From Earth to Saturn:

Getting a Grip on Vibration, Shock and Extreme Temperature

By Del Williams

A unique internal thread form is helping manufacturers combat vehicle vibration, shock and temperature extremes not only on the toughest earthbound applications but also on the frigid surface of Saturn's largest moon - for improved safety and performance as well as lower warrantee, service and assembly costs

When the Cassini-Huygens spacecraft enters Saturn's orbit in July 2004, it will have endured - for the first time in human history - not only the vibration, shock and temperature extremes of a Titan IV rocket launch, but also a seven-year journey from Earth across more than 750 million miles of space. Later, the Huygens probe will dive into the murky atmosphere of Titan, Saturn's largest moon, measuring atmospheric composition all the way down to Titan's frigid surface. For accurate atmospheric measurement of both Saturn from the Cassini orbiter and of Titan from the Huygens probe, several hundred bolts must maintain vacuum-tight sealed cavities for the duration of their mission, with no thread loosening or stripping.

Whether the goal is to work on a construction site, get to the next sand dune or travel to Saturn, operators of everything from the Cassini-Huygens spacecraft to ATVs, motorcycles, skid loaders, trucks and buses depend on quality vehicles that perform as expected time after time. Yet for all their high tech componentry, vehicles today must still hold together reliably and functionally with simple fasteners and thread forms. When components loosen, rattle or fail, the problem can often be traced back to the lowly threaded fastener, a technology as old as manufacturing, basically unchanged for centuries.

In these cases, the vibration, shock, or temperature extremes inherent in travel or work routines is often the culprit. These can drive up warranty and service costs, impair quality or safety and raise liability issues. Also important are fastener assembly costs, as well as service issues in the field where operators or mechanics may adjust vehicles and need access to reusable fasteners.

Fortunately, vehicle manufacturers as diverse as NASA, Dana Corp. and Gehl Products are taking advantage of a unique internal thread design that not only virtually eliminates warranty and service concerns related to the vibration and shock of travel but also enhances product quality, safety, ease of assembly and facilitates necessary adjustments in the field. Manufacturers are solving vehicle design issues and enjoying total cost savings in the six figures simply by changing the threads in their fasteners.

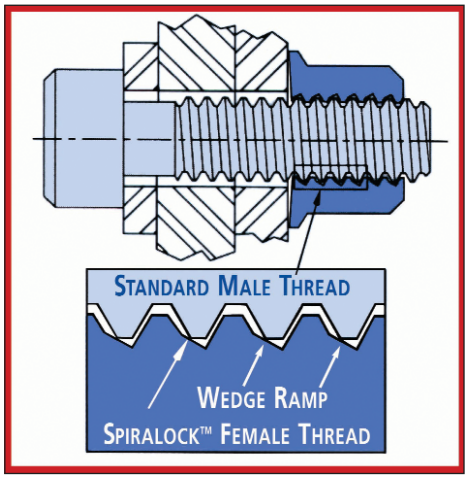
The Limitations of Traditional Threaded Fasteners

To keep threaded fasteners tight, traditional techniques include split washers, prevailing torque nuts, deformed threads, nylon plugs and chemical bonds. But these approaches not only have limited effectiveness against vehicular vibration and shock but also can significantly add to total costs through increased warrantee and service repair, more complex assembly and a general lack of reusability. These traditional fastening methods, in fact, are manufacturing "Band-Aids" that fail to get to the heart of the problem - the thread itself.

Inherent in any threaded fastening system is the necessity for clearance. In most cases, sufficient clearances are required for easy assembly of male and female threads. The design and size tolerances of standard thread forms also must allow for a variety of unavoidable problems such as drill, tap and die wear with resultant hole size variation, as well as errors in placement, machine setup, thread finish, etc. The result, falling within these manufacturing tolerance parameters, is engaged threads with clearance between the male and female members at the crest and root of each.

Unfortunately, the radial clearances between traditional male and female 60° "vee" threads permit relative sideways or lateral movement when shock, vibration or transverse loading occurs. Any sideways movement in the conventional threaded hole reduces locking friction between the thread flanks. As this happens, the tension, or load force, in the male fastener generates self-loosening rotational movement.

