STANLEY
Engineered Fastening

Vibration Loosening

How self-loosened bolts can quickly escalate from minor annoyance to major problem.

Loose bolts can be an irritating nuisance, but they can also lead to serious and even catastrophic results.

A failure of fasteners may cause costly product warranty recalls, production plant shutdowns, and ecological damage from leaked fluids or gases. Should a bolt loosen and fall any distance, it may also damage equipment or hurt someone, causing serious injury or death.

Given such examples, it may be impossible to overstate the importance of a properly tightened bolt that maintains its integrity.

"The safety and reliability of bolted joints often determine the overall reliability and safety of mechanical and structural systems," says Dr. Cheng Siong Phua, Vice President of Technology for STANLEY Engineered Fastening, Asia Pacific.

For example, in 2012, 432 barrels of synthetic drilling fluids were released into the Gulf of Mexico when 4-foot bolts on a drilling rig failed.[1] As a result of an investigation, the U.S. Bureau of Safety and Environmental Enforcement worked with the manufacturer to ensure that any faulty bolts deployed under federal jurisdiction were replaced. The manufacturer had to change out 10,000 bolts and disrupt deep-water operations, according to a summary of the BSEE's findings.[2]

It's easy to see that joint loosening is a serious issue: That's why STANLEY Engineered Fastening's core technologies address such solutions as vibration resistance, joint integrity, corrosion resistance, push/pull, quality assurance and built-in early detection mechanisms.

Even with STANLEY's support and expertise, and its vast resources of fastening solutions, it's worthwhile to learn what happens when vibration loosens a bolt, how to troubleshoot self-loosening, how to prevent weakened clamp force, and what goes into a properly tightened bolt.

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>
> *Jesse Tarr*
> *Owner, Wind Secure*

Tightening torque: T is only an estimate

“When you tighten a nut or a bolt, when do you stop? When do you decide that the joint is good enough?” asks Phua, in a reflection of his engineering training. “It can be measured.”

Engineering science includes this formula to determine torque:

Torque (T) = Nut Factor (K) X Bolt Diameter (D) X Resistance Force (F)

But keep in mind that T is only an estimate, Phua says. Every application should be simulated with tension-indicating equipment to help figure the appropriate tightening value for that particular job. Then he adds a cautionary reminder: When the appropriate value is determined, operators should measure whether it’s being attained in real-world situations.

That’s a lesson one bus manufacturer learned only after an investigation into its bolt failures.

The manufacturer used an M24 strength grade 8.8 bolt to secure one of four engine mounts to a bus chassis, according to a case study from the U.K.-based training and consultancy company Bolt Science.[3] Following the introduction of the bus into service and the use that followed, reports started coming in that bolts were occasionally found loose, and on a number of occasions, the bolts were failing.

The tightening torque that had been specified was 660 Nm, according to the case study. Engineers achieved this torque on the prototype test vehicles, but it proved to be difficult to achieve on production vehicles and also in service by maintenance staff. This was due partially because of space constraints and partially because of lack of appropriate equipment.

After troubleshooting, the tightening torque actually achieved was closer to 400 Nm, which was too low to maintain clamp force. That led to the loosened and failed bolts. The problem was resolved by using a smaller diameter bolt, increasing the strength grade, and using flanged fasteners. This increased the stretch of the bolt, resulting in less preload being lost from any embedding.

As the bus chassis example illustrates, in addition to determining the physical parameters of a joint, one of the most important things to know is where the fastener will be used, and what environmental factors it will be subjected to, says Phua.

Jesse Tarr, owner of Wind Secure in Lake Orion, Michigan, knows about environmental factors acting on a joint. He’s turned bolt self-loosening on wind turbine installations into a thriving business.

Tarr started his service company 11 years ago after noticing that the $6 million machines, which he had previously installed to spec, were subject to bolt loosening from vibration and other operational stresses. As a result, the steel rebar-reinforced concrete foundations were prone to breaking apart.

“If the bolts holding down the turbine get loose, it exerts a force on the foundation almost like a jackhammer,” he says.

Most of the loosening problems Tarr sees are due to improper tension being applied to the bolt, although the bolts could potentially loosen even if installed properly. With 160 steel bolts holding each turbine to its foundation, and 700 more steel bolts holding the turbine’s 300-foot tower sections and blades together, there’s enough work for Tarr and his 12-person full-time crew year-round, inspecting and repairing wind farm installations coast-to-coast.

