Preload- Part II: Tightening Strategies

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In Part 1 of this series we explored the fundamental concept of Pre-Load and what this means to the fastened joint. Although understanding this concept is a fundamental fastener engineering tenet, one likely cannot stop there and is led to ask the question of how one practically achieves this Pre-Load in the bolted joint. This is where the subject of "tightening strategies" arises.

Before we look at the different tightening strategies, let's briefly review the concepts of pre-load and torque-tension.

Pre-Load

One may recall from Part I that the bolted joint acts as a spring, so that the more the bolt is stretched the greater it compresses the joint. The forces that are developed in the bolt as a result of this stretching are known as the pre-load. As long as the pre-load exceeds the service loads that are trying to separate the joint or to get the clamped component to slip, the joint will remain intact and has a low chance of failure.

Figure 1 illustrates this concept. A spring has a hook on the end and is compressed when a 1,000 pound weight is hung from it (Position #2). The displacement is "locked" into place by removing the weight and setting a very lightweight, rigid block between the top of the hook and the bottom of the spring (Position#3). As long as no more than 1,000 pounds is reintroduced to the hook on the end, the system will not move (Position #4). Once a load greater than 1,000 pounds is loaded on the hook, however, the spring will further deflect, unseating the block, and causing the spring to no longer be "locked" into place (Position #5). This example is closely analogous to the way a bolted joint behaves when tensioned and stressed with service loads.

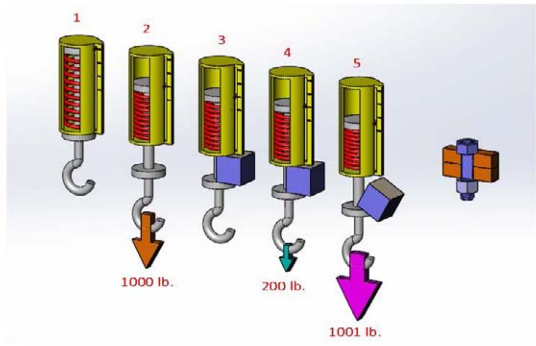

Figure 1

Torque-Tension

Many individuals get confused with this concept, believing that torque is the important feature of this relationship. As just described, though, it should be obvious and clearly understood that tension (i.e., pre-load) is all important for maintaining the integrity of the bolted joint.

However, the practical difficulty that one experiences is how to quantify the tension (i.e., pre-load). This is a value, that although measureable, is not easily measured in a production or everyday setting. Therefore, a measure that can be easily made in practice is required. This is where torque comes in. It is easily measured in a variety of ways and has a direct relationship to the pre-load. This relationship can be expressed by the equation T=kDP where 'T' represents the torque, 'k' a constant known as the "Nut Factor", 'D' the nominal bolt diameter and 'P' the pre-load (i.e., tension).

Although this equation seems pretty simple, it really is not because the "k factor" is a complicated and often elusive value to apply accurately because it is completely dependent on a combination of physical factors and surface conditions of the mating parts. Therefore, the equation can be applied theoretically using tables and charts of available information, but the result can be off by several magnitudes to the actual condition. If possible, it is always best to obtain these values empirically.

Once the Fastener Engineer has conducted these empirical experiments, he/she will have an assurance that if the joint conditions remain relatively unchanged from the experimental conditions, that when the right amount of torque is consistently and accurately applied that the desired tension will be achieved. From this information the Fastener Engineer can review his options, consider what tightening methods are available, and make the best choice about which tightening strategy to employ.

Tightening Strategies

The methods used to achieve the desired pre-load often vary from industry to industry but fundamentally rely on the same undergirding theory. The strategy that is adopted by a user or industry is influenced by a number of different parameters. These include the number of joints to be assembled (usually figured on an annual basis), the environment they will be assembled in (for example, a structural beam in outside conditions versus on an assembly line in an air-conditioned factory), preciseness of the tightening required (or in other words, the criticality of the joint), and the ability of the user or industry to invest in the necessary equipment required to achieve the actual practice. These methods are normally referred to as "Tightening Strategies'".

Torque Method

This is the simplest and most commonly employed tightening strategy. It takes advantage of the fact that the tension is directly proportional to a specific applied torque and assumes that the user understands this relationship. In other words, this practice assumes that the user understands that applying a specific amount of torque will generate a resulting specific amount of tension and not just turning the fastener until everything seems "tight".

Unfortunately, although this method is relatively simple, it is generally the least accurate of all the tightening strategies. This is for a variety of reasons, but mainly that the devices used to measure torque, especially those devices that are operated manually can have a significant amount of equipment or user variability. Naturally, this variation is reduced with high-end, automated equipment. When speaking generally about this method, though, it is universally accepted that the torque accuracy can vary by as much as +/-25%-30% using a calibrated torque wrench.

With this kind of variation, one can clearly envision the potential disaster that could strike if utilizing this method to attempt tightening to a very critical and precise tension setting. Therefore, this method tends to be utilized for joints that are important but not critical.

Torque-Angle Method

The next rung up the ladder is the Torque-Angle method. This can involve very expensive and sophisticated equipment as is often found in the automotive industry or very simply implemented as seen in structural bolting. Unlike the Torque Method which uses only the relationship of torque to achieve the pre-load, in the Torque-Angle Method the Fastener Engineer takes advantage of both the torque relationship and the understanding that displacement (resulting in additional bolt stretch) can be very accurately controlled by rotating the thread.

