A new approach to the tightness checking of bolts

By Bill Eccles, Bolt Science

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A frequent question that is asked relating to bolting is: 'We've just checked a nut that we tightened and it's well below what we tightened it to just minutes earlier – what's wrong?'

It's not widely known that the torque for a newly tightened nut or threaded fastener, in general, is different depending upon whether you attempt to untighten it or tighten it a bit more. Typically the torque needed to untighten a newly tightened fastener is around 10% to 30% less than the torque to tighten it further.

When you are tightening a threaded fastener a significant amount of torque is needed to overcome friction in the threads and under the nut face (or the bolt head, if the bolt is rotated). The proportion of the torque that is used to overcome friction depends upon the friction value but is typically in the 85% to 90% region. This is illustrated in Figure one, which shows that when tightening a nut/bolt with a coefficient of friction of 0.12, only about 14% of the torque is used to stretch the fastener producing the clamp load with 86% of the torque being lost overcoming friction. The torque needed to stretch the fastener always acts in the untightening direction and it's for this reason that the untightening torque is less than the tightening torque.

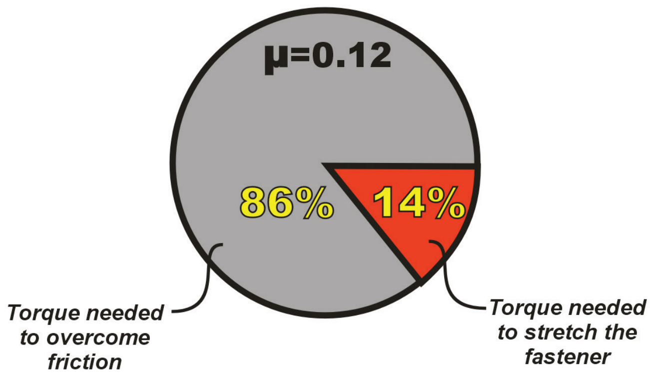

Figure one

Figure two shows what happens when you tighten, and then untighten, a threaded fastener. The tightening torque T_{On} produces a certain clamp force (F), it then takes a torque T_{Off} to untighten it. For a newly tightened fastener, T_{On} is greater than T_{Off}. If the fastener is left for a prolonged period, changes in friction can result in the untightening torque T_{Off} becoming greater than the original tightening torque T_{On}.

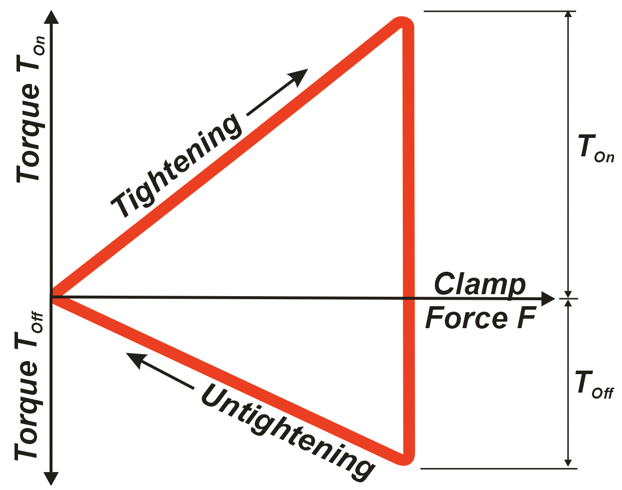

Figure two

In many applications the clamping force provided by tightening fasteners is of critical importance in determining the success, or otherwise, of the structural integrity of an assembly. A great deal of attention is often placed on ensuring that bolted connections are installed in a controlled manner so that a predictable clamping force is achieved. The most popular controlled method of tightening a threaded fastener is by applying a specific tightening torque. Below the yield point of the fastener, the relationship between the applied torque and the clamp force provided by the fastener, is linear. That is, double the torque and you double the clamp force. Once tightened, the clamp force provided by a bolted connection can decrease. The decrease can occur without any rotation of the thread, as in the case of stress relaxation, embedding, creep and similar effects, or, the bolt or nut may rotate decreasing the clamp force as in the case of self-loosening. Subsequently, concern over the loosening of bolts, in many applications, necessitates quality control measures to check their tightness. Tightness is usually assumed to be the measured torque value but in the majority of applications, it is the clamp force rather than the torque that is the critical factor. The problem is that there is no low cost method of assessing the clamp force provided by a previously tightened fastener.

Currently, the tightness of a bolt/nut assembly is usually assessed by a torque based method, the approach is referred to as torque auditing. Torque auditing is usually completed by one of three torque methods:

1. **On-torque method:** Measuring the torque needed to rotate the bolt/nut by a small angle (typically 2 to 10 degrees) in the tightening direction. This is the most frequently used method of torque auditing.

2. **Off-torque method:** Measuring the torque needed to rotate the bolt/nut in the untightening direction (which will normally be less than the tightening torque).

3. **Marked fastener method:** Marking the position of the bolt/nut relative to the joint, untightening it by an angle of approximately 30 degrees, then measuring the torque needed to tighten the bolt back to the marked position.

Each of these three methods have their deficiencies. The key assumption in each method is that the torque value measured is a true assessment of the tightness of the connection. The critical flaw in each of these methods is the assumption that the coefficient of friction has not changed between the tightening of the bolt/nut and the completion of the checking process. Changes in temperature, humidity and the effects of corrosion after the bolt/nut was originally tightened will affect the friction value and subsequently the torque value but not necessarily the clamp force. A change in the friction condition can make invalid the assumption that the torque value is a true assessment of the bolt's tightness.

