Experiment 2 (combined Familiarization and Exploration Lab) Strength of Fasteners

Overview

Threaded fasteners are an important part of many devices. The correct design and specifications of threaded fasteners require careful consideration of materials, environment, manufacturing and assembly procedures as well as the functional requirements of the assembly. Threaded fasteners can be more costly than some other fastener types, but they also have many benefits that make them very useful and convenient. These benefits include ease of repeated assembly and disassembly and simplicity of operation. In addition, most threaded fasteners are mass-produced in standard sizes and are readily available.

Two critical engineering objectives of threaded fastener design are the operational strength of the fastener and the setting of the required assembly pre-load. The pre-load must be sufficient to ensure that the fastener remains secure during service but also must not to be excessive that it makes the fastener prone to failure. This lab considers several of the factors that are important for effective threaded fastener design. The main steps you will take are:

1. Measure torque vs. bolt tension for various combinations of bolt conditions, also maximum bolt tension. You will need to recut screw threads on the broken pieces so that you can make three measurements on each of two bolts.
2. Upload your measurements to the course website to combine with the data from other lab groups. These data will then be used for subsequent statistical analysis.
3. Analyze your own data to try to identify trends in your measurements. What results were expected and well explainable? What other results were not expected or not well explainable? What useful questions were left unanswered by this first experiment? On the basis of these considerations, identify the objectives of some follow-up research experimentation that you would like to pursue.

Objectives

1. Investigate the relationship between the tension in a bolt and the torque used to tighten the attached nut.
2. Determine now the surface condition of a bolt affects the torque required to tighten the attached nut.
3. Determine now the thread details of a nut and bolt assembly affect the overall fastener strength.

Prelab Preparation

1. Using the theory described in the next section, calculate the torque in lb.in required to obtain a preload of 90% of the proof strength of a 5/16" UNC Grade 2 machine screw. Base your calculations on the maximum friction factor for hard steel on hard steel lubricated by turbine oil plus 1% graphite, see Appendix A. Compute each of the three components of the required torque and report them separately.

   Note: The effective contact radius of the threads between nut and bolt is half the average bolt pitch diameter. The effective radius of contact between the nut and washer is the average radius of the nut, which equals half the average of the the major diameter of the nut and the outer diameter of the nut (= 0.5").
2. What percentage of the torque calculated in Question 1 is caused by friction ?
3. Estimate how many turns of the nut are required to achieve the preload for the bolt in Question 1. The 7" length of the bolt between head and nut has full diameter, while the threads at the end go only just far enough to accommodate the nut. The component secured by the bolt may be considered rigid.
4. Graphite lubricant was used by mistake instead of turbine oil plus 1% graphite. The torque computed in Question 1 was used to tighten the bolt. Calculate the resulting preload stress in psi and compare this to the published breaking strength of the bolt.

   (Hint: In the various questions, you will need to pay attention when to use the full bolt cross-section area or the smaller area inside the threads.)

Torque vs. Preload Relationship for Threaded Fasteners

Screw threads can be likened to a ramp that has been coiled around a cylinder. The steeper the ramp, the greater the distance between each coil of the thread. This distance is known as the lead, which for single-thread bolts is equal to the pitch (distance between successive surface peaks). If the nut or bolt is turned after all the clearance has been removed, the joint will compress and the bolt will stretch. If the joint is stiff compared with the bolt, most of the deformation will take place in the bolt. The resulting preload in the bolt will be proportional to the rotation amount, the thread lead and the bolt cross sectional area, and inversely proportional to bolt length.

Equation (1) describes the relationship between the applied torque and the preload of a threaded fastener. It is a modification of an equation proposed by Motosh, and quoted by Bickford[1],

$$T_{in} = F_P \cdot \frac{P}{2 \cdot \pi} + F_P \cdot \frac{\mu_t \cdot r_t}{\cos(\beta)} + F_P \cdot \mu_n \cdot r_n$$

where:
- T_{in} = torque applied to the fastener
- F_P = preload created in the fastener
- P = thread lead (travel per revolution)
- μ_t = coefficient of friction between the nut and bolt threads
- r_t = effective contact radius of the threads
- β = the half-angle of the threads (30° for UN or ISO threads)
- μ_n = coeff. of friction between the face of the nut (or head) and washer
- r_n = effective radius of contact between the nut and washer surfaces

The three terms on the right side of the equation respectively describe the torque contributions from :

1. tightening the bolt
2. friction between the nut and the bolt
3. friction between the nut and the washer

The friction effects from the second two terms can often be significantly larger than the bolt tightening effect from the first term and can dominate the required torque. See Appendix A for published data for friction factors of steel on steel.

