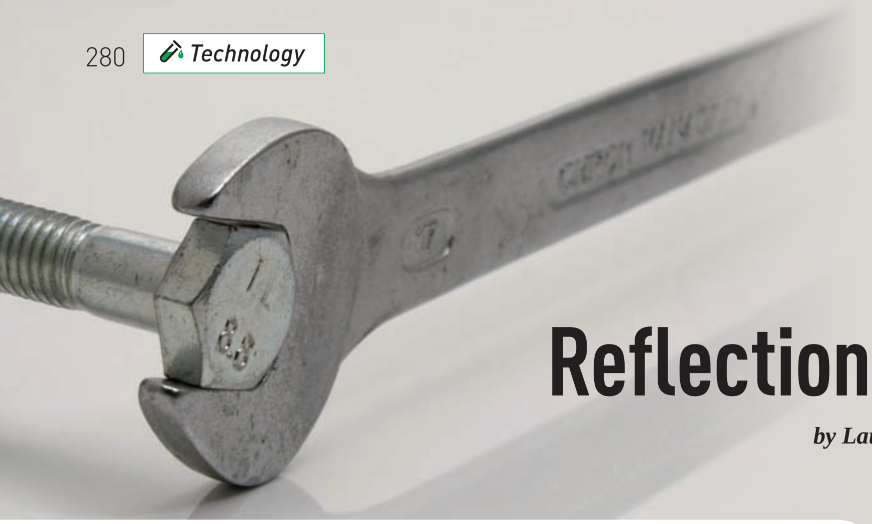


Reflections on Torque

by Laurence Claus

In the fastener world there is perhaps no more commonly used expression than "torque-tension". So common is this term in fastener circles that it is thrown out in everyday conversation and accepted by all at face value. One can understand this, as finding the perfect "torque-tension" behavior is the Holy Grail of fastener engineering. Unfortunately, like many technical terms that have been elevated to everyday usage, the vast majority of those hearing it fail to understand the fundamental principles it is meant to describe. Take for example a recent blog posting I encountered. It was addressing the question of which is more important, torque or tension. Although it was a well-intentioned posting, even the most novice fastener engineer realizes that the bolted joint is wholly dependent on properly achieved tension. Like many of the technical terms that make up the modern lexicon (such as fusion, heat treating, Xeroxing, and hundreds of others), the term "torque-tension" is broadly used by purveyors and users of fasteners, but generally poorly understood. So let us investigate this topic and see if we can find some simple answers into what "torque-tension" is all about.

When fastening a bolted joint it is common for individuals to talk about "torqueing the bolt". In fact, this terminology is far more common than the, perhaps, more accurate description of the process, "tensioning the bolt". In one sense it is not at all incorrect, as an installer is, in fact, applying torque to a bolt to cinch the joint together. However, it is misleading as it detracts from the main event, which is the stretching of the bolt to generate a set of axial forces that pull and hold the entire joint together. This is what the experts call generating the "preload" or, more simply, tensioning the bolt.

In fact, it is this tension that will define the life of the joint. If the tension is not sufficient to withstand service loading, the joint is ultimately on a crash course to failure. So if tension is really the critical element in the life of the joint, why has torque become the common way of describing the process?

The answer is relatively simple. It is not always easy to determine that a desired tension has been achieved. Although there are multiple devices or alternatives available today that provide a visual means of verification, these are often too expensive or impractical for use in high-volume, every day assembly. Therefore, the fastener engineer must rely on a different means of gaining the confidence that the bolt is tensioned properly.

For this we turn to torque. Torque is relatively easy to measure and for the majority of fastening applications relatively easy to control. **By a stroke of good fortune we also know that there is a relationship or interdependence between torque and tension. There are a number of expressions that can be used to express this relationship, but the most commonly used expression is known as the "Short Formula".** The short formula is expressed as:

T=kDP where, **T= Input torque**

P= the preload (or bolt tension)

D= the basic diameter

K= the "Nut Factor"

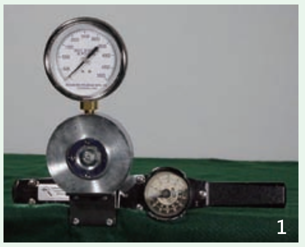
The components of this equation are pretty straight forward until we reach this value known as "k" or the "Nut Factor". Not to be confused with the coefficient of friction, the "k" value is a combined constant representing all of the frictional interactions going on in the joint.