While Tarr’s on-the-spot repair work to tighten bolts and repair concrete takes serious effort, some applications don’t lend themselves to fixes at all, and call for a blanket inspection process because so much is at stake.

Failure detectives go back to beginning

With joint failure, the initial focus is on checking whether the parts and assembly process meet design specifications, says Dr. Bill Eccles, founder of Bolt Science and a consultant who specializes in bolting problems.

"The materials that the parts are made of is also normally checked that they are to specification," Eccles says. "Usually this starts with a hardness check since this is a quick way to establish that the tensile strength is appropriate."

Eccles also checks the assembly process to establish if the fasteners were tightened correctly. Usually, this involves checking that the correct torque has been applied.

Once he establishes the parts and assembly process are correct, Eccles' focus turns to the design and the operation of the equipment, and he checks the original design calculations, if they exist.

He also assesses if the operation of the equipment is within original design restraints. For example, is a vehicle designed for on-road use working off-road, imposing higher loads on the structure?

Subsequent questions would relate to the design of the joint, Eccles says. It's not unusual to find that the designer missed, or was ignorant of, a particular loading condition that would impose loads such that the joint would slip, resulting in the fasteners loosening.

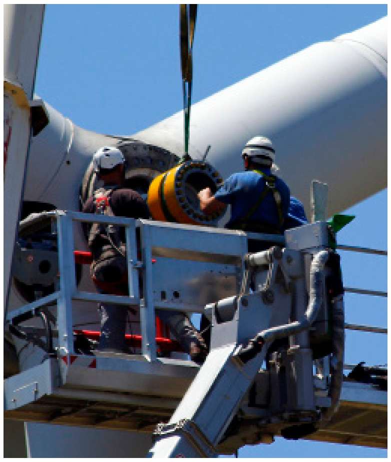
Normally, the investigator would complete a joint analysis that determines whether there is sufficient preload to prevent joint movement.

"Normal investigative tests would involve establishing whether the assumptions used in the preload calculations are valid," Eccles says. "Torque-tension tests are completed and sometimes supplemented by friction determination checks."

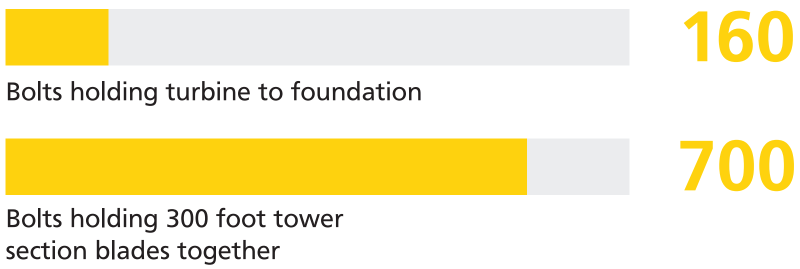
One resource available to Eccles and other joint failure analysts is the cache of data collected by modern bolt tightening equipment.

Government regulators require traceable data be collected and stored by companies operating in the aerospace, vehicular and medical industries. This collection of data is valuable as investigators try to figure out why a joint has failed.

"If loosening happens even years after the job, all data is archived in a server, including when the joint was done and who did it," says Vahid Amirzadeh, the Frankfurt-based European Senior Product Manager for STANLEY Engineered Fastening. "Then they can find out where the problem came from. Was it from the material or was it from the operator or the supplier? These are the different sources that can be identified."



Wind Turbine Steel Bolt Usage (Total: 860)



