Innovative Fastener Technology

A Marriage of Fastener Technology: White Paper on the Advantages of Helical Inserts in Threaded Nuts for Exceptional Performance.

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Abstract

As mechanical technology has improved with higher performing materials and processes, the science of threaded mechanical fasteners has been found to be lagging. Advanced applications requiring strength, minimal weight, and vibration resistance still use fasteners developed decades ago. This paper provides insight into the exclusive combination of two very old yet proven threaded fastening technologies, a combination that results in improved performance in the aforementioned areas.

Problem Statement

This white paper addresses the antiquated design technology of threaded nuts and the lack of significant solutions to improve their performance in the following areas: weight reduction, proof load retention, strength, and vibration resistance.

Background

There are a multitude of factors that contribute to the failure of a threaded fastener in a high tensile application, the most notable of which is hydrogen embrittlement. It is well documented that hard alloy steels are susceptible to brittle failure in the presence of absorbed hydrogen at a hardness threshold of 39 HRC. The tougher, more ductile properties of a soft alloy steel can tolerate the presence of hydrogen without any delayed degradation of mechanical properties (Brahimi, 2014). Notably, the FAA issued a Special Airworthiness Information Bulletin with regard to high performance nuts (SAIB #HQ-14-16) and the EASA also issued a Safety Bulletin (SIB # 2012-06R@) for significant cracking of the MS21042-4 nut due to hydrogen embrittlement.

To avoid the effects of hydrogen embrittlement, fasteners in high tensile applications must therefore have sufficient mass to accommodate the use of lower tensile strength alloy steels. Although high strength steels can be used to lower the mass and the subsequent weight of a fastener, their use in corrosive environments requires expensive cadmium plating techniques to eliminate the absorption of hydrogen.

To further elaborate on the failure mechanisms of threads, the following detailed explanation of threaded fasteners is necessary. Under ideal conditions, the 1st thread on the flange end of a bolted joint takes on 35% of the tensile load, the 2nd thread 25%, and the 3rd thread 18%. In sum, 78% of the tensile load is withstood by the first three threads. The 1st thread load ratio will increase up to 40% for bolted joints with minimal thread engagement. (Zhang, January 2018) The first thread failure is exacerbated by the dilation of the nut flange and thread bending due to a combination of stresses in the nut. Dilation and thread bending cause the major diameter of the nut thread to increase thus decreasing the shear stress area of the already critically loaded first three threads (Figures 1a & 1b). The phenomenon is the result of the tensile forces on the 60° “v” angle of the thread creating a wedge effect and a subsequent radial expansion of nut flange (Bill Eccles, Bolt Science 1990). This is the cause of stripped threads in a bolted joint. Whether the bolt or nut strips is dependent on the respective material properties.

