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A Better Technique for Controlling Torque to Preload Relationship in the Accurate Assembly of Tiny Threaded Bolt Joints

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Abstract

Our industrial, commercial, and even civil worlds are made possible by threaded fasteners or connections, which include all types of bolts. They offer an easy way to connect a limitless number of small parts to form large and practical objects like printing presses, cars, airplanes, and buildings. This paper describes the ways to determine torque to preload relationship in threaded connection and finalizing the optimum torque to be applied. Explains further "why appropriate bolt tension, also known as preload, is essential to an assembled joint's dependability and safety. A summary of the many approaches to producing that preload will be provided. The paper discusses the case study of threaded connection which is non lubricated and difficult to use the conventional methods to determine the torque to preload relationship due to its geometry.

Keywords: Bolted joints, friction, K-factor, Minitab, preload, Torque-tension relationship

INTRODUCTION

Threaded Connections

One of the most popular joining techniques is the bolted joint; additional typical joining techniques include adhesives, riveting, welding, press fits, pins, and keys. Threaded fasteners are primarily employed for their exceptional clamp load and ability to hold objects together, but their removability is also an important characteristic. For manufacturers, removability is often fundamental for maintenance, service, or repair, even if only a small percentage of products ever need to be disassembled [18].

The threaded fastener and the corridor to be connected together (the clamped corridor) are the two main components of a bolted junction (Figure 1). By threading the fastener into a nut or into vestments that have been tapped into a corridor, the common workshop was bolted by converting an original setting force ("preload") on the joint. For the duration of the joint, this preload guarantees that the clamped corridor will stay in contact and contract [18]. Clamp cargo is wielded by creating pressure in the fastener. In addition, at some point, one may wish to remove the clamp cargo and disassemble the corridor. Nuts and bolts fill this function well but understanding and addressing the principles behind threaded fasteners will help insure the anticipated long- term, dependable results [9,12,18].

Threaded Dimension

The distinctive dimensions of the internal and external threads must be known in order to analyse a joint. A nominal (major) diameter and either the pitch (for metric threads) or the number of threads per inch (for unified inch threads) are used to specify a thread size (Figure 2). The spacing between the threads is known as the pitch, or P. Pitch is correlated with threads per inch, or TPI, when expressed in inches by, [12,13].

$$TPI = 1 / P$$

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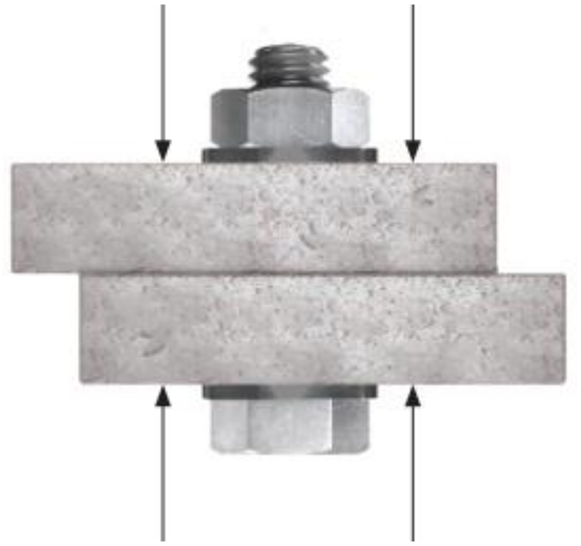

Figure 1. Threaded Joint.

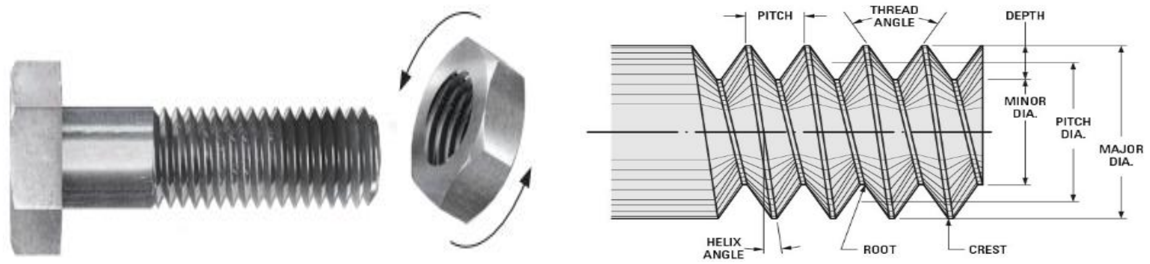

Figure 2. Thread dimensions.

