

The Art of Thread Forming Fasteners

Part One — General Principles

by:

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One of the roles of every Fastener Engineer or Designer is to look critically at each new problem and develop an elegant solution that is as simple in form as it is effective in practice and efficient in cost. That often means using the minimal amount of resources to gain the maximum achievement. The “art” of thread forming fasteners provides a powerful tool in the industry arsenal to achieve such results for customers.

When it comes to fastened joints made up of a threaded fastener and some type of nut member, there are really only two varieties, those that start with a nut member thread already in-place and those that depend on the threaded fastener to create its own mating thread. A great deal of technical information can be found where both screw and nut member are threaded, but far less is available and understood on those where the nut member thread is formed by the screw itself.

This two-part article series will attempt to remove some of this mystery. *Part One* will explore the basic guiding principles of thread forming. These are principles and behaviors that are true regardless of the screw or nut member material. When I am done, it is my hope that the reader will have gained an appreciation for how thread forming works and the general areas of concern for the Fastener Engineer when he or she designs such a joint.

Part Two will explore the more specific and specialized cases of thread forming into thermoplastic, light metal and steel materials. Although not the only materials available for thread forming, these three categories represent the majority of areas where thread forming fasteners are utilized today.

What is Thread Forming?

Starting with the very basics, what is thread forming? Simply, it is a process where the screw acts like a tap and forms a thread into an unthreaded nut member. For the purpose of this article, I am limiting the discussion to screws that deform material rather than cut it. There is a wide variety of screws that have features designed into them to cut the threads into place. Although these are considered self-tapping screws, they are a subset onto themselves and do not exhibit the same behavior as the screws that will be discussed in this article. This is an important distinction because in many cases over the years thread cutting screws have been misapplied resulting in less than stellar performance and discouraging users from employing a more appropriate thread forming strategy.

Material

One of the most basic principles of thread forming screw design and utilization is that the screw must be stronger and harder than the material into which it is forming a thread. Unlike a tap, which can be made very hard and strong and coated with high-performance, wear-resistant coatings, a thread forming screw must balance its functionality to act as

a tap with its functionality as a fastener. Fortunately, while a tap is expected to perform repeated trials, the thread forming screw only has to work as a tap once. However, in that one time it must be capable of acting as a tap without failing because the threads collapse or get sheared off as they are simply not strong enough to withstand the rigors of deforming the material into which they are intended to form a thread.

In addition to the screw being able to withstand the rigor of thread forming, the nut member material itself plays an important role. It must possess both a sufficient degree of plasticity to readily form threads and strength to support the stresses and loads exerted by the thread forming and clamping actions of the assembled fastener. This naturally limits some materials, which are too brittle or others, which are not “strong enough”. Examples of such materials on the brittle end of the spectrum might include cast iron, concrete, some thermosets and some highly amorphous plastics such as poly (methyl methacrylate) (PMMA) or polyether ether ketone (PEEK). Likewise, at the other end of the spectrum, most foams, even of the rigid variety, will not possess sufficient mechanical strength to accept a traditional metal thread forming screw.

Definitions

There is a lot of terminology that goes along with these concepts. The following definitions include the key concepts that are important to understanding the thread forming process.

Thread Forming Torque: This is the torque associated with the formation of the leading thread form. In other words, the torque associated with deforming the material for the first full thread. A pretapped nut member will not have any thread forming torque to speak of, so this torque is unique to screws that form mating threads.

Thread Friction Torque: This is the torque associated with frictional forces that occur with the increasing contact of the screw with each new thread formed.

Driving Torque: In a thread forming application, this torque is the one generated when the screw thread first engages the nut member to the point where the head of the fastener just seats against the component that is being captured. The maximum Driving Torque is the sum or combination of the Thread Forming Torque and Thread Friction Torque.

Failure Torque: The torque at which the joint fails. Failure can occur by a number of different mechanisms such as stripping, screw breakage or collapse of the nut member.