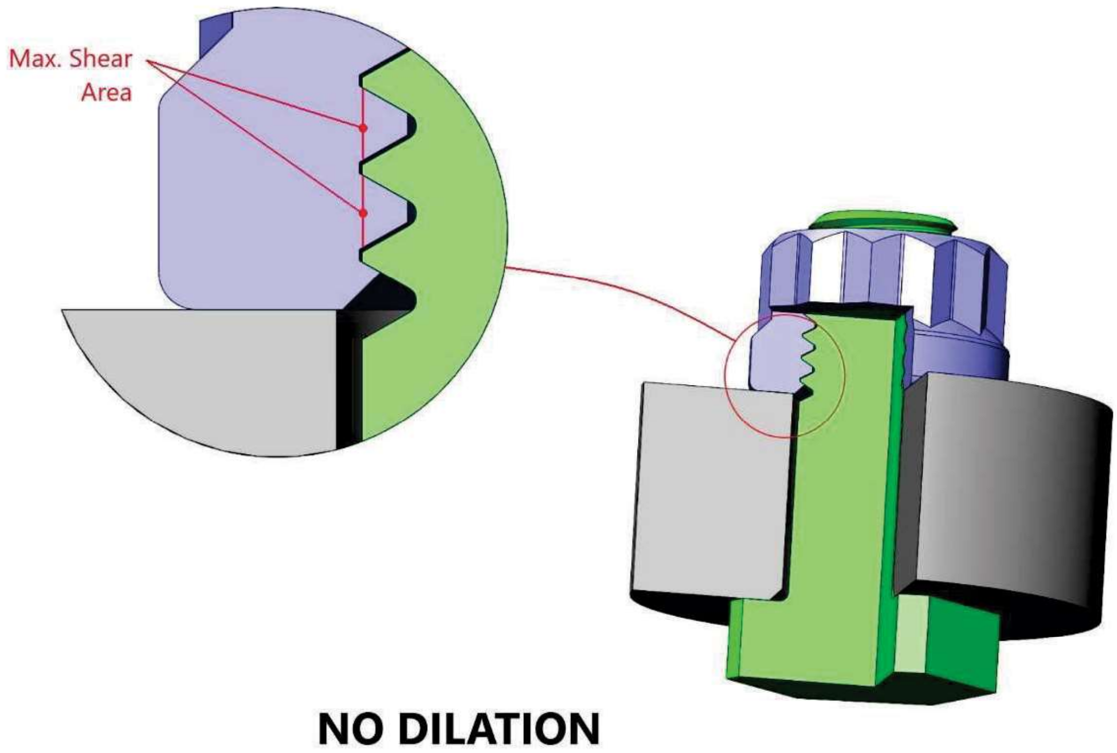


Figure 1a

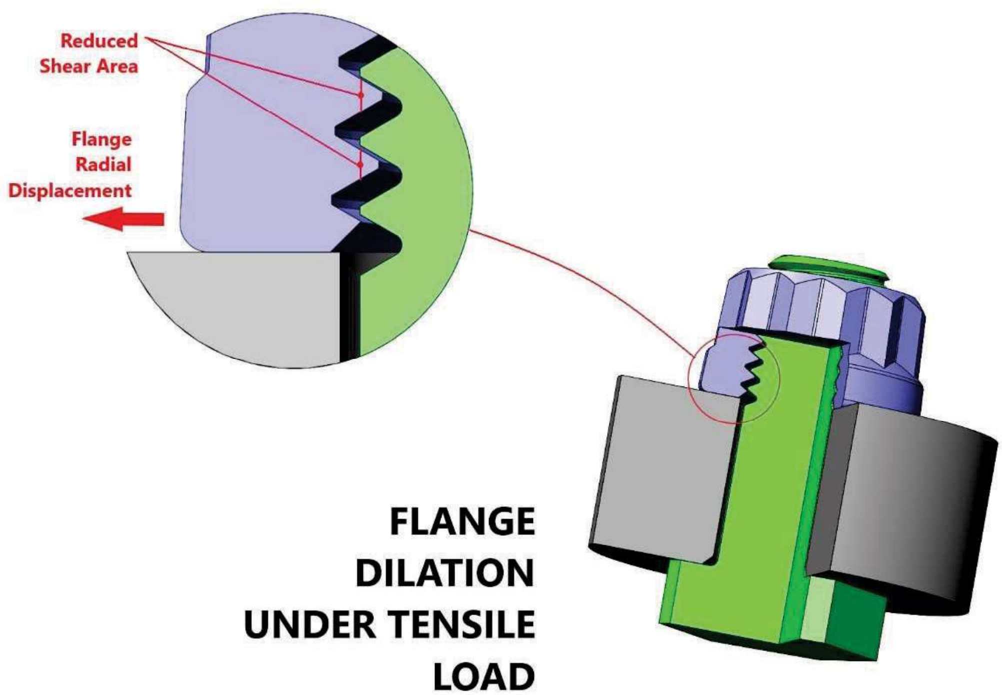


Figure 1b

Moreover, with an endeavor to reduce the weight of a bolted joint, dilation will become an issue when decreasing the size of a nut flange. Further, if lighter, less stiff nut materials such as aluminum are proposed, then the bulk stiffness of the nut flange becomes the issue. Even when attempting to reduce weight using high strength materials, there must always be plenty of thread engagement to address the thread tensile load sharing issue and material in the flange to address the dilation. This again, adds weight.

Beyond the strength and mass of high-performance fasteners, there is always the issue of proof load retention. Various mechanisms and locking compounds are commonly used to lock threads from the effects of vibration, but they all have some type of drawback. “Loctite Red” - style compounds work well but are messy, time consuming to install, and difficult to remove without heat. Locking wires and castle nuts are also time consuming and can be difficult to adjust to the exact torque needed. Lock washer devices such as Nord-Lock® add weight, cost, installation time, and can damage parent surfaces. Crimp style integrated thread locking features lack performance in maintaining acceptable proof load and are subject to inconsistencies regarding prevailing torque and breakaway torque. These crimp style thread locking features also are not available on lightweight materials such as high strength aluminum.

The retention of proof load for strength and integrity in a bolted system is obvious, but there are also applications where seals must be maintained under extreme aerospace vibration and temperature conditions. Leakage is common and often the repair or replacement of said sealing nuts is difficult due to a lack of accessibility.

The final element needing a background explanation is the helical coil thread insert. Per Barrett of NASA:

> “A precision coil of diamond-shaped spring temper CRES wire that forms both external and internal threads as shown in figure 2. The coil is made slightly oversize so that it will have an interference fit in the tapped hole. In addition, this insert is available with a deformed coil (Fig. 3) for thread locking. The wire thread insert is the most popular type for repair of a tapped hole with stripped threads since it requires the least amount of hole enlargement” (Barrett, March 1990).

Figure2, courtesy KATO Fastening

Coil thread inserts date back to the 1930s for the aerospace industry. At that time, lighter materials such as aluminum did not have the strength to handle the stress in threads and thus the helical inserts evolved. Coil thread inserts are used extensively in castings. The advantages of coil threads are the result of thread load sharing as described below by KATO:

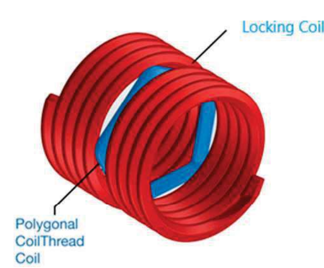


Figure 3, courtesy KATO Fastening

> “Coil thread inserts have resilient design characteristics to allow each coil to adjust independently for maximum surface contact with the parent material. As a result, loads are distributed more evenly. Stress and fatigue concentrations are reduced to maximize thread strength, thus, increasing the reliability and life of the fastening system.” (KATO, 1997)

As mentioned previously and to elaborate, with standard threads, the first thread under optimum conditions carries 35% of the tensile load. With coil thread inserts, because of the resilient design characteristics, the tensile load sharing between the coils is improved, thus the first thread under the same optimal conditions can theoretically carry less load. Also, since the thread in the parent material is larger due to coil presence, the shear strength of the parent thread is greater. This explains the strength increase of threads in softer parent materials.

