Torque-Turn Tactics

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Threaded fastener tightening processes involve controlling both input torque and angle of turn to achieve the desired result of proper pre-load of the bolted assembly. Torque/angle curves provide practical information to evaluate the characteristics of a given bolted assembly. The curves also provide information to qualify the capabilities of tightening tools to properly tighten a given fastener.

Over 200 factors can affect the tension created in a bolt when tightening torque is applied. Fortunately, torque/angle signature curves can be applied for each bolted joint. The curves, combined with a few simple calculations and a basic understanding of threaded fasteners' engineering mechanics, provide practical information to evaluate individual fastener tightening processes.

Energy Transfer

Tightening threaded fasteners is basically an *energy transfer process*. The area under the torque vs. the angle curve is proportional to the energy required to tighten the fastener. A starting point for analyzing threaded fastener tightening is the torque-tension equation: $T=KDF$, where T is torque in in.-lb, D is nominal diameter in in., F is force in lb, and K is the nut factor which varies 0.03-0.035. The equation yields the relative magnitudes of torque and clamp force and defines a linear relationship between torque and tension for developing tightening process models.

Modeling the Tightening Process

To control the tightening process, we must understand the relationship between torque and turn in tension development. To study tightening methods, we must know what happens during fastener tightening. The process includes turning (advance of the lead screw) and torque (turning moment) to produce preload (tension) in the fastener. The desired result is clamping force that holds components together.

The most general model of the torque-turn signature for the fastener tightening process has four distinct zones:

- the run-down zone, the area before the fastener head or nut contacts the bearing surface
- the alignment or snugging zone, where the fastener/joint mating surfaces draw into alignment
- the elastic clamping range, where the slope of the torque angle is constant
- the post-yield zone, which begins with an inflection point at the end of the elastic range

Where prevailing-torque locking features are employed, the model adds a prevailing-torque zone. Generally, the prevailing torque results from frictional drag on the shank or threads. Causes include misalignment of the parts, chips or other foreign material in the threads, or out-of-tolerance threads with unintended interference.

The non-linear alignment zone is a complex function of the mating threads drawing together, mating parts bending together, and fastener bending due to non-parallelism of the bearing surface to the fastener underhead surface.

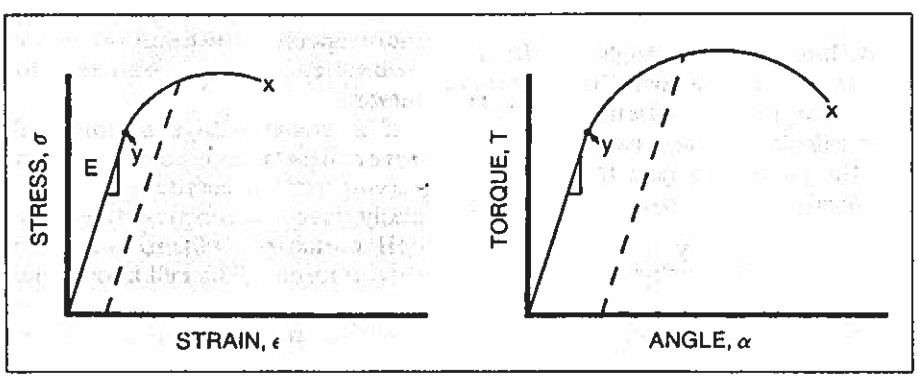
Stress/Strain Vs. Torque/Tension

It is helpful to picture the approximate equivalency of the stress/strain curve to the torque/angle curve (Figure 1).

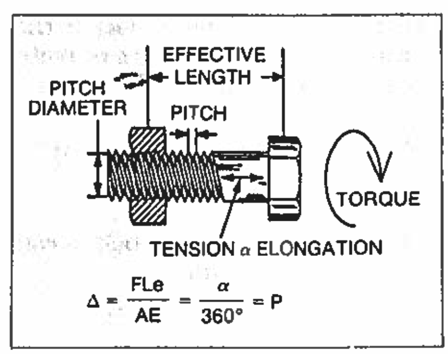
Deformation and angle of turn are geometrically related by the following formula: $\sigma = (\alpha \times P) / 360$, where σ is deformation, α is angle, and P is pitch of thread.

Only where the fastener is assumed to be tightened on a joint with infinite stiffness would this relationship correlate directly with the stress-induced total strain in the fastener. The total angle of turn is equal to the compression of the clamped components plus the stretch of the fastener. The chart in Figure 3 can be used to estimate the minimum angle of turn that will be required to stretch a fastener to the material's yield point. The chart assumes that the clamped components have infinite stiffness.