AS8879 describes the thread dimension and gives examples of standard UNJ thread designations [10].

Failure Mode of Threaded Joints [9].

- Self-Loosening
- Fracture

Problems Created by Incorrect Preload [9,12,18]

Below are some of the problems created by incorrect preload.

Static failure of the fastener, Static failure of the fastener, Vibration Loosening of the Nut, Fatigue Failure of the Bolt, Stress Corrosion Cracking, Joint Separation, Joint Slip, Excessive Weight, Excessive Cost

Methods of Pre-load Control

There are six main methods [15] used to control the preload of a threaded fastener. Specifically,

Angle Control Tightening

This system, also known as the turn of the nut system, was introduced for homemade assembly when a certain tightening angle was specified. The system has been applied for use with power wrenches, the bolt is tensed to a destined angle beyond the elastic range and results in a small variation in the preload due, in part, to the yield stress forbearance. The main disadvantages of this system taradiddle in the necessity for precise, and, if possible, experimental determination of the angle; also, the fastener can only sustain a limited number ofre-applications before it fails [15].

Yield-controlled Tightening

This system is also known under the personal name" Joint Control Method". veritably accurate preloads can be achieved by this system by minimizing the influence of disunion and its smatter. The "sense of sense" that a craftsman had with a wrench—which enabled him to reasonably accurately determine the fastener's yield point—is the source of the system. A control system that is sensitive to the necklace grade of the bolt being stressed is used with this electronic system. Quick detection of this grade's pitch change signals the attainment of the yield point and halts the tightening operation. To do this, detectors that read the angle and necklace throughout the tightening operation are incorporated. Since the control system measures both the length and the angle of gyration, fasteners that fall outside of their specified range can be identified using acceptable values [15].

Bolts Stretch Method

One issue with tightening big nuts is that very tall tightening ropes are required. Although this can be incompletely overcome by the use of hydraulic necklace wrenches (the response of the necklace still can be a problem), the use of hydraulic tensioning bias is commonplace for bolts over 20 mm in periphery. The system uses a small hydraulic ram which fits over the nut, the threaded portion of the bolt/ superstud protrudes well past the nut and a threaded sculler is attached. Hydraulic oil painting from a small pump act upon the hydraulic ram which in turn acts upon the sculler. This is transmitted to the bolt performing in extension being. The nut can also be rotated by hand with the aid of an integral socket.

Torque Control of Preload

Many of the common tightening methods achieve the preload force by applying torque to the nut or to the bolt head. One of the simplest and most popular ways to tighten a fastener is with a torque wrench; once the required torque is reached, the fastener is correctly tightened. In this instance, figuring out the torque number required to obtain the desired preload force in the bolt. [11,15,16]

This torque is calculated using [18,19]:

$$T = K_T\, d_{nom}\, F_{PL}$$

where d_{nom} is the nominal bolt diameter and F_{PL} is the bolt preload force. K_T is the torque coefficient and is calculated by [9]:

$$K_T = \left(\frac{r_t}{d_{nom}}\right)\left(\frac{\tan\lambda + f_t \sec\alpha}{1 - f_t \tan\lambda \sec\alpha}\right) + \frac{f_c r_c}{d_{nom}}$$

where r_t is the mean thread radius (the effective location at which the thread friction acts), r_c is the mean collar radius (the effective location at which the friction on the bearing face acts), f_t is the friction coefficient between the thread surfaces, fc is the friction coefficient between the collar (bearing face) surfaces, λ is the lead angle, and α is the thread half angle ($\alpha = 30°$, per ASME B1.1, 10.1b).

The value for r_t is calculated as half of the mean bolt diameter, which is the average of the minor diameter and nominal diameter:

$$r_t = \frac{(d_{nom} + d_{minor})/\,2}{2} = \frac{d_{nom} + d_{minor}}{4}$$

The collar area is the area of the bearing face of the part being rotated during installation (either the nut or the bolt head). The width across flats of a nut is typically 1.5 times the nominal diameter. In this case, the mean collar radius is calculated as:

$$r_c = \frac{(d_{nom} + 1.5\, d_{nom})/\,2}{2} = 0.625\, d_{nom}$$

The lead angle, λ, is calculated by:

$$\tan\lambda = \frac{l}{2\pi r_t} = \frac{1}{2\pi r_t (TPI)}$$

where l is the lead per revolution (= 1/TPI).

Shigley provides a table of torque coefficients based on bolt conditions, which has been adapted as shown below. When the bolt condition is unknown, a value of 0.2 is recommended for K_T.[14,17].