Coil thread inserts are also known for their thread locking capability. These locking inserts incorporate a locking coil consisting of segments that act as an elastic beam spring on the thread flanks of the screw/bolt. This interference creates prevailing torque resistance on male threaded fasteners to help prevent loosening due to vibration or impact. (Fig. 4).

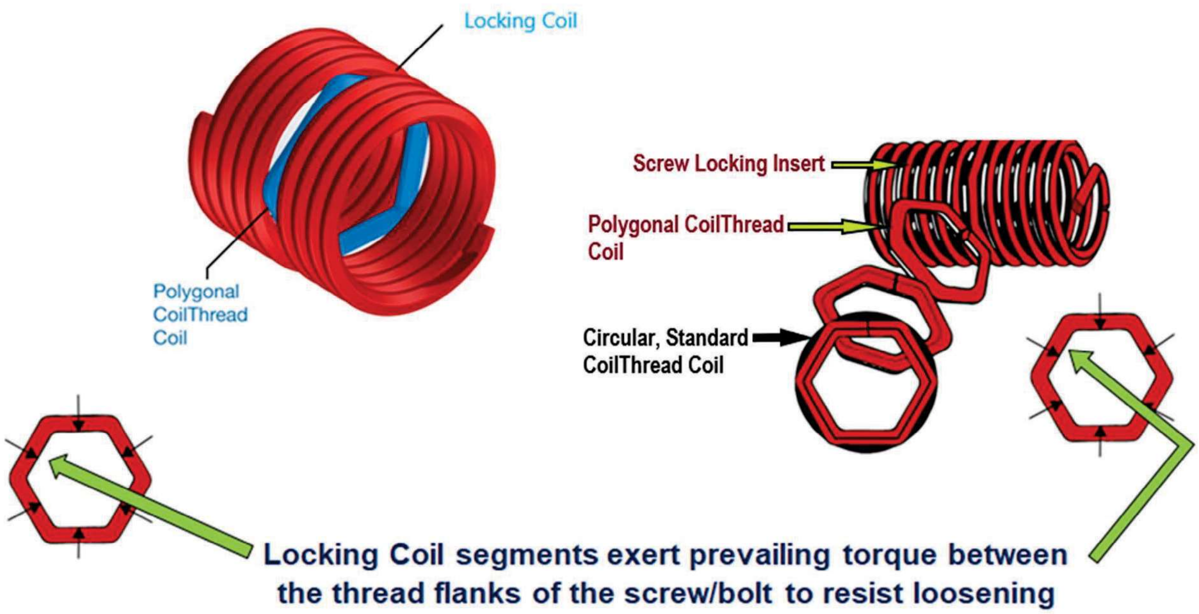
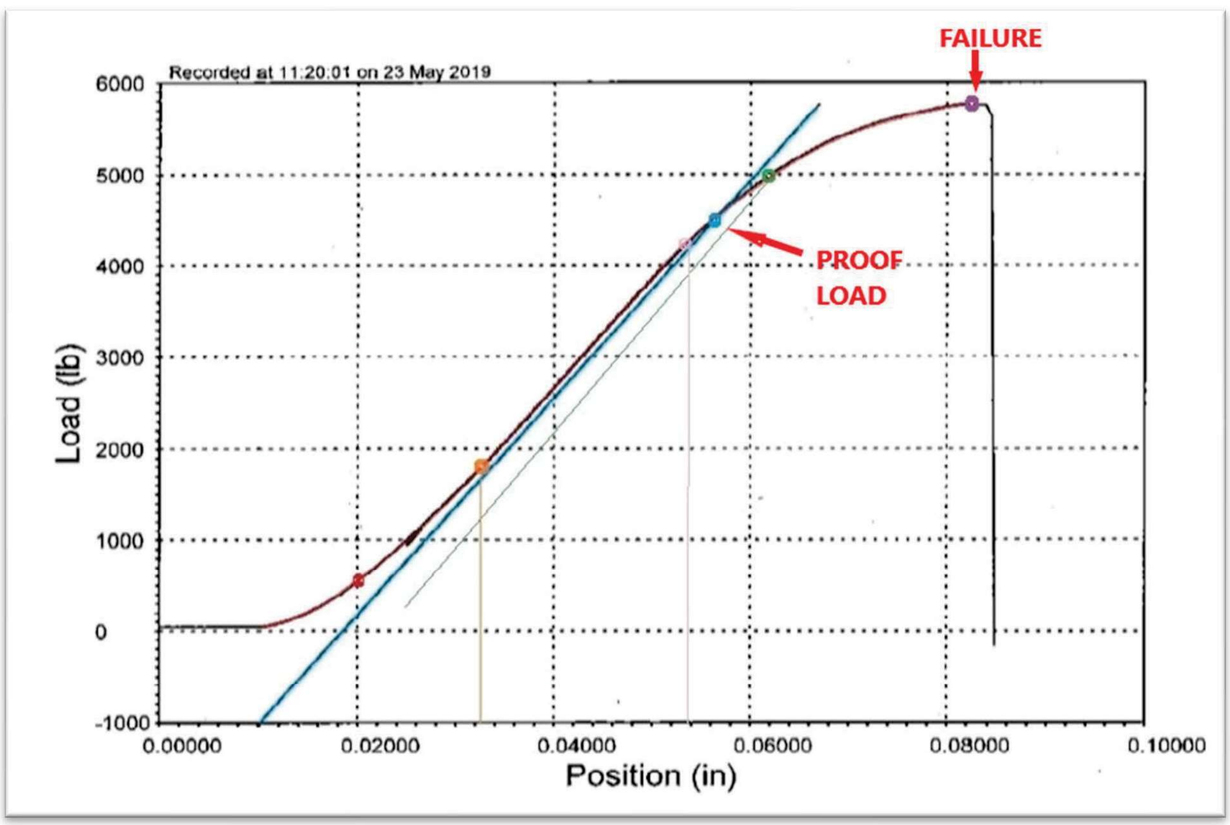