Ensuring Bolts Stay Tight – Even In Space

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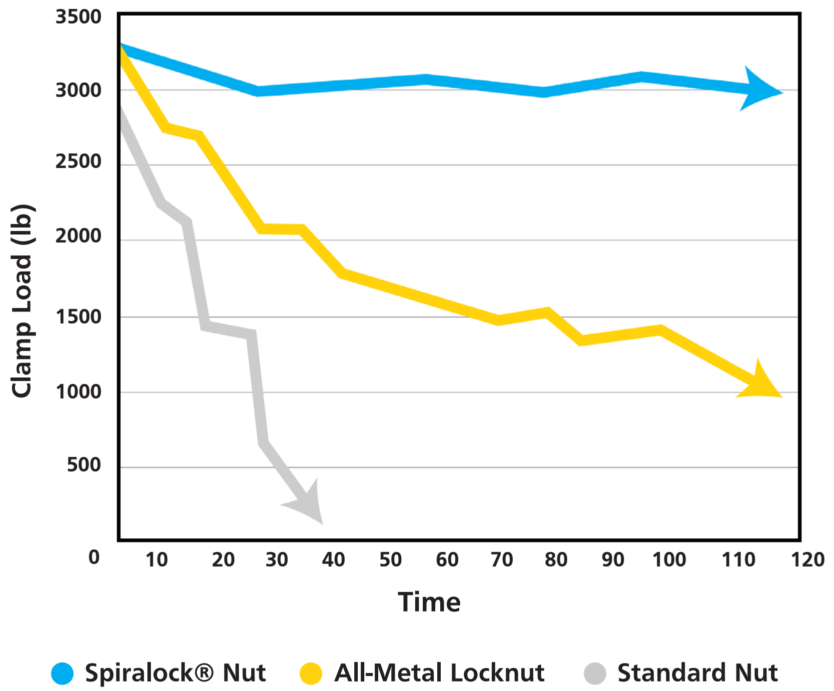


The Spiralock® thread form has been tested at the Massachusetts Institute of Technology, the Lawrence Livermore National Laboratory and the Goddard Space Flight Center. Spiralock® joints remained tight during tests that were 10 times the vibration of the Space Shuttle's solid rocket boosters.

Maximillian Braun, Application Engineer for STANLEY Engineered Fastening's Spiralock® products in Giessen, Germany, says "One question we would ask an aerospace customer is 'Is your part flight critical, is it safety critical?' If it is, we discuss with the customer and go up to 100 percent inspection because you're risking lives if it's not working correctly."

Repeated research has confirmed the Spiralock® threads carry load much more uniformly than do standard threads. The uniform loading reduces the load concentration at the first engaged thread, thereby decreasing joint failures due to shearing. In addition, the thread form distributes joint load more radially, preventing threads from slipping even in extremely high vibration.

Textbook examples of prevention

In general, the strategy for preventing self-loosening of fasteners depends on three variables, according to Bolt Science:

- Applying the correct torque to provide sufficient clamp force prevents relative motion between the bolt head or nut and the joint.

- Employing tested and proven thread-locking devices.

- Using joint and fastener designs that accommodate the effects of embedding and stress relaxation.

Engineers and designers have devised many solutions to keep joints tight: They use a range of adhesives, double nuts, mechanically locked fasteners, lock wire and pins, the Stage 8 fastening system, and more, according to the ***Introduction to the Design and Behavior of Bolted Joints***, an engineering textbook.[4]

Coincidentally, the textbook mentions STANLEY Engineered Fastening's Spiralock® brand self-locking threaded solutions, citing its design as being "especially effective."

From the textbook:
"The bolt threads here are conventional, but the root of the nut threads is a tiny ramp or inclined plane. As the nut is tightened, the tips of the male thread are forced into interference fit with the ramps. This eliminates all clearance between male and female threads.

"The inventor of this thread form, Harold (Ace) Holmes of Detroit, is a firm believer in the Junker theory of vibration loosening. He designed the Spiralock® thread form to eliminate loosening by eliminating slip clearance — and the results seem to support Junker's theories."

> **"The Spiralock® resolution brought us valuable savings in manpower, time and money."**
>
> *Rich Demski*
> *Pierce Manufacturing, Chassis Product Manager*

A key Spiralock® benefit over conventional locking methods is that the male fastener can be loosened and re-tightened many times without any loss in locking force, thus reducing maintenance costs. The thread form works with standard male fasteners and eliminates the need for add-on locking components such as lock washers, thread adhesives, crimping or inserts, to name a few. The 30° wedge ramp cut at the root of the female thread also significantly reduces common stripping or shearing problems because the design distributes the clamp load much more evenly over the threads, which improves safety.