The relationship between Torque and Preload still requires an understanding of the portions of thread disunion and bearing disunion. There are numerous variables that make these values delicate to prognosticate, including but not limited to, Material, face finish, Thread forbearance (Allowance, Pitch, Minor, and Major periphery) Cleanliness, Lubrication (In our case it's dry), Thread manufacturing process(cut or rolled) Speed of assembly, Length of the thread engagement, Condition of bearing shells, Hardness of accoutrements being threaded together, Operator, Tools etc.[9],[18].

With numerous factors affecting the KT and latterly Pre-load, factual testing with Design of trial will be veritably expensive and time consuming. Also, without directly measuring Pre-load, and depending upon back out necklace values will be less dependable.

Because of the numerous variables that affect the value of the necklace measure, any tightening system that measures a preload force laterally via a necklace value will be innately inaccurate. It's for this reason that there's such a large query in preload delicacy when using a necklace wrench.

LITERATURE REVIEW

1. *Yanyao Jiang, Jianjun Chang, Chu-Hwa Lee,* during experimental study of the torque-tension relationship for bolted joints developed an experimental procedure to investigate the frictions in bolted joints. The device used in the study provided an easy means of understanding the torque to preload relationship. They used a standard nut and bolt assembly in experiment. The device can be used for understanding the contributions by thread friction, nut face or clamped part friction or washer friction.
2. *Xiwen Zhang, Xiaodong Wang, Yi Luo,* in this study an improved model-based torque method was proposed for the real-time precise control of the preload of the miniature bolt joints. The torque gradient determined by friction effects was considered in the model. Moreover, the system stiffness and rotation speed were also incorporated into the model. Miniature bolts tightening experiments which were conducted have demonstrated the validity of the proposed method, and the results indicated that the scatters of bolts preload for the target preloads of 90, 120 and 150 N were ±12.9, ±10.0 and ±8.9%, respectively. The magnitudes of the actual preload errors for most bolts were no less than 10%. However, if more accurate system stiffness can be obtained, better preload accuracy will be achieved. The method offers the benefit of convenience and does not require any special equipment; therefore, the proposed method is suitable for control the preload in real-time. It is a promising method for the preload control in the precision assembly of miniature bolt joints.
3. *D. Andy Hissam,* in his study of determining Torque limits to maximize preload for High-Strength Threaded Fasteners, developed a methodology for determining torque limits for high-strength structural fasteners. This empirical-based methodology maximizes the preload that can be placed on the fasteners during installation. Once a torque limit is determined for a specific fastener combination, it can be applied to any joint using the same combination. This research was motivated by the major shortcoming found in other methods for determining torque limits: failing to fully address the statistical challenges of dealing with preload scatter. Since preload scatter can be so significant (sometimes exceeding ±35%), it must be carefully considered, especially when maximized preload is desired. To meet these challenges, the probability of yielding the bolt during installation had to be determined. In addition, the preferred sample size for torque limit testing had to be defined.
4. *Q.M. Yu, H. L. Zhou,* in this study a precise 3-dimensional finite element model of bolt and nut considering helix angle has been established to simulate the retightening process for threaded connections of pressure vessel. They found out that friction coefficient of sliding surfaces has a

great influence on tightening torque coefficient. They also recommended that we should pay more attention to the lubrication of contact surfaces between nut and flange in the pre tightening process of threaded flange structure of pressure vessel.

5. *Swapnil Thigale, Pranjali Aher,* in this study the author recommended that 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.
6. *Q.M. Yu, H. L. Zhou, Xj Yang,* An experimental study on the relationship between necklace and preload of threaded connections, a new measuring device for preload was designedPre-tightening test of the bolts and nuts of three specifications M8 X 1, M10 X1.25, and M10 X1.5 were conducted at room temperature. The relationship between necklace and preload during thepre-tightening process has been delved by trial. The influence of lubrication and roughness on nut factor was anatomized. The influence of the torturing times on the nut tone- locking necklace has been studied.
7. *D. P. Hess,* Preload from Tightening and Removal Torque, presented a novel approach to determine preload at installation or point of use with a common torque wrench. The approach uses both tightening torque and removal torque. This work revealed preload is proportional to tightening minus removal torque and that taking this torque difference subtracts out friction. Tests performed with bolts, nuts, lock nuts, inserts and locking inserts to assess this method of determining preload showed good agreement with measured preload. The tests performed found the uncertainty in preload from torque difference to be less than the uncertainty in preload from just tightening torque alone.
8. *Mr. Tejas Mukund Nesarikar,* the work carried out in this discussion is substantially concerned with the assaying the loosening characteristics i.e., bolt preload decay. The study is carried out to find out the significant effect of vibration on the fastener system. The experimental study shows that in dynamic condition fasteners loosening effect caused due to the increase in frequence which results in the reduction in the tensing necklace as the tensing necklace is directly commensurable to the bolt preload. The stability of fastener system under vibration is completely dependent upon the tensing necklace. Hence it's necessary to design the fastener system when it's subordinated to transverse vibration.