Figure 4, courtesy KATO Fastening

Solution

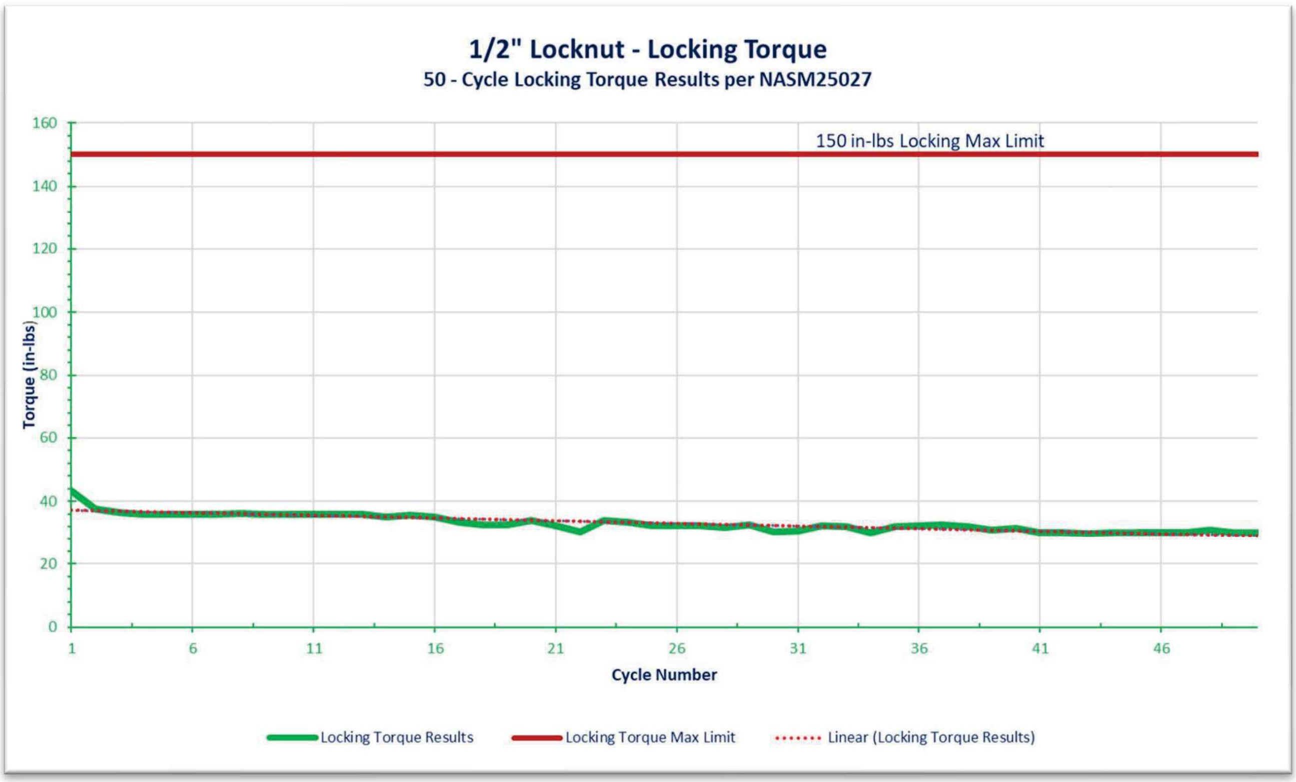
And so the marriage: adding coil inserts with or without locking features to threaded nuts from the common variety to advanced aerospace nutplates and dome nuts creates exceptional performance improvement. Considering weight reduction - the most desirable and universal product improvement - lighter materials such as aluminum can used without a sacrifice in strength. Case in point: IFT LLC, utilizing their patented technology, developed a product combining an aluminum nut with a coil insert (Fig. 5).The hybrid, a ¼-28, UNJF , 12 point, aluminum nut was subjected to the rigors of independent qualification testing to aerospace standard NASM25027. The aluminum nut with a coil insert had a weight savings of 52% compared to a similarly sized alloy steel nut. The lightweight nut also had an integrated locking coil in the thread insert. The aluminum nut passed all the strength and performance criteria based on an alloy steel locknut. Most notable was the tensile strength – failing at 5,643 lbf, which exceeded the requirement of 4,580 lbf by 23% (per NASM 25027 Table I). Also worthy of note is that the linear portion of the stress displacement curve reached the required ultimate tensile strength of 4580 lbf (per NASM 25027 Table I). This means the proof load of the nut was within the required ultimate strength of the fastener (Graph #1).