Installation Torque (also known as Seating Torque or Tightening Torque): The torque at which the installer seats the fastener against the component being captured. This value will be above the Driving Torque, but below the Failure Torque. The joint should have generated a clamp load when fastened at this torque setting.

Clamp Load (also known as Preload): The axial load that holds the joint together. Once the joint is tightly snugged together, additional torque applied will be converted to generate this axial load.

Driver Repeat Accuracy: The percentage of accuracy a driver either has or must possess to assure that a joint is consistently torqued according to the design parameters.

The Thread Forming Process

The thread forming process begins with the screw being driven into an unthreaded pilot hole. The thread forming screw will possess special geometry or features, which begin to deform the material into the mating thread configuration. **Figure 1** illustrates a graph of torque versus time (or angular rotation). One sees that there is an almost immediate jump in torque (Point 1 to Point 2). This is the contribution of Thread Forming Torque. In theory, this value will be the same for each subsequent thread formed.

As the screw continues to wind its way into the pilot hole, more and more threads are formed resulting in greater interaction between the screw threads and the mating nut member. Friction results at these interfaces and creates the Thread Friction Torque. In **Figure 1**, this is illustrated by the gradual increase in torque as the time increases (Point 2 to Point 3).

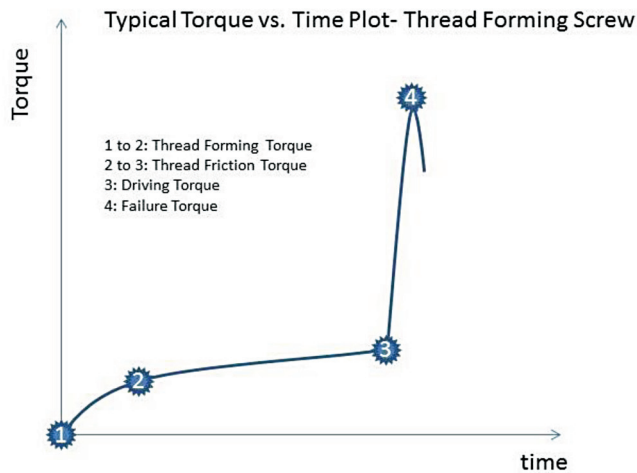


Fig. 1 — Torque versus time (or angular rotation).

Eventually, all the threads are formed and the screw head seats against the component it is capturing. In **Figure 1**, this point is represented by an inflection point seen on the graph (Point 3), which is the Driving Torque. Remember that the Driving Torque is a combination of the Thread Forming and Thread Friction Torques.

As more torque is applied to the screw, it is converted into a clamping or axial load. **Figure 1** shows this sharp, nearly instantaneous increase (Point 3 to Point 4) until a second inflection point (Point 4) is obtained. This is where failure occurs and may take several different modes such as stripping, screw breakage or joint collapse. In most instances, the mode of failure is heavily dependent on the material of the nut member and the length of engaged thread.

Developing an Installation Torque

When designing a joint, the Fastener Engineer's primary goal is to maximize the spread between the driving torque and the failure torque. In a thread forming scenario, it is desirable to have the driving torque as low as possible and the failure torque as high as possible. This provides the greatest margin of safety when fastening the joint. Additionally, for thread forming, excessive driving torque leads to operator fatigue and ergonomic issues, while low failure torques lead to poor product quality or potentially high scrap rates.

Figure 2 shows the representation of a series of drive and failure torque tests. It is good practice to perform multiple

tests, which this graph illustrates by showing the representative statistically maximum and minimum values. Again, the spread (or ratio) between these two factors is of key importance. If this spread is too narrow, it is possible that an Installation Torque that guarantees the screw is always driven, but never fails may be impossible to achieve. Therefore, it becomes incumbent on the Fastener Engineer or Joint Designer to take all possible factors into consideration and design all aspects of the joint to optimize performance.

Once the ratio between the statistically maximum Driving Torque ($T_d \text{ max}$) and the statistically minimum Failure Torque ($T_s \text{ min}$) is established, the Fastener Engineer or Designer can work to develop the proper Installation Torque. The strategy employed here will vary depending on application specific factors, but the value chosen must be sufficient to safely fasten the joint without failure while compensating for the variability of the drive equipment (Driver Repeat Accuracy).