CASE STUDY

Design of Threaded Joint Connection

Two threaded components and related assembly are used in a hydraulic system where the operating pressure is at 27.58 N/mm^2, undergoes cyclic loading in which the Impulse peak pressure of 41.37 N/mm^2, and the operating temperature range is -40 to +138 degrees C.

The material of both components is Corrosion Resistance Steel and has no lubrication provided between them. Thread size of 1.0625-18 UNJ is used.

Representative picture of Threaded components as shown below, other components of an assembly are not taken into consideration.

Design of Threaded Joint Connection

The method used to control preload is “Torque Control” in this case. When tightening a fastener with a torque wrench, which is one of the easiest and most common methods, the fastener is properly tightened once the specified torque is achieved. In this case, it is necessary to determine the torque value necessary to achieve the desired preload force in the bolt. This torque is calculated using [9,15, 18].

$T = K_T d_{nom} F_{PL}$

where d_{nom} is the nominal bolt diameter and F_{PL} is the bolt preload force.

Above equation assumes K_T uniform nut factor while calculating the Torque or Preload. In order to ensure the validity of the equation, the nut factor, as defined in the above equation (sometimes referred to as the short form relationship), was determined experimentally rather than using engineering principles. There is the following method of determining the K factor [9].

Determining K Factor (Experimental Approach)

The k-factor is the simplest way to describe the friction of a threaded assembly. The K-factor can be determined using a clamp load transducer along with a torque-measuring device [18].

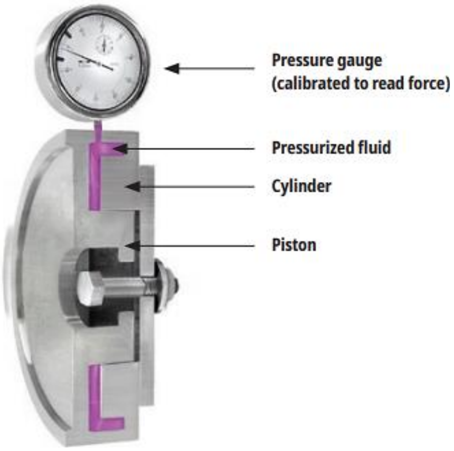

Figure 3. Torque to Tension Tester.

When a fastener is loaded and tensed into a clamp cargo transducer, it clamps onto a piston that generates hydraulic pressure internally. This pressure is indicated on a pressure hand but is calibrated to the piston face area to indicate clamp cargo. Pressure hand (calibrated to read force) Pressurized fluid Cylinder Piston It should be noted that the k- factor doesn't describe a particular thread lubricant similar as grease, oil painting, anti-seize or thread locker (Figure 3). It describes the disunion of the specific assembly tested. When performing k- factor determination tests of a simulated threaded assembly, care must be taken to duly replicate the configuration of the bolted joint so that both thread disunion and bearing disunion are duly dissembled. Over numerous test replicates using the specified tackle and necklace tools, a realistic assessment of the anticipated dissonances in pressure can be determined. This Method is only suitable for standard Nut and Bolt configurations, which cannot be used in case study as it is not feasible with the configuration and size of the components in question.

Determining K Factor (Analytical Approach)

Shigley provides a table of torque coefficients based on bolt conditions, which can be assumed as a guideline but with caution. Per the guidelines when the bolt condition is unknown, a value of 0.2 is recommended for K_T [14].

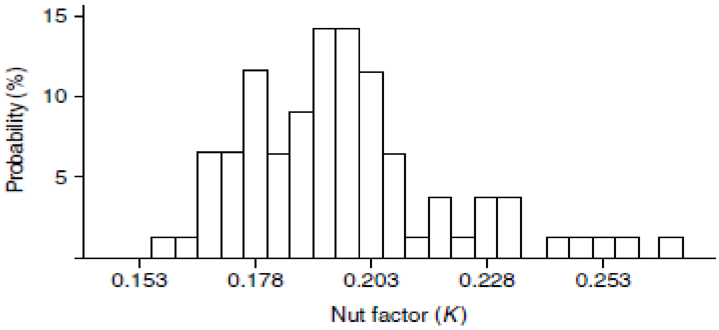

Figure 4. K factor Variation

Source: "Introduction to the Design and Behavior of bolted joints" by John Bickford. Page 147 provides nut factor for "Steel on Steel as received" and it's variation data [9].

