The Barn Raiser

Mid-South Engineering Company

Issue No 53 Working Together First Quarter, 2015

Back to the Basics:
Fasteners: Torque vs. Tension

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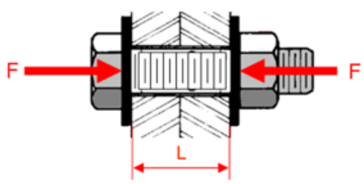
Bolts, Capscrews, and Studs are used as fasteners for many applications in mechanical devices. On our rotating machinery, we have critical fasteners for couplings and anchor bolts, etc. and also non-critical fasteners for holding side covers, etc. In these cases, the fasteners work using the same principle, by providing a clamping force to hold two or more pieces together in compression. Let us now do a brief review of the fundamentals of fastener theory and application.

The figure below shows the clamping compressive Force, F, applied to the pieces. An equal and opposite Force, F, acts on the fastener to put it in tension.



As a fastener creates the compressive clamping force which holds two or more pieces together, there is an equal and opposite force that acts on the faster which places it in tension. This tensile force creates a stress in the fastener. Stress is defined as the applied Force per unit Area. Stress is denoted by the symbol, σ.

$\sigma = F/A$; where: F = Force applied to the fastener
A = Original cross sectional area of the fastener
Stress is often measured in engineering units: psi or MPa.

This tensile force on the fastener causes it to stretch or deform a small amount. This stretch is known as "strain" and is denoted by the symbol, ε. Strain is defined as the change in length of material divided by its original free-length.

$\varepsilon = \Delta L/L$; where: ΔL = the change in length of the fastener
L = the original free length of the fastener

As force is applied and strain occurs, a tensile stress occurs in the fastener. Within the "elastic range" of the material there is a relationship between stress and strain.

$\sigma = E\varepsilon$; where: E= constant, the Modulus of Elasticity
For steel E = 30.0 * 106 psi
= 20.7 * 104 Mpa

The materials typically used in machinery fasteners (various steel alloys) have what is known as a Yield Strength, which is the amount of stress that can be applied to the material where it just begins to show plastic (or permanent) deformation. Depending on the material composition and heat treatment, there can be a wide range of Yield Strengths:

Mild Steels : 20-50 ksi (~ 140-345 MPa)
High Alloy Steels: 60-125 ksi (~ 415-860 MPa)

The material selection for the fastener is usually based on the application i.e. the force requirement/ corrosion resistance / etc. Typically, fasteners are designed be utilized anywhere from 50% to 90% of Yield Strength.

By substituting and rearranging the above formulas, we can calculate this tensile force on the fastener, F, to be:

$$F = EA\,(\Delta L/L)$$

Therefore, if we know, or measure the fastener's:

- Material Composition i.e. Modulus of Elasticity, E
- Original Cross Sectional Area, A
- Original Length, L
- Change in Length, ΔL

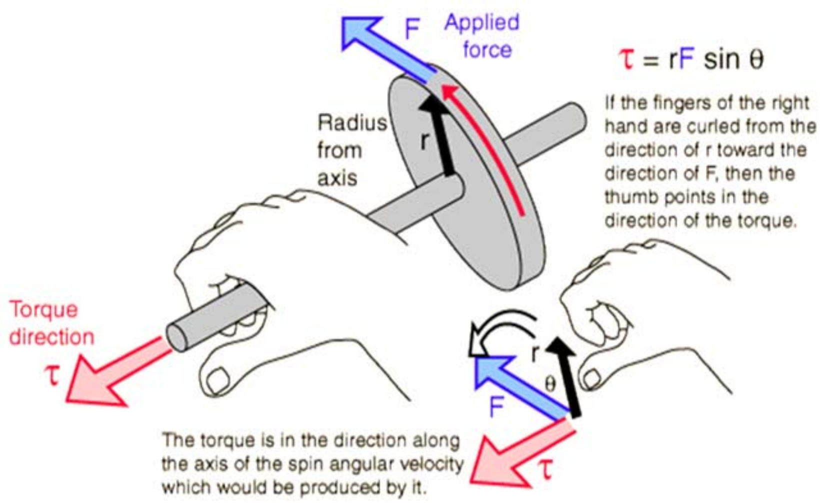
We can calculate the tensile force on the fastener and therefore, its equal and opposite clamping force imparted on the pieces it is holding together.