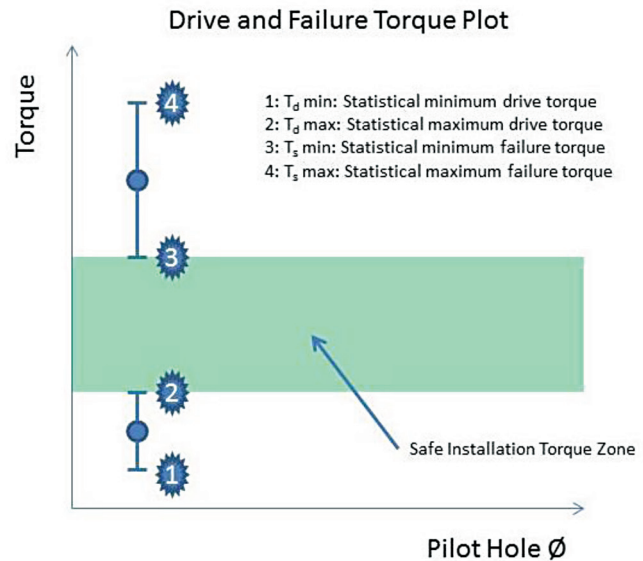


Fig. 2 — Series of drive and failure torque tests.

Thread Forming Screw Design

When designing a thread forming screw, the Engineer's primary goal is likely to incorporate design features in the screw that allow the lowest possible Driving Torque and highest possible Failure Torque without compromising the strength or integrity of the screw. With this goal in mind, it provides the lens with which to compare the claims of different thread forming screws.

In general, features incorporated into thread forming screws are intended to either reduce the Thread Forming or Thread Friction Torques. For example, any feature that provides for more efficient forming is intended to reduce the Thread Forming Torque. Common features include sharper thread profiles, longer thread forming zones on the screws (more gradual transitions) and reliefs or geometries intended to promote easier deformation. The other approach is to reduce the Thread Friction Torque. This is commonly accomplished by lubrication or having less thread contact. Often times, features are incorporated in combination.

Unfortunately, these features and combinations often compete against one another, so that improving one feature

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results in the reduction in performance of another. For example, it is not uncommon to find that Driving Torque is reduced, but at the expense of the Failure Torque. Therefore, it is important to understand how different features actually affect the overall performance of the system.

Common Problems/Failures

As with any system, potential failures exist. Instead of concluding that thread forming screws represent bad technology, the Fastener Engineer or Designer should understand the possible reasons why the system is not working as desired and be prepared to correct the situation. The accompanying **Table** shows some common failures and their potential causes. This is not definitive for all applications, but should provide some general troubleshooting guidelines.

These are some of the basic principles applicable to all thread forming fasteners. *Part Two* of this series will take a look at some of the unique considerations of thread forming into certain types of materials, specifically thermoplastics, steels and light metals. Although the basic principles covered here in *Part One* will apply to all thread forming applications, I will show that there is not a universal design that works in all materials. In other words, what works well for steel may not be appropriate for plastic and vice versa. www.NNITraining.com

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Table. Common Failures and Their Potential Causes.

Common Failure	Potential Cause(s)
Screws not driving completely	Driving Torque too high Installation Torque set too low Driver variability is excessive Poor or no lubrication Undersized Pilot Hole
Screws Stripping	Installation Torque set too high Oversized Pilot Hole Excessive draft in pilot hole Driver variability is excessive Lubrication has changed performance (K factor different than expected) Undersized thread diameters Insufficient engagement End Load is too high
Screws Breaking	Installation Torque set too high Engagement is too high Poor or no lubrication Undersized pilot hole
Screws won't start	No end load Lead threads are not sharp Wrong pilot hole size Misalignment- needs a counter bore or lead-in. Lead-in improperly manufactured