- The standard deviation for this K data is 0.05, and the mean is 0.199. Plus, or minus three standard deviations, therefore, takes us from a K of 0.15 to a maximum K of 0.25 [9].
- The data suggest that we can expect a scatter of +/- 25% in the preload achieved at a given input torque. (Simple Equation) [9].

Based on above the K factor variation to be assumed as 0.15 to 0.25 for steel on steel non lubricated threads (Figure 4).

If we assume desired preload is minimum 500 lbf, then with the application of 100 in-lbs of torque will result into following by using equation per [9].

Table 1. Preload variation due to other factors.

Applied Torque Inch-lbs	Preload With Minimum K factor of 0.15	Preload With Nominal K factor of 0.199	Preload With Maximum K factor of 0.25
100	627.45	472.95	376.47

Based on the calculations in table 1, it is evident that even by applying the equal amount of torque, due to K factor variation is amount of preload generated is showing higher variation [21,22]. If desired preload is 500 lbf then in 2 cases above, we are developing preload less than 500 lbf.

To further consider other factors' effect on Preload uncertainty following Table 2 ,3was created to come up with the total amount of preload variation that can be predicted.

Table 2. Preload variation due to other factors.

Factors Affecting Preload		Less Preload (in % to Nominal)	More Preload (in % to Nominal)	Comments
Tool Accuracy	The accuracy with which the torque wrench produces the thing it's supposed to produce.	5	5	3 Sigma Variation Current torque wrenches accuracy is +/- 2% clockwise, +/- 3% counterclockwise.
Operator Accuracy	This factor defines the amount of scattering introduced by operator errors, operator carelessness, etc.	5	5	3 Sigma Variation
Control Accuracy	This is the accuracy with which the selected control variable—torque will produce the bolt tension. Based on literature the typical scatter for steel on steel nonlubricated threaded joint is +/- 25%. For the conservative approach we will use torque–tension scatter of -30% on the negative side	30	25	3 Sigma Variation
Short term relaxation	Assumed embedment relaxation of - 10%. Relaxation will never increase bolt tension, so the plus scatter is zero.	10	0	3 Sigma Variation
Effect of Plug load	The load variable involves an in-service condition. In service	10	0	3 Sigma Variation

	external load -Plug load will reduce the Pre-load.			
	Total Variation in Pre-load	34	26	**RMS Variation**

To determine the torque range necessary to achieve the desired preload force which is more than 1500 lbf in the threaded components used in case study,

$T = K_T\, d_{nom}\, F_{PL}$

where d_{nom} is the nominal bolt diameter and F_{PL} is the bolt preload force [23,24]. The equation was used with variations of -34% and +26% [9].

Table 3I. Calculation of Preload and Assembly Torque.

Parameter	**Maximum**	**Minimum**
Maximum Torque (in-lbf) [T]	560	498
Nut Factor [K]	0.199	0.199
Diameter (in) [D]	1.0625	1.0625
Preload by Equation [F = T/KD] (lbf)	2635.29	2343.53
% Uncertainty	+26%	-34%
Preload (lbf)	3320.47	1546.73

CONCLUSION

In Summary, the correct Pre-load is essential in threaded joints to prevent its typical failure modes of static, fatigue failure and loosening. The Preload depend upon Coefficient of Friction between threads and bearing surface. It is very difficult to estimate the Coefficient of Friction by analytical methods as variation in piece to piece affects it. The Coefficient of Friction affected by number of factors like Material, Surface Finish, Cleanliness, Operator, Speed of tightening, Lubrication etc. to name a few. It is wise to determine Coefficient of Friction and in turn K Factor (Nut Factor) by experiment with actual components with good number of sample size to accurately calculate the K factor. This experiment requires standard nut and bolt configuration and not economically viable considering cost (samples. Equipment's) time and variability.

Paper presents the way of calculating the scatter in Preload analytically by considering different factors and its portion of variability in percentage. By doing this exercise, designer can conservatively decide the assembly torque range to produce desired Preload which will prevent loosening of threaded components and also not results in static and fatigue failure avoiding leakage in fluid carrying systems.

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