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New Insights of How Non-Traditional Products Can Improve Reliability

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Abstract

Root cause failure analysis is often employed when critical pieces of equipment fail. True root cause failure analysis forces you to ask 'why' five times. We have observed through reading case studies that the 5th question will sometimes identify the mode of failure – a fastener loosened - instead of the root cause of the failure – insufficient clamp load.

This session will use case studies and laboratory data to provide new insights into the root cause for typical mechanical loosening and sealing failures. It will explore the reasons why some of these root causes are most effectively addressed with 'non-traditional' chemical solutions.

Bolted joints have a very complex relationship between clamp load, and the torque-tension relationship of threaded fasteners. A common perception is that with a specified torque a bolted joint produces consistent clamp load. Load cell tests of identical bolts sourced from multiple manufactures demonstrate that the actual clamp load when torqued to a specification can vary by over 20% if used in as received condition. The use of a chemical thread treatment can dramatically reduce the deviation and provide additional reliability benefits.

Gas and fluid leakage are common maintenance reliability issues. Root cause analysis has been applied of typical flange and threaded fittings configurations. The results identify several failure modes which can be countered with specific types of chemical sealants.

Machinery Equipment Reliability can be influenced by many factors. Through experience we have observed a number of factors which can influence this. Many are considered non-traditional even though they have been around for many years.

In this paper we will discuss the following areas and how they tie to producing a reliable joint.

True Root Cause of Failure

Root cause failure analysis is employed when critical pieces of equipment fail. True root cause failure analysis forces you to ask 'why' five times, the goal being to resolve the problem into the most basic elements.

We have observed through reading case studies that the 5th question or ultimate root cause will go down to the level of the fastener loosened or the gasket leaked. This fails to probe down to the assembly process to get to why this occurs, and to avoid it happening again. In examining either a loosened bolt or leaky gasket, it often comes down to a fastening system that has failed to provide adequate clamp force. This is the true root cause, and it is avoidable with proper assembly techniques.

Bolted Joint Mechanics

A bolted joint is at its most basic form a wedge wrapped around a cylindrical part. As the bolt is turned, the threads effectively wedge the two parts together. The more the bolt is rotated, the more clamp load is achieved.

As we move to a practical system both the nut and the bolt have tolerances to ensure they will not bind when assembled. By default this means that a bolted joint will have variable gaps dependant on the combination of tolerances in each part.

Picture 1: Tolerance of bolted system

Surface finish of bolts is related to how they are manufactured, the dies used to produce them and technology used to form the part. Though threaded fasteners conform to well- recognized standards, each manufacturer has slightly different processes that will lead to small but ultimately significant differences to surface finish and under head profile that affect the bolted system.

When a threaded system is assembled the presence or absence of a lubricant will greatly change the lubrication co-efficient. Bolts received from a manufacturer may have permanent coating or plating, residual cutting fluids, anti-corrosion oils, etc. The challenge is these are not documented, and often overlooked as to their influence on the bolted joint.

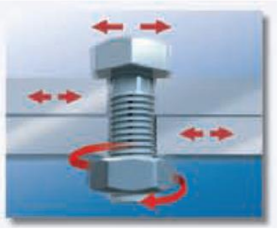
Most fasteners are in dynamic systems subject to vibration. Though high vibration captures attention, even low force vibration over time can cause issues. In the electrical industry it is common for mail electrical panels to require re-torqing of set screws due to the effect of the AC current over time.

A bolted system has variables that are difficult to model. As discussed, tolerance, surface roughness and friction of the surface all impact the assembly and lead to potential issues.

Vibration Loosening

This effect is tied to tolerance. Under vibration, a machine moves back and forth. The bolted assembly due to required manufacturing tolerances has empty space. In a simplistic manner it is often assumed that if you tighten a bolted assembly enough the friction of the surfaces will stop the assembly from loosening.

Under the constant vibration that machinery produces, eventually the bolted assembly will move relative to each other. The rate it occurs will vary, but if a harmonic is reached the disassembly can be very rapid.



Picture 2: Vibration induced motion of bolted system

Returning to the description of the joint as a wedge, any movement back and forth is like standing on a ski hill and sliding back and forth. Under these conditions you tend to move downhill (the path of least resistance), which on a bolted joint system part is to come apart.

Many methods are available on the market to combat this. One of the more effective means is to place a self-curing chemical into the joint to fill the machining tolerances and produce a solid filler. This addresses the root cause of the failure, by eliminating the empty space in the threaded assembly.

Picture 3: Sealing all inner space of bolted system

Mechanical systems to stop vibration run a wide spectrum of designs and effectiveness. Some mechanical systems actually speed the rate at which fasteners come apart. The best of these work but are very costly in comparison to chemical threadlocking systems.

Chemical threadlocking, despite being proven in over 50 years of service, is still considered a relatively new and non-proven technology. It provides a cost to benefit ratio that remains one of the lowest cost, but delivers high performance.

Friction Effect on Clamp Load

When a bolted system is assembled, the clamp load is generated by putting energy into the system, which stretches the bolt. The bolt stretch compresses the assembly to create the clamp load. The most commonly used method of achieving this is to apply a known torque that equates to a certain clamp load. It is a common perception that with a specified assembly torque, a bolted joint produces consistent clamp load.