Figure 5



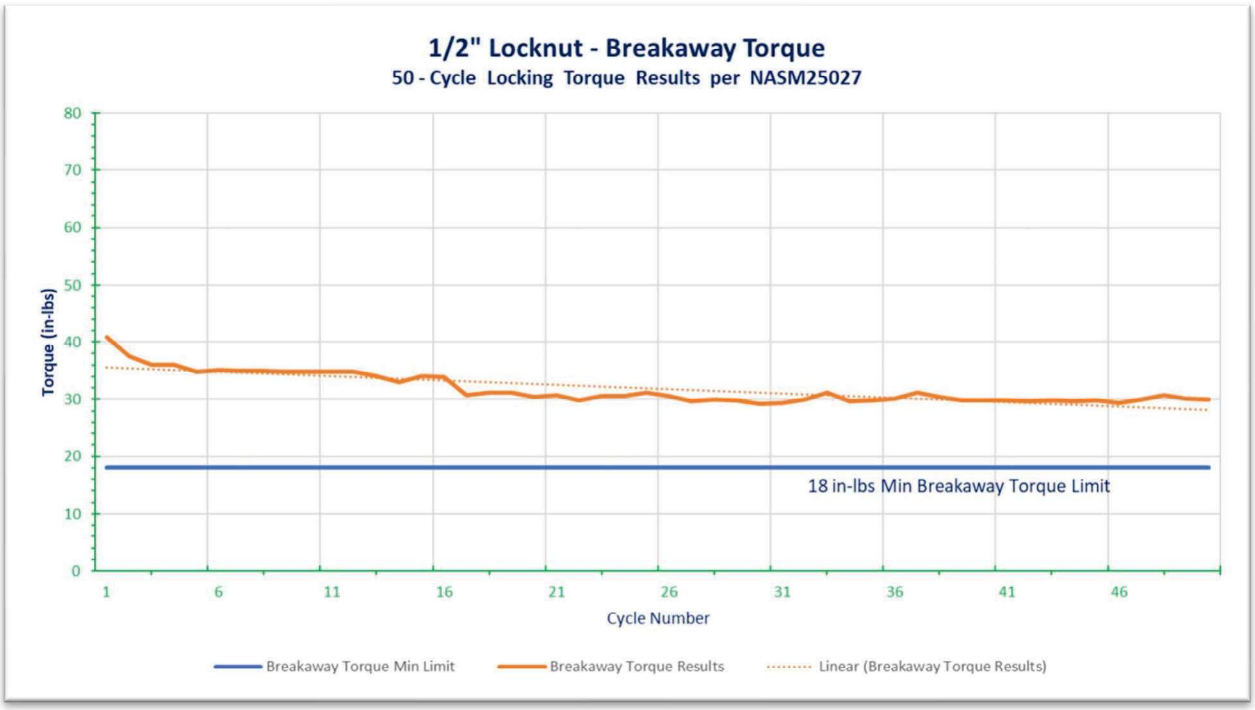
Graph #1

Note that the nut also passed all the rigors of vibration testing per NASM1312-7. Furthermore, the IFT nut showed exceptional results relative to locking torque and prevailing torque compliance, consistency and longevity. Shown in Graph #2 is the test result of locking torque as defined by NASM25027 of a typical IFT ½" hybrid locknut with a locking coil thread insert.



Graph 2

Graph #3 shows the test result of breakaway torque as defined by NASM25027 of a typical IFT ½" hybrid locknut with a locking coil thread insert.



Graph 3

Referring back to the airworthiness directive and hydrogen embrittlement in MS21042-4 nut (*1/4-28 Thread, Self-Locking Nut, 450°, Reduced Hexagon, Reduced Height, Cad-Plated Steel, No Dry Film Lube*), the axial tensile strength of 180 KSI required for these nuts demands that the nut material be made from alloy steels above 40 HRC. Therein lies the issue with strict process control to significantly minimize hydrogen as a result of the cadmium plating process, the failure of which results in brittle product.

A new design (patented)developed by IFT, LLC uses a locking coil insert integrated into a nut made of alloy steel tempered below the 39 HRC hydrogen embrittlement threshold (Fig. 6).Adherence to all the dimensions and weight of MS21042-4 was conforming. Since the relatively

Figure 6

soft temper of the new design was 37 HRC, the resulting tensile strength was 162 ksi, far below the tensile strength of 180 ksi associated with existing hydrogen embrittlement prone MS21042 nuts. The tensile strength was lessened but the ductility and the fracture toughness was greater, and, most importantly, the 1st thread carried much less stress as a result of the thread load sharing associated with coil inserts. Empirical data showed that the first thread carried 30% of the load in the coil insert as opposed to 38% in the standard coil-less product. Axial tensile load testing revealed an average strength of 6,521 lbf exceeding the requirement of 6,200 lbf. In other terms, a product tempered to 162 ksi yielded a performance tensile result of 180 ksi. Testing of the product at an independent lab demonstrated compliance with NASM1312-8 and test specimens were used from the entire range of manufacturing tolerances. Note Figure 8 showing an FEA of an axial loaded nut with improved load sharing as depicted by the stress in the upper and lower coil.