The method described in this article is an attempt to improve upon the present tightness checking methods to allow the clamp force being provided by a previously bolted connection to be assessed and, potentially, corrected. This is achieved by performing a tightening-untightening-retightening sequence (referred to as the 'On-Off-On' method) on the bolt/nut involving the measurement of torque. The 'On-Off-On' tightening sequence can provide information as to the clamp force provided by the bolt, which allows a better indication of the structural integrity of the joint than existing methods.

$$F = \frac{\pi}{p}\left[T_{On} - T_{Off}\right]$$

Figure three

By studying the underlying relationships between the tightening and untightening torques, a simple formula can be derived relating the tightening torque T_{On} and untightening torque T_{Off} to the clamp force (F) present in the fastener. This relationship is shown in Figure three, the p in the equation is the pitch of the thread[1]. So for example if on a previously tightened M12 nut/bolt (pitch p = 1.75mm), a torque T_{On} of 80Nm was measured and the T_{Off} value was 60Nm, the clamp force would be estimated as being 36kN. Essentially the larger the difference between the on and off torque values, the larger was the force present in the bolt.

To apply the 'On-Off-On' method to establish the tightness of the bolted connection, the torque needed to incrementally rotate the nut in the tightening direction is measured, then measured in the untightening direction, before final retightening. A series of images illustrating this approach is given in Figure four.

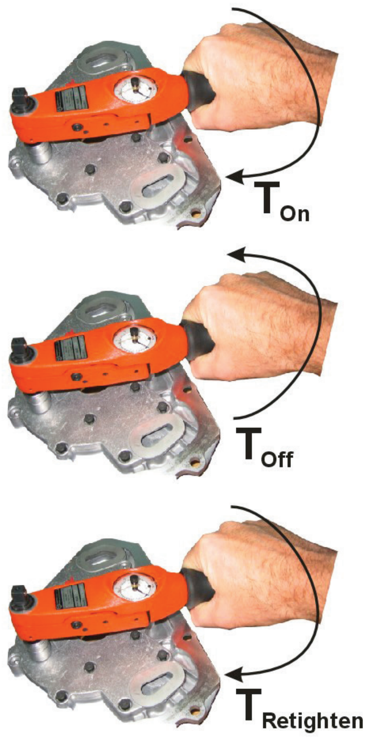

Figure four

A large number of tests have been conducted by the author to assess the validity of the 'On-Off-On' method. The tests conducted indicate that when the fastener coefficient of friction is low (<=0.08), the 'On-Off-On' tightness auditing method is an accurate prediction of the load in the bolt. With fasteners displaying typical values of the coefficient of friction (0.08 to 0.18), the tests indicate that the method is a good indicator of the bolt load. At high friction values (>0.25), such as may be displayed by galvanised bolts tightened without a lubricant, the approach has limited potential.

The 'On-Off-On' tightness auditing method is more accurate when:

- Well lubricated fasteners are used that have inherently low friction values.
- The auditing process is conducted after a relatively short period of time after the fastener installation.

The 'On-Off-On' tightness auditing method would tend to be less accurate when:

- The fasteners are not lubricated and have an inherently high friction, for example, a galvanised finish without a lubricant being used.

- A significant period of time has elapsed since the fastener installation and the operating environment is such that corrosion is likely to occur.

1 More details of how this relationship is derived is presented in the paper: 'A new approach to the checking of the tightness of bolted connections' presented at the LUBMAT 2014 conference in Manchester in June 2014.

Depending upon the method of applying the torque and knowledge of the friction conditions, the scatter in the bolt load can vary between +/-17% to +/-33%. The variation in bolt load is largely due to the variation in the fastener friction rather than the accuracy of the applied torque value. The typical accuracy of the 'On-Off-On' tightness auditing method is well within these limits.

Establishing what load/torque that the bolts in a joint should be tightened to can be problematic for some maintenance activities. The 'On-Off-On' method could, potentially, provide important information about the load that the existing bolts are sustaining – allowing the torque that a new bolt should be tightened to be better estimated.

Measuring the on-torque alone can be a poor indicator of the retained clamp force of the joint. It is frequently used since usually there is no practical alternative. In short, for most applications the conventional torque auditing approach can be effectively used (that is, measuring the torque needed to fractionally rotate the fastener in the tightening direction), the 'On-Off-On' tightness auditing method can also be implemented. A major advantage of the 'On-Off-On' tightness auditing approach is that additional information can be derived regarding the integrity of the joint without a significant change being made to existing working practices.

Establishing the likely retained clamp force present in a joint can be a crucial factor in determining whether the structural integrity of the assembly is likely to be satisfactory, or likely to be impaired. As such, this new approach can be a useful tool in helping to ensure product safety and reliability. There are limitations to this new approach to fastener tightness checking, principally its accuracy in high friction conditions, but it is a useful indicator as to the retained fastener clamp force in many circumstances. ■

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About Bill Eccles
Bill Eccles is a chartered engineer and has a Doctorate in Engineering on the self-loosening of threaded fasteners. In 1992 he set up Bolt Science, which is a company that provides independent technical expertise in bolted joint technology. Bill also delivers training courses around the world on the analysis of bolted joints and bolting technology.