In the Torque-Angle Method the bolt is usually "snugged up" using the torque method and then rotated some fraction of a full rotation to achieve the final tension. The snug position is normally between 60-75% of the Yield Strength. Yield is the point where the bolt's elastic behavior transitions to plastic behavior or when the bolt no longer is able to recover its original length when load is released. Practically speaking, the snug position is often defined as where an impact wrench begins to impact. (In structural applications it may also be defined as the condition achieved by one worker using "full effort" of an ordinary spud wrench.) By rotating the bolt a fraction of a rotation the bolt stretches further and the load is increased.

The reason that this is more accurate is that this method reduces some of the variability inherent in the Torque Method. Although there is always some variability in the screw thread, by comparison to a torque wrench it is quite small. The pitch between the threads is precise so that the relationship between rotation and linear displacement is predictable and accurate. Therefore, if the goal is to accurately and consistently reach a certain pre-load, establishing a consistent starting point and then making the final "precise adjustment" through angle of turn nets consistent and accurate results.

In structural fastening this method is referred to as the "turn-of-nut" or "turn-of-bolt" method depending on which element is rotated in the turn. **Figure 2** illustrates this methodology. The nut is made "snug tight" and then, depending on the joint conditions such as the number of plates clamped and bolt length-to-diameter ratio, a standard is referenced to provide guidance for the amount of "turn" required. Normally the nut will receive between 1/3 to 1 full turn. This can be seen in the rightmost nuts in **Figure 2**, where it illustrates clearly how the nuts have been rotated about 1/3 turn or 120°.

Figure 2

A more sophisticated form of this method is often used by the automotive or other high volume but joint critical industries. Instead of doing this by hand as described above, highly automated drive equipment that employ sophisticated computer controllers in combination with precise servo drive motors are used. This equipment is not portable and very expensive, so that it can only be justified for applications with sufficient volume or criticality to warrant the investment.

Torque-Angle-to-Yield

This is really just a more sophisticated Torque-Angle Method. In some instances it is desirable to tighten a joint just up to or slightly beyond Yield. In most applications one would shy away from going all the way to Yield for fear of damaging or risking potential fracture of the bolt. However, where maximizing the pre-load is of the utmost importance, taking advantage of the entire range of elastic behavior of the bolt provides an elegant way of attaining its full potential.

The catch, however, is that you must employ a tightening strategy that provides the control needed to assure hitting this point consistently. Therefore, these systems, like the Torque-Angle equipment described immediately above, incorporate very sophisticated control systems and drive motors. Again, the expense is quite high and only justifiable when the volume and criticality are present. Additionally, users of these systems augment the consistency by specially designing the fasteners as well to provide consistent, predictable, and uniform stretch throughout.

Tension Control

This method is similar in sophistication and end result of Torque-Angle-to-Yield Method except that instead of applying a staged process, the control system is able to monitor the Torque versus Time (or Torque versus Angle) and recognizes when the behavior begins to transition from linear to non-linear behavior (the point of Yield). It is able to abruptly shut-off the driver to prevent over-tightening. The result is a joint tightening to near its maximum pre-load. Once again, the equipment is very expensive and so justified only when volume and criticality warrant it.

Ultrasonics

Ultrasonic techniques have been around for many years and have commonly formed the solution for tightening very large fastened joints. This technology continues to develop and may one day be a practical method for high volume, smaller fastened joints.

The principle is relatively straight forward and very similar to how a police officer uses a radar reflection to determine how fast you are driving. It works on the principle that an ultrasonic signal will take a highly predictable amount of time to travel through the bolt and reflect back to a transducer. As the bolt stretches (or gets longer) the time required for this signal to travel out and back will change. Thus the amount of bolt stretch and resulting pre-load can be accurately measured. These systems often require some complicated calibration of the transducer, but once calibrated are very effective.

Hydraulic Tensioning

This method is normally reserved for larger diameter bolts. In this case, a special hydraulic tool is clamped to the end of the part and pulls the bolt to the desired tension (i.e., the desired amount of stretch). The nut is then tightened in-place, the hydraulic puller removed, effectively "locking" the tension in the joint.

Load-Indicating Devices

In addition to the methods described above, there are a variety of other devices or methods that will supply the user with an indication that the desired pre-load has been achieved. These fall broadly into a category known as Load-Indicating Devices. In some instances these "devices" actually provide a variable measure of tension while in other cases they simply provide an "indication" such as a color change or squirting out silicon from beneath a load-indicating washer that the desired tension has been reached.

These devices have been used for many years in the structural bolting domain because of the benefits they provide in ease of use and productivity gain. Although not prevalent today in smaller fastener applications and other industries such as automotive, it is likely that as technology advances and they become more affordable to the mass market, we will see additional uses of these fasteners or fastening techniques in the future.

Conclusion

It probably cannot be reiterated enough, that generally the single most significant attribute of a bolted joint is its achievement and retention of pre-load. Without this, joints would simply fail. Therefore, understanding how to achieve and meet the desired pre-load values is critically important. This is accomplished by understanding the different "Tightening Strategies" and employing the right one for the specific circumstances.