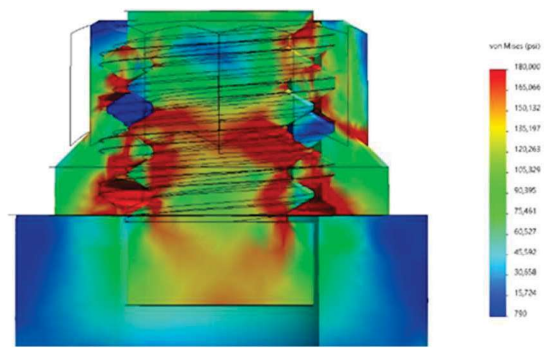
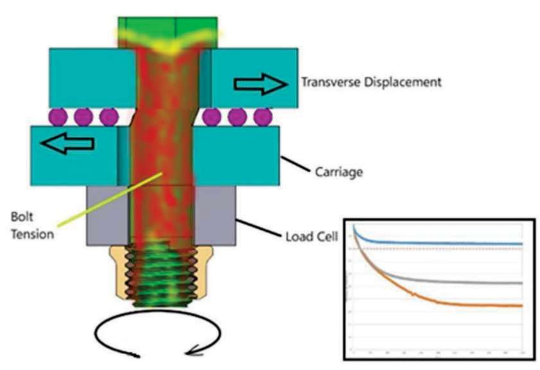


Figure 8

IFT,LLC has independently tested a multitude of custom nuts integrating locking coil inserts that conform to vibration standard NASM1312-7 but the ultimate test for vibration resistance relative to proof load is the Junkers test. Developed in the late 1960s by German engineer Gerhard Junker, the mechanical testing device measures preload in nut and bolt by means of a load cell. The nut and bolt are subjected to shear loading by means of transverse vibration and proof load is constantly measured. (Junker, 1969)



Junkers Test Depiction

To further investigate the thread locking capabilities of a hybrid nut with an integrated locking coil insert, IFT subjected a ¼-28 alloy steel nut to an independent Junkers test per ISO-16130. The main purpose of the test was to compare the proof load retention of the IFT thread locking feature in a low-profile nut to that of a purchased competing product. The competing product was a NAS9926 self-locking nut, low height, 12 point, and made from A286 steel. Note that this nut had a crimp style thread locking feature common to the aerospace industry. Relevant size and material strength properties of both nuts were the same for accuracy.

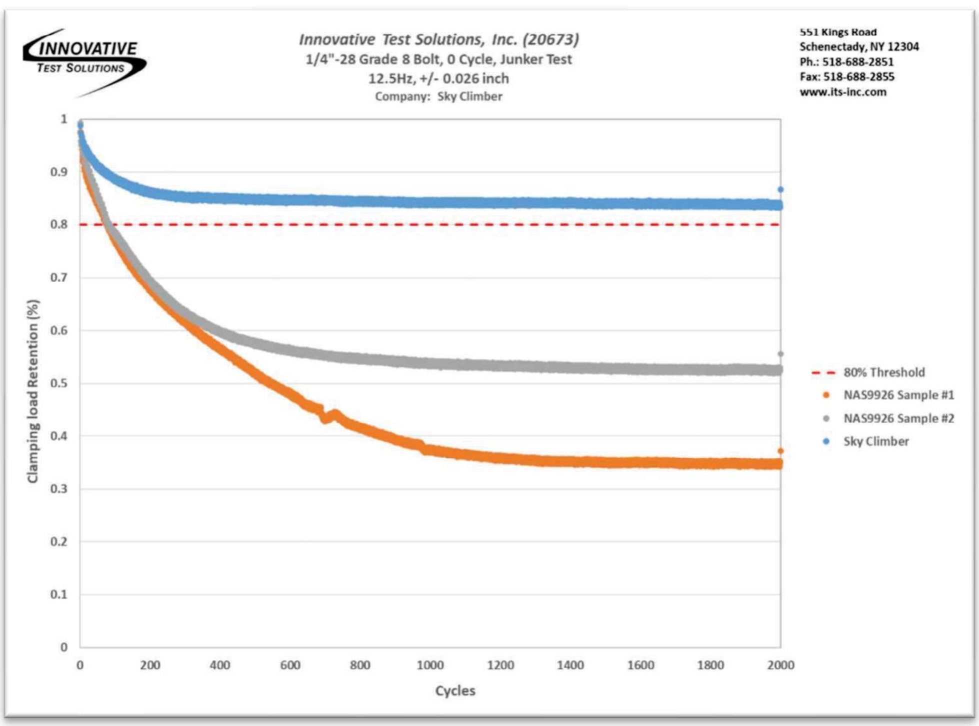
Test procedure highlights:

- A reference test was carried out per ISO-16130 paragraph 6 establishing the transverse displacement and the pre-load of the test.
- The frequency of the test was 12.5Hz.
- The length to diameter ratio of the test bolts as specified by ISO-16130 paragraph 7 did not apply to accommodate the test machine.
- Virgin nuts (no prior threading) were used.