Moreover, common stripping or shearing problems can occur when conventional 60° "vee" threads position the majority of the clamp load on the first engaged thread, permitting subsequent male threads to virtually "float" within the female threads. Testing has found that the first two threads carry as much as 80 percent of the load. When the load is applied, the male fastener stretches between the head and the first engaged thread. As clamp load continues to increase, the second thread takes some of the load. In many cases, however, the force required to transfer a significant amount of the load to the third and fourth threads begins to shear or strip the first thread.



Spiralock's unique 30º wedge ramp female thread securely connects standard male thread forms.

Solving Fastening Problems with A New Thread Design

Through the physics of the thread itself, Madison Heights, Mich.-based Spiralock Corp. introduced a new thread form designed to address the fastener loosening and stripping problem caused by vehicular vibration, shock and temperature extremes. The secret to Spiralock's thread form is a 30º wedge ramp cut at the root of the female thread. Under clamp load, the crests of the threads on any standard bolt are drawn tightly against the wedge ramp. This causes thread contact forces to be applied at approximately 60º from the bolt axis, rather than 30º away as in a standard thread form. The mechanical advantage, the angular relationship between the unique wedge ramp and the male thread, restricts bolt or screw movement.

The wedge ramp not only eliminates the transverse motion that causes loosening under vibration but also distributes the loads of the threaded joint throughout all the engaged threads.

Research studies at both the Massachusetts Institute of Technology and the University of Michigan confirm that the percentage of the load carried by each engaged thread produced with a Spiralock tap is much more uniform than with conventional 60° thread forms.

More importantly, the studies show that the percentage of load on the first engaged thread produced with a Spiralock tap is significantly lower. One particular test achieved 18 percent versus 34 percent. As a result, Spiralock thread forms eliminate intense concentration at the first engaged thread, thereby reducing bolt failures and improving product performance.

The wedge ramp allows the fastener to spin freely until clamp load is applied. At that point, the crests of the standard male thread form are drawn tightly against the wedge ramp, eliminating radial clearances and creating a continuous spiral line of contact along the entire length of thread engagement. This spreads the clamp force more evenly over all engaged threads, reducing fatigue failure and increasing the integrity of the threaded joint. This dramatically increases the holding power of any standard male fastener, without excessive torque or messy friction additives.

In extensive laboratory tests, Spiralock threads have demonstrated superior resistance to vibration loosening. These tests compared three types of female thread forms: a standard nut, a prevailing torque locknut and a Spiralock nut, under comparable, controlled conditions. The standard nut lost its preload (tension) clamping force almost immediately, and the prevailing-torque locknut lost 70 percent of its preload clamping force. The Spiralock nut, however, maintained its preload clamping force for the entire test period. Additional tests verified these results and demonstrated that the Spiralock threads, unlike the others, can be loosened and retightened many times with no appreciable loss of holding power. This can substantially reduce maintenance costs, since it eliminates the need for add-on locking components such as lock washers, thread adhesives, crimping or inserts, to name a few. Elimination of these secondary locking components also prevents loosening problems caused by forgetting to add them in the reassembly or service phase.

Threads Withstand Blast-Off Vibration and Temperature

NASA was one of the first to appreciate the advantages of the new thread when designing the main engines of the Shuttle orbiter. Each of the three main engines develops 400,000 lb. of thrust and terrific vibration. But the Space Agency also wanted a 15-cycle reuse capability per fastener.

Under its own test, NASA determined that the fasteners in Spiralock-threaded holes did not back off or loosen when subjected to ten times shuttle-specified vibrations, and they stayed that way ten times longer than called for. As far as its 15-cycle reuse capability was concerned, NASA tests found the Spiralock-thread fasteners delivered 50 uses, with no loss of clamping power. To this day, every shuttle engine carries no fewer than 757 Spiralock fasteners.

For atmospheric measurement of Saturn and Titan on the current Cassini-Huygens mission, NASA used the Spiralock internal thread form to resist vibration and temperature-induced thread loosening on mass spectrometer instrumentation. Together in the Cassini orbiter and Huygens probe, several hundred fasteners had to maintain vacuum-tight sealed cavities from final assembly and testing through launch, until the end of the seven-year mission.

