International Journal of Scientific Engineering and Research (IJSER)
ISSN (Online): 2347-3878 (UGC Approved, Sr. No. 48096)
Index Copernicus Value (2015): 62.86 | Impact Factor (2015): 3.791

Analysis of Tightening Torque in Fasteners

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Abstract: ***Generally in fasteners the tightening torque that is applied to a bolt or screw is calculated considering their proof strength. They are usually preloaded in tension to 75% of its proof strength. Sometimes this value of tightening torque is not applicable when fastening is done for tapped holes. In case of tapped holes, if the yield strength of internal threads is less than the yield strength of screw stripping of internal threads can occur which leads to failure of joint. In this paper different cases are considered for fastening and the method to calculate the correct tightening torque under each case is explained. It also takes into consideration of length of thread engagement and stripping of internal threads.***

Keywords: Tightening torque**,** preload, proof strength, stripping of internal threads

1. Introduction

Threaded fasteners are used for holding things together when they are properly tightened. There must be appropriate tension in fastener to ensure proper performance. The bolts are preloaded to provide the clamping acting.

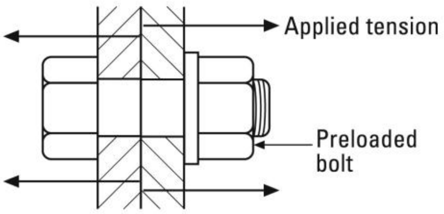

Figure 1: Preloaded bolt

Preload is the tension developed in a fastener while tightening. Due to this, the bolt goes in tension and clamping force is generated.

Following are the benefits of preloaded bolt.

1) Provides rigidity in joints.
2) Avoids loosening of bolts due to vibration.
3) Better fatigue performance.

In case of tapped holes the strength of internal threads plays a very important role for calculating tightening torque.

Figure 2: Tapped hole showing thread engagement

When torque is applied in excess there is failure in threads. If the material of internal threads is having low yield strength stripping of internal threads occur. The yield strength for most of the fasteners is usually specified. In order to avoid shearing the internal thread sufficient length of engagement between the internal and external thread should be ensured to provide adequate shear area for internal threads.

2. Theory

Generally, a bolt is preloaded by applying torque to either the bolt head or the nut. It should 75% of fasteners proof load and for structural applications and 90% of proof load in case of high strength fasteners for permanent fastening. The preload developed in a bolt is due to the applied torque and is a function of the geometry of threads, the bolt diameter, and the coefficients of friction that exist in the threads and under the torqued bolt head or nut. When a fastener is torqued, a tension preload develops in the bolt and an equal compressive preload develops in the parts being fastened.

3. Calculation the torque

There is a linear relationship between applied torque and preload which is used to calculate the tightening torque. It takes into account the thread geometry and friction in the threads and under the bolt head or nut. Tightening torque is given by:

$$T = K \times d \times F$$

Where:

T = Tightening Torque.
F = Clamping force.
d = Nominal diameter

Note:

F = Fp, When proof loading is considered.
Fp is 75% of proof load of bolt.
F = Fi, When Stripping of internal threads is considered.

The nut factor K accounts for the thread geometry, friction, pitch. [1] When ISO and Unified National Standard threads are used the nut factor is

$$K = \frac{d_m}{2d}\left(\frac{\tan\psi + \mu\sec\alpha}{1 - \mu\tan\psi\sec\alpha}\right) + 0.625\mu_c$$

Where:

d_m = the mean thread diameter, close to pitch diameter.
d = nominal bolt diameter.
tan ψ = (thread pitch)/ (π x d_m)
Thread Pitch = 1/N where N is the number of threads per inch or mm.
μ = friction coefficient in the threads
α = half the thread angle (typically 60°) = 30°
μ_c = friction coefficient under torqued head or nut.
Generally the value of K is found experimentally. The following table shows some typical conditions and corresponding values for K. [1]

Table 1: Experimentally calculated K values

Bolt Condition	K
Non-plated, Black Finish	0.3
Zinc Plated, Dry	0.2
Lubricated	0.18
Cadmium Plated	0.16

Fp = 75% Proof Load
Fp = 0.75 x Proof Strength x Ats
Where:
Ats = Tensile stress area

For UN threads

Ats = 0.7854[D - (0.9743/n)]^2

Where:

D = nominal bolt diameter in inch
n = no of threads per inch.

For Metric Threads

Ats = 0.7854[D – (0.9743/n)]^2

Where:

D = nominal bolt diameter in mm.
For internal threads shear area is calculated as [2] :

$$AS_n = 3.1416\,(1/P)(LE)(d\text{ min.}) \times \left[\frac{1}{2(1/P)} + 0.57735\,(d\text{ min.} - D_2\text{ max.})\right]$$

And for external threads.[2]

$$AS_s = 3.1416\,(1/P)(LE)(D_1\text{ max.}) \times \left[\frac{1}{2(1/P)} + 0.57735\,(d_2\text{ min.} - D_1\text{ max.})\right]$$

Where :
ASn = minimum thread shear area for internal threads
ASs = minimum thread shear area for external threads
1/P = number of threads per inch.
LE = length of thread engagement.
d min. = minimum major diameter of external thread
d_2 min . = minimum pitch diamter of external thread.
D_1 max. = maximum minor diameter of internal thread.
D_2 max. = maximum pitch diameter of internal thread.