Junker test are results shown in the Table #1 and Graph #4 below:

Table 1

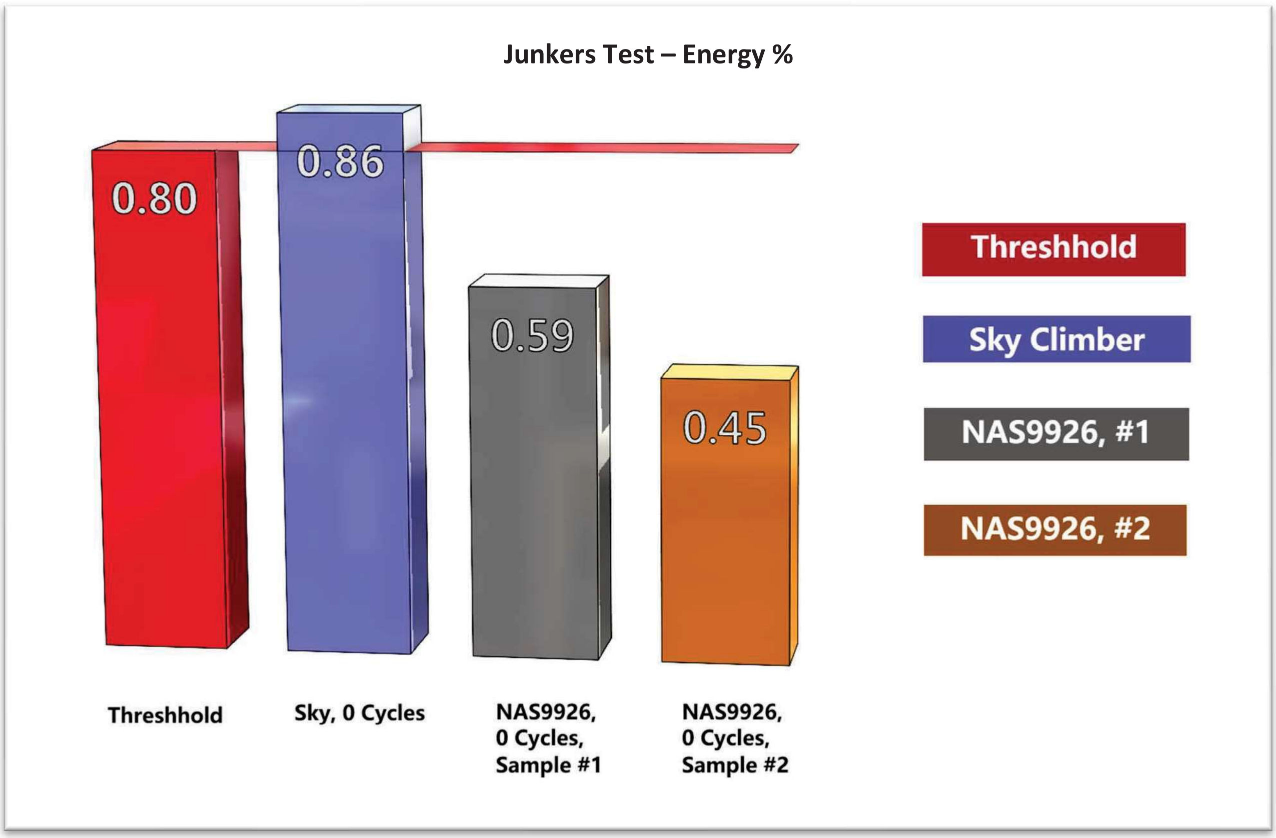
ZERO CYCLES JUNKERS TEST											
Nut Type	Lubricant Used	Test Date	Test Temp. (F)	Test Rate (Hz)	Transverse Displacement (in)	Initial Torque (ft-lbf)	Initial Compressive Load (Lbf)	Final Compressive Load after 2000 Cycles (Lbf)	% Retention of Compressive Load after 400 Cycles	% Retention of Compressive Load after 2000 Cycles	Does Hardware Retain 80% of Initial Compressive Load after 2000 Cycles?
NAS9926 #1	None	2/25/2021	75	12.5	+/- 0.026	10.3	1957	728	57%	37%	NO
NAS9926 #2	None	2/25/2021	75	12.5	+/- 0.026	11.8	1971	1096	60%	56%	NO
Sky Climber	None	2/25/2021	75	12.5	+/- 0.026	14.8	2000	1734	85%	87%	YES



Graph #4 (% Retention from Table 1)