"To survive the vibration and high temperatures of launch, we required the most reliable locking engagement thread," said Dan Harpold, a NASA scientist who worked on the project. "Screws had to remain tight without opportunity for retightening. With conventional threading, however, screws loosened up and backed out under testing."

Among the tests carried out were a series of about 12 high temperature "bake outs", where screws and their matching internal thread forms were heated from room temperature to 300° C to simulate temperature-induced thread loosening.

"The Spiralock thread form retained a tight seal at 300° C," said Harpold. "Once torqued down properly,

the screws stayed put in the threads, which helped us meet our flight schedule. To date, not one has come loose that I'm aware of."

Thread Stripping Prevention on the Toughest Terrain

On the trails, dunes, forests and mountains of Earth, a popular, rugged ATV vehicle endured its share of fastener and thread stress due to vigorous off-road shock and vibration. Part of Howard Reaser's job was how to mechanically deal with that stress as Product Application Engineer at Fredericktown, Ohio-based Dana Corp., an axle manufacturer for ATVs and the leisure utility vehicle market.

"The aluminum, split axle, housing for a brand-name ATV had to withstand heavy off-road punishment and vibration without fastener loosening, stripping or oil leakage," said Reaser. "Since the axle supported the tires, the bolts were constantly shock loaded as the ATV maneuvered over tough terrain."

In design testing, Reaser and other engineers noted that conventional fasteners tended to loosen and strip under the punishment provided at a severe off-road testing ground. "Because there wasn't equal loading on all the threads, some of the bolts loosened and stripped," said Reaser. "That was unacceptable, as the ATV market is extremely competitive. Riders want ATVs that work flawlessly wherever they go. And since they often make modifications to tweak performance, fastener reusability was an issue as well."

After thorough testing on the proving ground, Dana Corp. chose Spiralock taps for the aluminum split axle ATV housing. Spiralock's thread form works especially well in soft metals and materials prone to stripping, such as aluminum, due to its uniform load distribution. By spreading the load over the entire engagement and redirecting the forces radially into compression, significantly higher loads can be achieved without stripping threads.

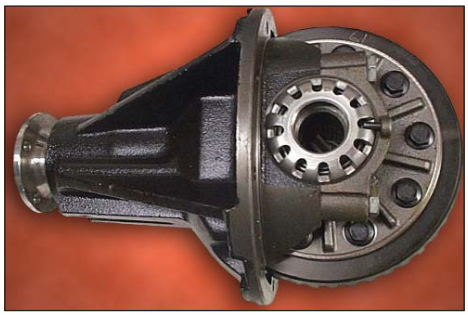
"The thread loosening and stripping problem is gone and due to fastener reusability in the field and elsewhere, service life is extended as well," said Reaser. "Load distribution on the threads is the key difference between Spiralock and conventional thread forms. Their form seems to equal out the load on all the threads, rather than just the first few."

Extensive testing on Junkers transverse loading test equipment has proven that holes (or nuts) threaded with Spiralock taps outperform a wide variety of self-locking fasteners. In all tests performed, Spiralock nuts stayed locked long after a standard nut and a prevailing torque locknut failed. In many tests of this type, a Spiralock nut remained tight even when vibration amplitude and frequency were increased to the point where the bolt itself failed.

"With Spiralock threads, we haven't had an issue on 20,000 axle assemblies to date, with 12 fasteners per assembly," said Reaser. "And we haven't had to replace any axle housings in the field. We're eliminating future problems by getting it right from the start, so service and warrantee costs will be much lower."

Saves $100,000 in Warrantee Service, Many Assembly Hours

Skid-steer loaders, all-purpose machines for strenuous construction applications, often change operators every two hours because they receive so much abuse. For site preparation, in quarries and barges, and in rental fleets, they are used for digging, pushing, pulling, and even building demolition. They need to withstand jarring and vibration under constant, heavy use to minimize production downtime, keep projects on schedule and maximize control and safety.