COMMON CAUSES OF JOINT FAILURE

Self-loosening is caused by many types of dynamic load, such as vibration, changes in temperature, insufficient clamp load, and poorly fitting parts. Each allows relative movements to increase the risk of self-loosening, according to a 2017 article in ***Engineer Live*** magazine.[5]

Each load change leads to a short-term, frictionless situation where the bolt unwinds from the nut. The sum of these almost infinitesimal movements ultimately results in the loosening of the threaded assembly.

By far the most frequent cause of loosening is side sliding of the nut or bolt head relative to the joint, resulting in relative motion occurring in the threads. If this does not occur, then the bolts will not loosen, even if the joint is subjected to severe vibration.

Relative motion occurring in the threads can be attributed to three common problems:

- Bending of the parts, resulting in forces being induced at the friction surface. If slip occurs, the head and threads will slip, which can lead to loosening.

- Differential thermal effects caused by temperature fluctuations or differences in clamped materials that have different reactions to changing temperatures.

- External forces applied on the joint, which can cause the joint surfaces to shift, leading to bolt loosening.

Holmes' invention improved safety, simplified assembly and cut costs for Oshkosh Truck Corporation, a manufacturer of heavy-duty military and commercial vehicles, and for its subsidiary, Pierce Manufacturing, maker of custom firefighting apparatus. All three applications — military, commercial and firefighting — depend on equipment that functions properly without fail to ensure smooth operations and to safeguard the lives of those operating it.

Oshkosh was prompted to try Spiralock® when its previous locknuts and adhesive were ineffective at preventing vibration loosening. This led to increases in warranty and service costs.

Testing of Spiralock® nuts and taps in critical Oshkosh threaded joints resulted in an end to the loosening problems as well as documented cost savings. Oshkosh was able to simplify the assembly process, reduce harm to the environment and employees, and lower costs associated with the purchase and use of the thread-locking compounds.

Eliminating service and warranty issues related to fastened joints provided additional cost savings.

At Pierce, loosening striker bolts on fire truck doors caused rattling problems. Engineers tested a series of standard locking nuts, but without satisfactory results until the Spiralock® locking thread form technology came into the picture. An Oshkosh engineer recommended testing a Spiralock® nut on the door striker bolts, and the loosening problem was solved.

The application was initially tried on one model of Pierce truck but quickly advanced to five different models, which now all use Spiralock® nuts.

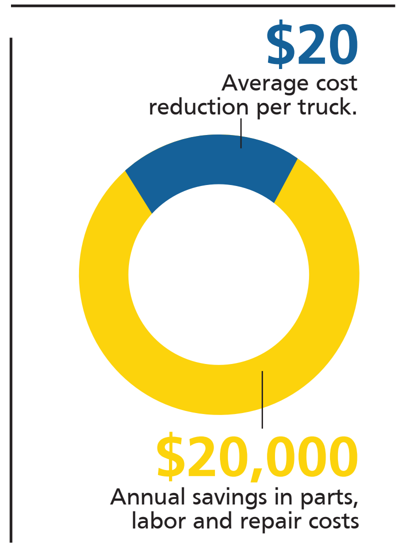
"The Spiralock® resolution brought us valuable savings in manpower, time and money," reports Rich Demski, the chassis product manager at Pierce.

With an estimated average cost reduction of $5 per door ($20 per truck), Spiralock® technology saves Pierce roughly $20,000 annually in parts, labor, and repair costs on this application.

Also, switching to a Spiralock® nut allowed Pierce to eliminate a weld-on cage nut on fire truck door latches. Spiralock® engineers went a step further and designed a custom nut that prevented slippage during assembly. This brought further improvements in the production area. What was once a two-man operation became a one-man task.

"Working with Spiralock® engineers was a great experience," adds Peter Chard, Pierce's Senior Manufacturing Engineer. "We came looking for a nut to eliminate rattling and loosening, and we got one that eased assembly as well. We ended up with a better design and happier customers."

Spiralock® Technology for Pierce Manufacturing



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Sources

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[2] "QC-Fit Evaculation of Connector and Bolt Failures Summary of Findings," Bureau of Safety and Environmental Enforcement, 2014
[3] Bill Eccles, "Failure of an M24 Engine Mounting Bolt," Bolt Science, 2006
[4] John H. Bickford, "Introduction to the Design and Behavior of Bolted Joints, Fourth Edition," 2007
[5] Paul Boughton, "Preventing Nut and Bolt Self-Loosening," Engineer Live, 2017

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