In one of the bigger misfortunes in our industry, the "k" value is usually expressed and understood exclusively in terms of the plating or coating that is on the fastener. In doing so, we inadvertently neglect all of the other factors that affect the friction in the joint. Some studies have cited as many as 75 different factors that may have an impact on the friction of a bolted joint. Some of the more important factors are:

- Type and properties of the coating or plating
- Thickness of the coating or plating
- Condition of the coating or plating
- Surface roughness
- Hardness of the joint component parts
- Types of materials of the component parts
- Lubrication (including the temperature it is operating at, type, amount, condition, amount of contamination or debris in the lubricant, location of the lubricant, and the way it has been applied or comes in contact with the fastener)
- Speed of assembly
- Fit between threads
- Cut versus rolled threads
- Whether a washer is present or not

It is simple to sum up, therefore, that there are many factors acting during joint tightening that affect the friction and, thus, the tension. One may be able to exert a degree of control over some of these factors, but control of them all is impossible. All of these factors work together to define what John Bickford, author of "An Introduction to the Design and Behavior of Bolted Joints" calls the "Control Accuracy" or "the ability of the variable (torque) to create what we are after (tension)". [1] Bickford goes on to say that experience and testing suggest that using a given torque will create a tension scatter of +/-30% in a large group of as-received bolts. [2] What is likely the most important take-away from this is that to accurately understand the relationship between torque and tension, one must conduct experiments. In fact, calculating the installation torque using the short formula from published values of "k" is entirely unreliable. One must conduct multiple experiments to obtain enough data to generate a reliable statistical prediction of the predicted torque-tension relationship.

To illustrate these points further, let us conduct a simple experiment for ourselves. Figure 1 shows a typical Skidmore testing apparatus and dial torque wrench. The Skidmore is little more than a hydraulic load cell that measures tension at given torque values. There are other, more sophisticated, testing devices which measure torque-tension and are able to resolve the amount attributed to friction in the threads and under the head. However, for the purposes of this experiment, the Skidmore will work perfectly. In Figure 2, a typical as-received ¼-20 Grade 5 nut and bolt pair have been loaded into the Skidmore and tightened with a calibrated, click-type torque wrench set to 10 ft-lbs. The resulting tension is about 2500 lbs, as seen on the Skidmore's dial indicator. So we can say that for this nut and bolt pair, when we applied 10 ft-lbs of torque we obtained 2500 lbs of tension. If we apply our results to the short equation, $T = kDP$, we find that "k" has a value of 0.19.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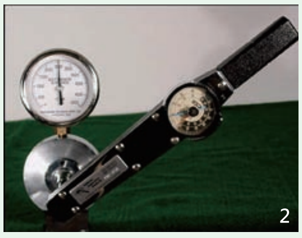
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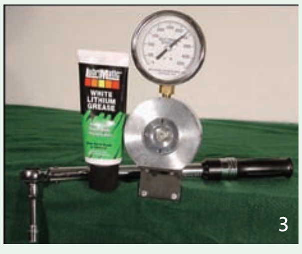
Now let us repeat this experiment but add a little bit of lithium grease (lubricant) to the joint. If we apply the same torque as before, we see that we get drastically different results. Instead of achieving about 2500 lbs, we instead achieve almost 3400 lbs or about a 36% increase in tension (See Figure 3). If we again apply the short formula, we find that the "k" value is 0.14. Conceptually everything remained the same except the addition of lubrication. We can conclude then that **reduction of friction will increase tension.**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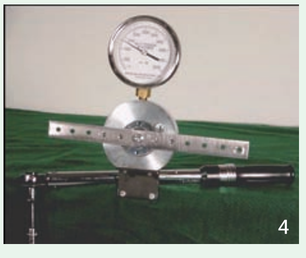
Let us repeat the experiment one last time and look at the other side of the coin. This time, we are going to change our nut from one that has a smooth bearing surface to one with a serrated bearing surface. As the nut is tightened, these serrated teeth dig into the contacting surface generating an increased level of friction. Figure 4 shows the Skidmore dial after applying the same torque value as our other trials. In this case the measured load is 1400 lbs, almost one half of the standard, baseline torque-tension determined in experiment 1. In fact, when the "k" value is calculated it works out to be a much higher value, 0.34.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So, in summary a number of points emerge from this section. They are:

