Thread and Under - Head Friction

by Dr. Michael P. Oliver

In previous articles, I have discussed the complexities and the physics of tightening a threaded joint. In this article, I would like to build on those discussions and talk a little more about friction: understanding how it is developed, its relationship to clamp-load, and how to use frictional data for design and application purposes.

Most any mechanical engineering text book, design guide, or torque reference manual will have one of two equations that will correlate applied torque to generated clamp-load, Equations 1 and 2. Equation 1 can be calculated or taken verbatim from the German DIN946 specification. Note the thread and under-head coefficient of friction (CoF) variables are associated with the applied torque, or torque in. Equation 2 is just a simplified version of this equation whereas K, the "nut factor" accounts for the two frictional variables and a geometric factor.

Equation 1 $$T_{in} = P\left(0.159 Pitch + 0.578\, d_p\, \mu_{thd} + \mu_{und}\frac{(d_w + d_h)}{4}\right)$$

Equation 2 $$T_{in} = KDP$$

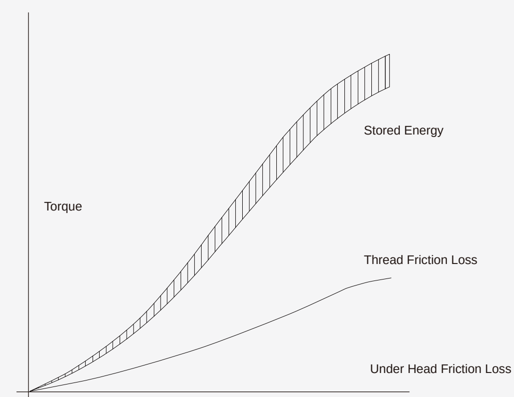


Figure 1

Before any further discussion on either of the two equations, some back-ground on friction needs to be addressed. We know that there are the two contact areas when a bolt is used to create a joint with the aid of a nut. The two areas are the under-head of the bolt (providing it is the bolt that is rotating) and in the threads between and nut and the bolt. The energy required to overcome the friction generated by these two areas is quite large. The friction can consume up to 90% of the total energy applied to the joint. This leaves just 10% to develop the clamp-load necessary to hold the joint together. This is also stored energy and is depicted in Figure 1. The relationship between clamp-load and torque is well under-stood. It is linear to the point of yield (the point where plastic deformation starts to occur).

Another important piece of information here is that the two contact areas create different frictional values when the joint is tightened. Figure 2 shows an example of a run-down of a bolt generating clamp-load as well as thread and under-head coefficient of friction. Here, the thread CoF is larger than the under-head CoF. But this is not always the case. There are some occasions when the opposite is true as well as times when they are equivalent. The point here is that the CoF values will vary and without conducting the experiment to determine what they are, the user must be wary.

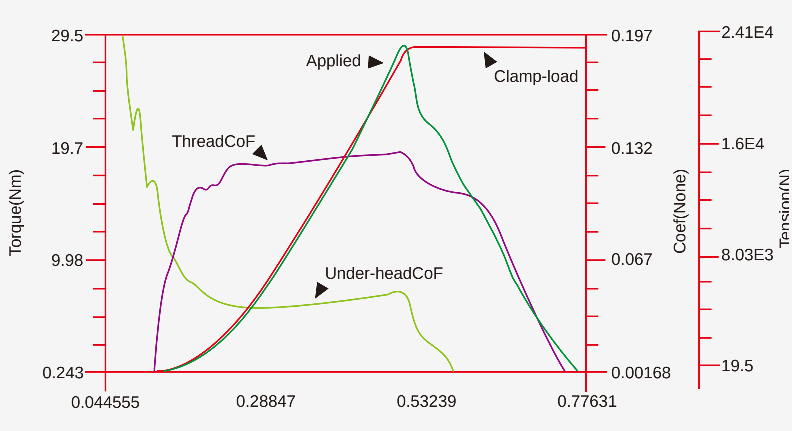
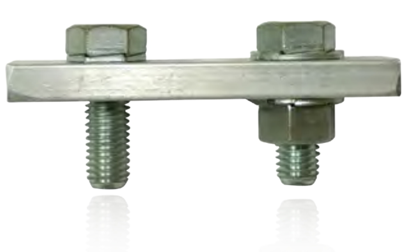


Figure 2

The best approach to obtaining CoF values is to perform experiments using intended fasteners and bearing surfaces. But this approach takes equipment and production or prototype parts. So what is an engineer or designer to do when access to experimental equipment or parts are not possible? One excellent reference is the German VDI 2230, "Systematic Calculation of High Duty Bolted Joints, Joints with One Cylindrical Bolt, Part 1", This code is actually used in several commercial software codes used for design work. However, in the back of the guide, they list two tables that separate the thread and the under-head CoF values. They are further segregated by materials and coatings/platings.

Now you have CoF values, you have the equations, but still you have an issue. The values for the two tables, the tables listing the thread and the under-head CoF values over-lap. What to do? You simply work the equations two ways. One way with the thread CoF value being higher and the next with the under-head CoF being higher. Consider this your safety factor. These two frictional values can be inputted into Equation 1 as well as Equation 2, with the proper definition of K (which actually has three parts). Either method gives good estimates. However, values of K are more apt to be pulled from tabular data and are actually shown as one value for both frictional areas. This method is not a preferred method in my opinion. It does not account for frictional variation between the two contact areas, the pitch of the thread, nor the outer nor inner diameters of the bolt/nut head or through hole respectively.



Access to experimental fastener test equipment will tell you exactly what is going on with your joint. Companies who apply the coatings and plattings use this type of equipment to verify that their product meets their own fractional requirements as well as their customer's specifications. For this to occur, you will need several pieces of equipment. You will need a torque/tension load-cell. This device will measure tension, either under-head or thread torque (depending which side of the cell the driving or torqueing is being performed on). You will also need a rotary torque transducer for measurement of applied torque and a data acquisition unit with the applicable software to make sense of all the inputted data. The software in the data acquisition system, if it is designed for fastener testing, will have a graphical interface unit that you will input all the pertinent fastener data: nominal thread size, thread pitch, flange diameter of the rotating member, and inner diameter of the test washer through hole. Following the test, the software will take the three channels of data collected: the applied torque, the developed clamp-load, and the under-head or thread torque (again, depending on which side of the torque/tension load-cell the test was conducted on). The first thing the code does is compute the missing torque value according to Equation 3.

Equation 3

Once all three toque values are known, the two friction coefficients can be determined by solving Equation 1 for each friction, Equation 4 (thread) and 5 (under-head).

Equation 4

$$\mu_{thd} = \frac{\left(\frac{T_{thd}}{P}\right) - 0.159\,p}{0.578\,d_m}$$

Equation 5

$$\mu_{und} = 2\left(\frac{T_{und}}{PD_{km}}\right)$$

The resulting data is then plotted according to the user's preference. Any of the collected and calculated values can be plotted in any combination of ways. There are very few companies that I know of that make data acquisition units designed for the fastener community that I know of. The one I have used for the past 15 years is Micro Control. There are several other companies that supply similar frictional calculations, but I am not familiar with them. The reader can also search out other companies that do not cater to the fastener industry and create your own algorithm along with conventional data acquisition components.

Caution must be used when using any type of equation for design purposes, especially when it comes to threaded joints. K factors are available, but do not tell the whole story about the joint. A better approach is equations that contain separate values for the thread and under-head regions. The best and most desirable approach is through testing. It requires specific equipment as well as the knowledge on how to both use it and interrupt the data. But the effort will tell the user what the joint is doing and what factors affect the developed clamp-load.