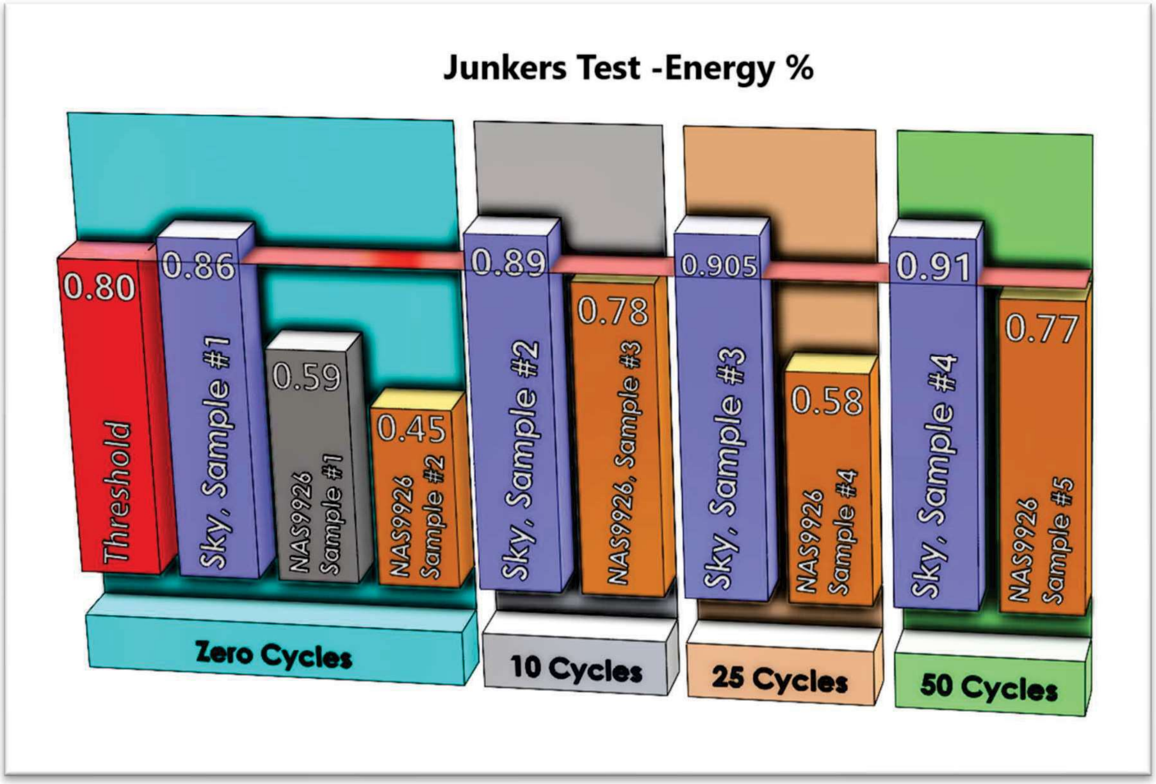
Notably, the IFT hybrid nut retained 87% of the compressive load versus the worst case NAS9926 nut retaining only 37% of the load.

Graph #5 shows a comparison of the area under the curves depicted in Graph #4. This translates to the total retained energy percentage of the bolted system.



Graph 5 (Energy, Area Under Curve)

Further Junkers testing was done to show the effect of thread cycling on the load retention capabilities of the IFT hybrid nut and the NAS9926. Cycling is defined as assembly and disassembly of the nut and bolt – threaded in, threaded out. Specimens were tested at 10, 25 and 50 cycles. Results of the retained energy of the system are shown in Graph #6



Graph #6

Note that the results improved for both nut styles with cycling. This is the result of roughing of the contact surfaces of the nut locking features and consequent increase in friction. Also note the consistency of the IFT nut results as compared to the fluctuating NAS9926.

Conclusion

It was clear years ago when the aerospace industry used coil thread inserts in castings and aluminum parts that the technology produced a superior bolted joint. Now, the technology has taken a step further and we can show that joining coil inserts with nuts produces a superior nut. To provide weight reduction, nuts made from aluminum, plastic, or carbon fiber are now possible with an integrated locking in the thread coil. Given the load sharing properties of coil inserts, these lower strength materials perform beyond their mechanical properties in terms of axial tensile load capacity. Further, in cases such as the MS21042 hydrogen embrittlement issue, the load sharing properties of coil inserts allowed the hybrid product to be made from a tougher, more ductile temper of steel, and, most importantly, a temper below the hydrogen embrittlement threshold of 39 HRC.

In terms of vibration resistance, independent testing has proven that the integrated locking feature in a thread coil performs with outstanding results when subjected to the rigors of a 30,000 cycle vibration test per NASM1312-7. Further, more rigorous Junkers testing showed proof load retention over 80%. This is a marked improvement over crimp-style thread locking and a result approaching that of expensive, weighty, add-on devices such as Nord-lock®. The thread locking feature in a thread coil also provides consistent, long life performance in terms of locking and breakaway torque, insuring guaranteed reusability for the life of an application.

Additionally, another result of this design is that coil inserts can be replaced if thread damage occurs. This is important in higher end aerospace applications such as nut plates or dome nuts when the nut assembly is permanently attached to a structure.

For higher performing threaded nuts in terms of weight, performance, vibration resistance and strength, integrating a locking coil insert is the optimum choice. In advanced applications where manufacturers are limited by decades-old fastener designs, this marriage of coil inserts and engineered materials equates to improvements over existing technology and new solutions to tough fastening applications. This technology is patented by IFT.

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