through a full development test sequence to validate the design and performance characteristics. The proposed test sequence is shown in Table 2. Items 1 through 4 and 8 have been performed on the current development units.

The units will go through environmental testing, including vibration, shock, and thermal vacuum cycling. They will be actuated after each environment, including during TVAC at hot, cold, and ambient temperatures, and at a range of actuation currents. Finally, additional actuations will be performed for a total of 60 planned actuations per test device. This quantity allows for margin above the 50 actuations expected to be part of the Thin Pack's specifications.

Throughout the test sequence, after each actuation the units will be preloaded (225 or 290 N), then have their circuit resistance measured to continually assess the device's health.

Additionally, as mentioned previously, the force to release the payload will be measured using a test rig representative of the development units.

Table 2. Thin Pack Development Test Sequence

Seq #	Test Name / Test Parameters
1	Electrical tests @ Reset State (Circuit Resistance, Insulation Resistance, No Fire Current) [Circuit Resistance re-checked throughout test sequence]
2	Actuation – No Load, Ambient (Low, Nominal, High Current)
3	Proof load – Max (445 N)
4	5X Actuations @ Load (Ambient, Nominal Current)
5	Random Vibration
6	Input Shock
7	Actuation @ Load (Ambient, Nominal Current)
8	Output Shock Test (Ambient, Nominal Current)
9	2X Actuations @ Load (Ambient, Nominal Current)
10	TVAC Cycling & Actuation @ Hot, Cold, & Ambient (Nominal Current)
11	No Fire Margin Tests @ Temp
12	47X Actuation @ Load (Ambient, Nominal Current)
13	Re-Characterize the Load vs Stroke for comparison to Pre-Test Data, No Fire Current Margin test, Transient Current susceptibility test

Lessons Learned

The design, build, and preliminary testing of the Thin Packs resulted in a number of lessons learned, as listed below.

1. The Thin Pack can hold and release loads of at least 225 N (50 lbf).
2. The Thin Pack output shock is extremely low at <50g max up to 10,000 Hz.
3. Units of this small size are inherently challenging to assemble.
4. Great care must be taken to balance the internal forces, including: the pull force of the SMA wire, spring forces to release the nut and reset the device, and frictional forces between sliding components.
5. To maximize the actuation margin, friction should be minimized through surface finish, component coatings, and grease.

References

1. Awan, Iqra Zubair and Abdul Qadeer Khan, "Fascinating Shape Memory Alloys." Journal of the Chemical Society of Pakistan, (Vol. 40, No. 1, 2018), 1-23.