- **Tension is our primary and exclusive value of interest. Tension alone will define the lifetime performance of the joint.**
- **Torque is interesting because it is the common control variable used to achieve the desired tension. This is only possible because there is a direct relationship between torque and tension.**
- **This relationship between torque and tension is primarily a function of the friction between the thread and bearing surfaces of the fastener components in the joint. The more friction there is, the lower the tension generated and, vice-versa, reduced friction provides more tension.**
- **This relationship is governed by the "k" value or "Nut Factor" which is influenced by many different factors. In fact, some experiments have identified almost 75 factors that can play a significant role in affecting the friction.**
- **Since so many factors can actually influence the friction, the only meaningful "k" value is the one gained experimentally employing actual field or assembly conditions.**

Now that we understand these points, how does one go about using torque to generate a consistent and reliable tension value?

The answer to this question lies with the fastener engineer or designer relative to the desired outcome they are shooting for. In most cases, the joint being designed is not a critical one so that a moderate level of control on the torque should provide adequate results with respect to the tension. In these cases, the assembler employs what is known as "Torque Control". This simply means that the only method being used to achieve the desired tension is by applying the designated torque value. As we have previously discussed, we know that many factors are in play, which results in dispersion of both the applied torque and the resulting tension. However, because these joints are not critical, and theoretically achieving a tension within a statistically generated minimum and maximum band is acceptable, the control method is generally considered quite satisfactory.

If, however, the desired level of tension needs to be more precise, this method of control may simply not be good enough. In this case, the next step up the "control ladder" is to utilize what is known as torque-angle control. In this method the fastener engineer or designer takes advantage of the precision and consistency of stretch that can be achieved by utilizing the thread geometry. In other words, because threads are manufactured to exacting tolerances, fastener engineers are able to predict exactly how much a bolt will stretch if you rotate it a precise number of angular units. The reason for this is simple, the thread will advance (or, in this case, stretch) the exact amount determined by the bolt's thread pitch (generally a very precise and well controlled manufacturing characteristic). In a torque-angle tightening strategy, the part is torqued, generally until it is just snug and then rotated a fraction of a full rotation to achieve a final, precise value of stretch and, thus, tension.

Finally, some joints are fastened to the point where the bolt is either in or very near its yield point. Designers sometimes employ this strategy because it optimizes the strength characteristics of the bolt to achieve the maximum tension. The challenge, however, is that as bolts slide up the scale in strength they become more brittle. This means that with higher strength bolts there is far less margin to overshoot the yield point without potential catastrophe. Therefore, those who assemble bolts into yield must take extra special care. Fundamentally though, the tightening process is just a more precisely controlled version of torque-angle control.

In summary, one sees that although our primary goal is tension, torque is an important and vital way in which the assembler is able to achieve it. One must be respectful of the relation that is inherent between these two values. If not performed with care and insufficient or excess tension is reached, the entire joint is placed at risk. To prevent this, one must understand the basic principles of the relationship and recognize that many factors contribute to the effect that friction will have on the joint. Perhaps those that possess this basic understanding and realize that tension is the all-important end game will resist the urge to refer to simply "torqueing" a bolt or arguing that torque is "most important".

[1] Bickford, John. "An Introduction to the Design and Behavior of Bolted Joints, Ed. 3". Marcel Decker, New York, 1995. Pg 222.

[2] Ibid