Why is this important to know? For most of us, it is not important to know this relationship. However, there are many aspects of our daily activities that directly impact whether or not we end up with the proper force applied by our fasteners. In some cases, such as on anchor bolts, this is absolutely critical.

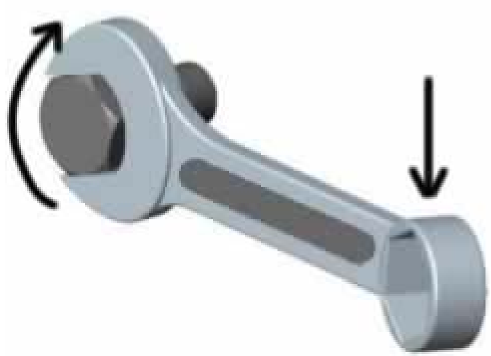
The equations tell us that the only way to truly know the clamping force applied by the fastener is to measure the change in length or stretch of the fastener.

When we use a hydraulic tensioning device, a calibrated torque wrench, or a hand wrench, we are only approximating this measurement with indirect approximations of stretch.

Methods to apply Bolt Stress / Clamping Force:



Torque – applied by "calibrated" mechanic arm strength or calibrated torque wrench



Torque has many variables which make it really only an approximation of bolt stress / force. These variables include the accuracy of the torque wrench and multiple sources of friction that are difficult to account for:

a. Friction in fastener threads due to thread mechanical condition / cleanliness / corrosion /surface treatment

b. Friction at Nut Face due to surface roughness

c. Lubrication specified. Depending on the lubrication specified, the torque required to achieve the specified bolt stress can vary greatly. A lubricant must always be specified with a Torque value or the wrong amount of stress can be imparted into the fastener, which could cause unnecessary damage to the mechanical components.

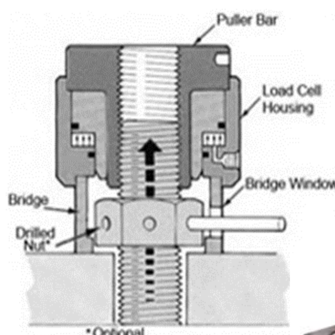
For example, the torque required for 1" (~25mm bolt) to achieve 50% Yield Stress on a B-7 bolt is shown below. As you can see, depending on the lubricant used, there is a big difference in the torque required to achieve the same bolt stress.

NOTE: For any critical fasteners that are torqued using a torque wrench they are required to be tightened and loosened multiple times as below due to the relaxation that occurs as the threads in the nut and stud seat with each other i.e. a small amount of plastic deformation / creep occurs.

1. Tighten to full tightening torque and wait for at least one minute. Then loosen the nut to 10% or a ½ turn of its original full torque.
2. Tighten again to full tightening torque. Then loosen the nut to 30% or ¼ turn of its original full torque.
3. Tighten to full torque. If this fastener has a locking device, then secure the locking device.

Hydraulic Tensioning:

Hydraulic tensioning is a big improvement over Torquing in terms of accuracy. One of the main benefits of hydraulic Tensioning is that friction is taken out of the equation. Hydraulic Tensioning relies on the accuracy of a pressure gage to approximate the stress applied to the fastener. Therefore, the condition and calibration of the pressure gage is critical to achieving the correct bolt stress / force.



Hydraulic Tensioning provides a very good compromise on accuracy, practicality, and effectiveness. When utilizing Hydraulic Tensioning; there is also the issue of making sure that the threads on the nut and the threads on the stud have a chance to seat due to the relaxation that occurs as the threads in the nut and stud seat with each other i.e. a small amount of plastic deformation / creep occurs.

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