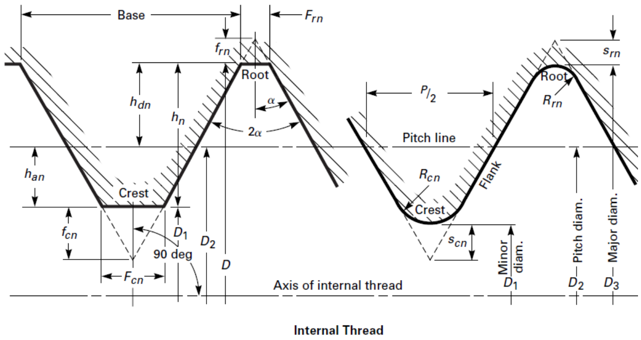

Figure 3: Unified Inch Screw Internal threads. [2]

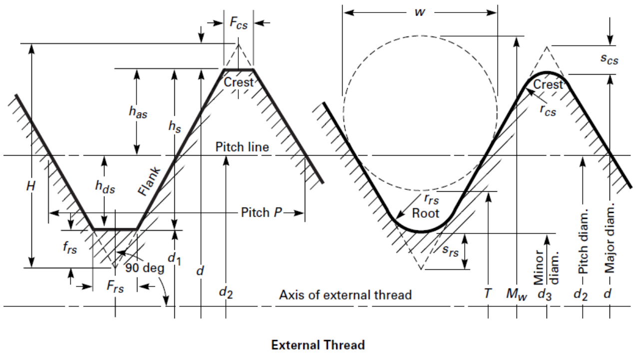

Figure 4: Unified Inch screw external Threads. [2]

Tightening Torque under different cases:

3.1 Nut and bolt (Bolted Joint).

In case of Nut and Bolt joint, the bolt is generally torqued to value considering the proof strength and the bolt material. The bolt preloaded to 75% of its proof strength.

Example 3.1:

Bolt size: 5/16”
Grade: SAE grade 2
Proof Strength: 55000 psi [4]
1/P = Threads per Inch.
1/P = 18
d =0.3125 in
Ats = 0.0524 in^2
T = K x d x Fp
Let K = 0.2 (considering dry conditions).
Fp = 0.75 x Proof Strength x Ats
Fp = 0.75 × 55000 × 0.0524
Fp = 2161.5 lbs.
Hence,
T = 0.2 × 0.3125 × 2161.5
T = 135.09 lbs-in.

In the case 135.09 in-lbs. is the tightening torque that must be employed.

3.2 Tapped Hole:

In case of tapped holes the strength material of internal threads plays a vital role. If applied torque is more than the shear strength of internal threads, they can strip off. Given below are two cases that generally occur. With help of suitable examples the calculation of torque in each case is explained.

Case 1: The internal threads having low shear strength but having adequate shear area (Sufficient length of engagement).

Example 3.2: In this example a screw is fastened into a tapped hole. The material in which tapping is there has yield strength less than that of the screw. Here tightening torque is calculated considering both Proof loading as well as stripping of internal threads. Let T_1 be torque considering for Proof loading and T_2 be torque considering stripping of internal threads.

Bolt size: 5/16"
Grade: SAE grade 2
Proof Strength of Screw: 55000 psi [4]
Material Yield Strength: 20000 psi
Material Shear Strength = 0.5 × Yield Strength. [3]
Material Shear Strength = 10000 psi
1/P = Threads per Inch.
1/P = 18
d = 0.3125 in.
dmin = 0.3026 in.
D_2max = 0.2817 in.
Ats = 0.0524 in^2
Considering Proof Loading:
T_1 = K x d x F
Let K = 0.2 (considering dry conditions).
Fp = 0.75 × 55000 × 0.0524
Fp = 2161.5 lbs.
Hence,
T_1 = 0.2 × 0.3125 × 2161.5
T_1 = 135.09 lbs-in.
Now Considering Stripping of internal Threads:
T_2 = K x d x Fi
Fi = Internal thread shear strength × Asn
Let Le = 0.5 in. (Sufficient length of engagement)
Asn = 0.3409 in^2
Fi = 10000 × 0.3409
Fi = 3409 lbs.
T_2 = 0.2 × 0.3125 × 3409
T_2 = 213.06 lbs-in.

In this case T_2 is greater than T_1. Hence, the correct tightening torque is 135.09 lbs-in. that must be applied. If value of torque is more than 135.09 In-lbs the bolt will fail in tension due to yielding. So even though the material of internal threads has low yield strength the torque is applied considering the proof loading of bolt as there was adequate length of 0.5in. that was sufficient enough to avoid stripping of internal threads.

Case 2: The internal threads having low shear strength and less shear area (Insufficient Length of engagement).

Example 3.3

Consider a similar case as mentioned in example 3.2 but here let us consider the length of engagement (Le as 0.15 in.)
Now the procedure to calculate T_1 will be same.

Hence T_1 = 135.09 lbs-in. However, now as length of thread engagement has been changed from 0.5 in. to 0.15 the shear area of internal threads has been reduced. Let us consider the torque in this case to be T_3.

Asn = 0.1022 in^2.
T_3 = K x d x Fi
Fi = Internal thread shear strength × Asn
Fi = 10000 × 0.1022
Fi = 1022 lbs.
T_3 = 0.2 × 0.3125 × 1022
T_3 = 63.87 lbs-in.

As we can see the torque in this case is less than T_1 and hence the T_3 is the correct tightening torque that must be applied. If the applied torque is more than 63.87 lbs-in. (T_3) there will be stripping of internal threads.

4. Conclusion

The tightening torque that is employed to fasteners should be carefully calculated. Application of incorrect torque leads to failure of fasteners. When nut and bolt type of fastening is used the tightening torque is selected as per proof loading condition of bolt. In case of tapped holes correct value torque is calculated considering both proof loading of screw as well as stripping of internal threads.

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