Spiralock thread forms are used by Dana Corp. to fasten the ring gear shown above to the driveline of axles.

A decade ago, Roger Albertson, a manufacturing engineer at Gehl Products, a Madison, South Dakota based manufacturer of construction equipment, sought a solution for the abuse Gehl skid loaders received in the field, as warranty service costs were too high.

"Under constant back and forth motion and jarring vibration, certain fasteners wouldn't hold tight on typical threading," said Albertson. "We tried just about everything from locknuts and adhesives to inserts, washers, and double nuts. But they either came loose in the field, posed assembly problems, or both. Another complication was that operators had to adjust the drive chains every 100 hours in the field, so fastener reusability was a requirement as well."

After testing and investigation, Gehl Products chose to use Spiralock threaded fasteners for added vibration resistance and holding power. Because the design change worked so well, Gehl Products later added Spiralock fasteners to all hard joints on products, such as motor mounts, lift control levers and rods, for locking ability and ease of assembly. Unlike torque nuts that resist, Spiralock fasteners spin freely until they "lock" to hold assemblies together. Use of them has eliminated Gehl Products need for locknuts, flat washers or other secondary locking mechanisms that add cost and complexity to assembly.

"The change has virtually eliminated service and warranty concerns in these areas," said Albertson. "This not only keeps customers happier but also keeps our assembly line operators more productive. And when required, customers can easily make adjustments in the field without fasteners loosening, stripping or ending up as a warranty problem."

"In the nine years since we first installed Spiralock fasteners, they've not only held tight but also allowed for repeated reuse and adjustment in the field," continued Albertson. "By minimizing the need for warranty service and simplifying assembly, I'd estimate we've saved over $100,000 in the last nine years."

Gary Svidron, a design engineer for International Truck and Engine Corp., a Warrenville, Ill. based manufacturer of trucks, buses and diesel engines, also sought fastener resistance to vibration and shock. In particular, he faced a design challenge in securely fastening a turbocharger to an exhaust manifold on a six-cylinder diesel engine used in trucks and buses, where fasteners had to retain clamping power at high temperatures.

During pre-production testing, standard nuts and other traditional fasteners came loose due to sustained road vibration, and adhesives simply didn't work because engine-operating temperatures were too high.

"Joint integrity on the turbocharger/exhaust manifold was critical to prevent gasket leaks, warranty costs, and exhaust leakage, which can cause particular problems in states like California with strict emissions standards," said Svidron. "Moreover, truckers and bus drivers can't tolerate downtime, since staying on the road is their livelihood. To keep them on the road and warranty costs down, we needed fasteners that quickly and securely clamped in place for the life of the engine. This would make it easy for our dealers' service technicians who have to keep our customers on the road."

After pre-production dynamometer and field testing, International Truck replaced standard flange nuts with stainless steel Spiralock fasteners. "We've not only solved the joint integrity problem, but also avoided potential assembly issues with prevailing-torque-style fasteners and improved assembly production," said Svidron. "Since the Spiralock fasteners spin freely until it's time to tighten them, they take significantly less time to tighten than resistance-heavy locking methods such as prevailing torque nuts. With four fasteners per assembly on volume of many thousands of engines per year, we're saving a large amount of assembly time."

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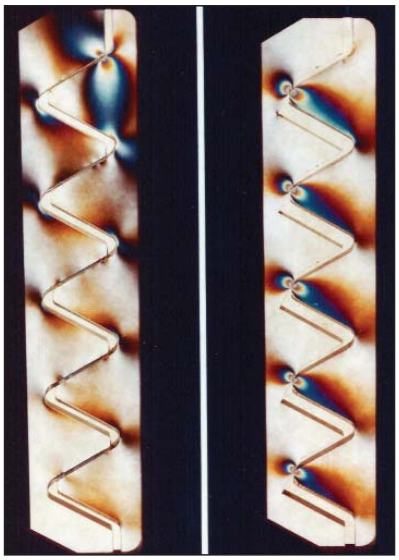

Photoelastic comparison of connection using Spiralock thread with connection using conventional thread illustrates how the load carried by each engaged thread is more uniform with Spiralock.