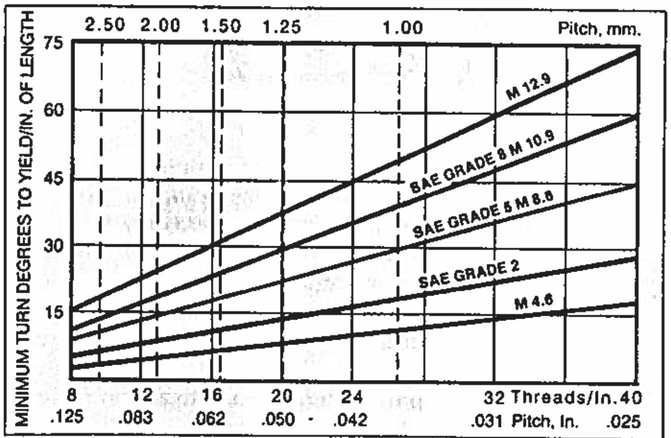
The basic relationship of stress to strain in the elastic region is given by the equation: $\sigma = \varepsilon \times E$ where σ is stress, psi; ε is strain, in./in.; and E is



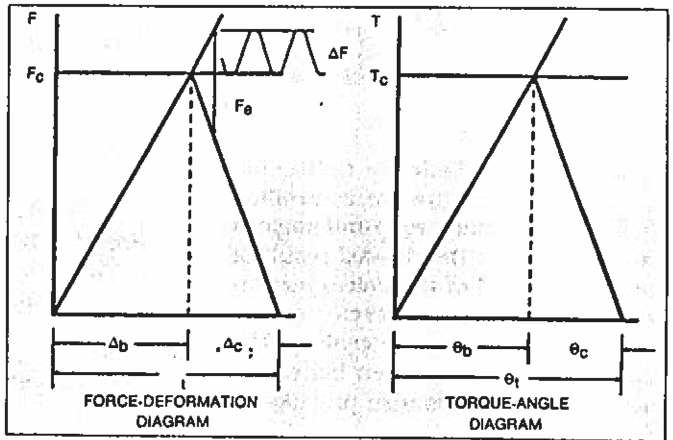
1. Relationship of stress/strain vs. torque/ angle



2. Deformation is geometrically related to angle of turn.



3. This chart estimates the minimum angle of turn required to reach a fastener material's yield point.



4. This composite diagram illustrates the relative angular motion required to both stretch the fastener and compress the joint.

Young's Modulus, psi. The stretch of a bolt or metal rod loaded in tension is calculated by use of the equation: $\Delta = (F \times L) / (A \times E)$

Turning the bolt stretches the fastener and compresses the parts being clamped. Therefore, it is necessary to know the spring rates of both the bolt and the clamped components to use the turn-to-tension procedure to establish clamping load. A simple experimental procedure for estimating joint and bolt stiffness follows.

The slope of the Force-Angle of Turn relationship is represented by the equation:

$$\frac{\Delta T}{\Delta \theta} = \left(\frac{K_B K_C}{K_B + K_C} \right) \frac{P}{360}$$

where K_B is bolt spring rate, lb/in and K_C is joint spring rate, lb/in.

Taking the first derivative of the basic equation $T=KDF$, yields the relationship: $\Delta T = K \times D \times \Delta F$ or $\Delta F = \Delta T / K \times D$

Substituting for ΔF in the Force-Angle of Turn equation yields a Torque-Angle/slope equation that estimates the spring rate of bolted joints. The equation is as follows:

$$\frac{\Delta F}{\Delta \theta} = \left(\frac{K_B K_C}{K_B + K_C} \right) \frac{P \times K \times D}{360}$$

If the spring rate of the bolt is estimated by the equation:

$$K_B = \frac{F}{\Delta} \text{ lb./in.} = \frac{A \times E}{Lc}$$

and the slope of the elastic clamping region of the Torque-Angle Curve, $\Delta T / \Delta \theta$ is determined from the curve and a value for K is assumed, then the spring rate for the joint is calculated:

$$K_c = \frac{\Delta T / \Delta \theta}{\left(\frac{P \times K \times D}{360} K_B - \frac{\Delta T}{\Delta \theta} \right) \times K_B}$$

Force-Deformation/Torque-Angle

Similar to the correlation between the material stress-strain diagram and the torque-angle diagram, it is possible to illustrate the correlation between the classic force-deformation diagram and a special torque-angle diagram. Figure 4 illustrates the relative angular motion required to both stretch the fastener and compress the joint.

As the force-deformation diagram shows, the bolted joint responds in a predictable manner when subjected to external working loads. Preload efficiency factors, based on the effective spring rates of the bolt and the clamped elements, are key to analyzing the fatigue resistance safety factor.

With a torque vs. angle plot from an assembly, it is possible to estimate the preload efficiency factor and calculate an approximate value for the effective spring rate for the clamped parts. The equation is:

$$\phi = \frac{K_B}{K_B + K_C}$$

The accuracy of the calculated values for joint stiffness and clamping efficiency factor depend on the degree of accuracy of the assumed value for *K* and the effective length assumed for the bolt. The preload efficiency factor , multiplied by the external applied load, calculates the maximum change in bolt loading to be expected when applying an external load to the assembly. This applies only up to the point where the joint separates. Above the separation load, 100% of the external load goes directly on the bolt.

Torque-Tension Correlation Coefficient

The equation $T=KDF$ applies to the linear elastic zone of the torque vs. angle tightening curve—after considering the prevailing torque and alignment zone torque influences. The factor *K*, often referred to as the "nut factor," can be expressed as a combination of three factors: K, K_2, and K_3 where *K* is a geometric factor, K_2 is a thread friction-related factor, and K_3 is an underhead friction-related factor. When designing special fasteners, or solving a specific problem, it is often desirable/necessary to have more specific information on the underhead and thread friction factors.

It is possible to experimentally determine the underhead and thread friction coefficients. A specially designed torque-tension load cell measures clamp force and thread torque. The cell allows measurement, study, and analysis of the frictional losses in the threads and underhead region of fasteners. □