All nuts and bolts have a surface roughness that produces friction. This has implications when fastener systems are assembled using torque or energy input to correlate the clamp load generated to the amount of energy going into generating clamp load through bolt stretch.

Other methods exist to determine the correct bolt stretch, but have limitations in general service. One example is torque to yield bolts commonly used in the automotive cylinder head assembly, and another is directly measuring bolt stretch with a run out gauge commonly used in wind tower base securing.

In order to quantify this, the following test was conducted.

Bolt Variability from Different Manufacturers

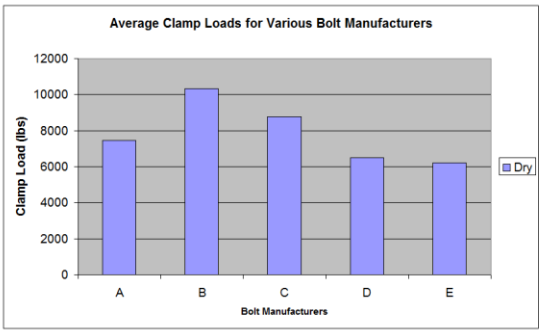
Tribal knowledge within our company had long held that the surface finish, along with the variances in under head bolt design, would produce a wide scatter when each bolt was torqued to the recommended amount.

As an experiment to verify this hypothesis, we acquired 5/8"-NC Grade 5 Zinc plated bolts and nuts from five different bolt manufacturers. Bolts were assembled with a calibrated torque wrench 112 foot-pounds (152 Nm).

We placed each bolt system into a Skidmore-Wilhelm clamp load tester. When the bolted system torqued it squeezes a hydraulic reservoir, producing a pressure that can be measured and directly correlated by knowledge of the diameter of the piston to measure the clamp load.

Picture 4: Torquing of bolts in load tester

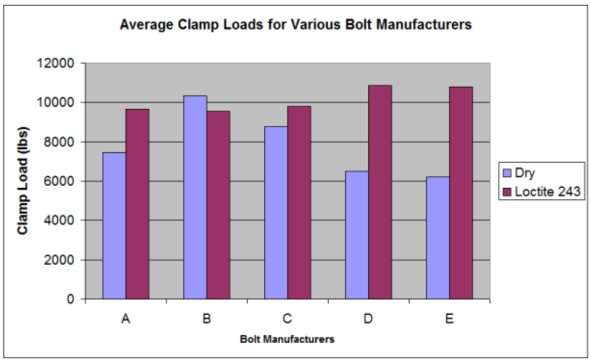
The first test utilized bolts in as received results to illustrate the variance in clamp load. Using bolts in as received condition is common. Table 1 illustrates how this produced a standard deviation in clamp load of 4100 lbs (21%).



Graph 1 – Bolt clamp load variance in As Received condition

In an era of cost avoidance it is not uncommon for manufactures to shop for interchangeable items based on cost. Thus using even with a properly calibrated torque wrench, the clamp load generated can vary significantly.

In the second part of the experiment, we assembled bolts from the same five manufacturers with a chemical threadlocker to observe what effect it had. The results shown in graph 2 demonstrate a significant reduction in clamp load scatter.



Graph 2 – Bolt clamp load variance with chemical threadlocker

In absolute values the range of data dropped to 1300 pounds of clamp load difference from highest to lowest values. Utilizing a liquid threadlocker reduced the effect scatter of clamp load from bolt manufactures.

This is a significant benefit of a chemical threadlocker in being able to reduce variability of the bolted assembly. Consistent lubrication by specifying the material to be used as the assembly fluid is a big benefit. Chemical threadlockers not only stop vibration loosening, but also allow more consistent clamp load by removing variability from the system.

Non-Traditional Chemical Threadlockers – Alternate Forms

One of the barriers to chemical threadlocking was that maintenance staff found carrying liquid materials an issue, due to the potential for spillage. One company has been active in industry at resolving this concern by the introduction of patented technology that allowed for solid format, or “stick” threadlockers.

This innovation was targeted at applications which are done in the field or at the machinery location. The goal was to develop products that could easily go into a tool box, or even a pocket for easy access. A side benefit was discovered in that with this stay in place format, users could apply chemical threadlockers to all fasteners ahead of time, speeding re-assembly.

Non-Traditional Chemical Threadlockers – Primerless on Inactive Materials

A concern with end users was the requirement for flammable primers on chemically inactive materials like aluminum. Many plants and mines banned their use for safety reasons.

Chemical threadlockers normally require free metal ions to cure, and these are found on the surface of metals that corrode like steel. One company in industry has been active in developing materials that cure without a primer, which eliminates both a step and a flammable solvent from the workplace. These primerless materials are a large step forward in making this technology more accepted in the workplace.

Gas and fluid leakage are common maintenance reliability issues. Root cause analysis has been applied of typical flange and threaded fittings configurations. The results identify several failure modes which can be countered with specific types of chemical sealants.

Conclusion

Bolted joints have a very complex relationship between clamp load, and the torque-tension relationship of threaded fasteners. A common perception is that with a specified torque a bolted joint produces consistent clamp load. Load cell tests of identical bolts sourced from multiple manufactures demonstrate that the actual clamp load when torqued to a specification can vary by over 20% if used in as received condition. The use of a chemical thread treatment can dramatically reduce the deviation and provide additional reliability benefits.

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