[1] Bickford, John H., *An Introduction to the Design and Behavior of Bolted Joints,* 2nd ed., Marcel Dekker, Inc., New York, 1990.

Lab Description

In this lab you will examine two common methods for preloading bolts:

1. Rotate the bolt head or the nut using a torque wrench until a specified torque reading is reached.
2. Rotate the bolt head or the nut until all clearance is removed, then continue rotation by a further specified amount. This is called the “turn of the nut” method.

You will investigate some of the factors contributing to uncertainties in each of these methods and will be asked to draw some conclusions from your measurements. The factors you will examine are:

- Rolled threads. Factory-made bolts have their threads made by rolling. The resulting work hardening tends to increase thread strength.
- Machined threads (cut using a die). No helpful work hardening is added.
- Unlubricated clean surface. This is the common case.
- Rusty surface. This creates higher friction between the nut and bolt
- Lubricated surface. Reduces friction between the nut and bolt
- Coarse thread. 5/16” UNC has 18 threads per inch
- Fine thread. 5/16” UNF has 24 threads per inch

In the lab, you are asked to do six tests on bolts with different combinations of the above factors.

1. Rolled UNC thread, unlubricated
2. Machined UNC thread, unlubricated
3. Machined UNC thread lubricated
4. Rusty UNC thread unlubricated
5. Machined UNF thread unlubricated
6. Machined UNF thread lubricated

Procedure

1. Using the toggle switch at the back, turn on the power to the bolt force indicator. The displayed number indicates bolt tension force in pounds.

2. Divide your lab team into two pairs of people. One pair follows steps 3-11 using the first bolt and the second pair follows steps 12-14 using the second bolt. The required activities involve bolt testing and bolt thread cutting. Seek to organize yourselves such that when one pair is bolt testing the other is bolt thread cutting.

   Safety Instructions: Do not stand on the left side of the apparatus while tightening each bolt. The torque wrench and protractor reader should wear safety glasses.

3. Load a "dry" (unlubricated) non-rusty bolt into the apparatus, with two cylindrical spacers at the left side. Secure the retaining arm to the head of the bolt to prevent it from turning.

4. Add a "dry" washer at the nut end of the bolt to provide clearance for the protractor scale. Then screw on a "dry" nut for the first measurement. Tighten the nut just enough to take the slack out of the bolt assembly.

5. Attach the torque wrench on the nut and lighten it in increments of 20 degrees. After each increment, record the torque and the bolt tension. Release the torque briefly to make the reading visible. Continue until the bolt breaks. Watch the bolt force carefully and note the maximum force.

6. Remove the broken bolt. Use a file to remove the distorted material near the bolt break. Then use a die to extend the existing screwthread so that the distance between the screwthead and the bolt head is 5½". Take care to keep the die perpendicular to the bolt so that the thread will run parallel with the bolt length.

7. Wash the bolt with soapy water to remove cutting oil remaining from the screw cutting process. Then carefully dry the bolt. Remove one cylindrical spacer on the left side and reassemble the equipment also using a "dry" nut and "dry" washer.

8. Repeat steps 4 and 5.

9. Repeat step 6, this time with the distance between the screwthread and bolt head equal to 4¼".

10. This time, add grease to the screw threads to provide lubrication. Remove the second cylindrical spacer and reassemble the equipment using a greased nut and a washer greased on the outside surface. *(Be sure to keep the "dry" and greased nuts and washers separate, else you and the lab groups following you will get false results. Put grease only on the nut side of the greased washer; the side touching the protractor scale should be kept "dry").*

11. Repeat steps 4 and 5.

12. Take the rusty bolt and repeat steps 4 and 5.
13. Repeat steps 6-11, but using a UNF die instead of UNC. This will require some care because the UNF thread is not compatible with the original UNC thread. It will help to file a bevel around the top of the previous screw thread to create a conical starting surface for the UNF die. Be careful to keep the die perpendicular to the bolt length while working. Once past the original coarse threads, the new fine threads should be good.
14. Tidy up after you are finished.

Lab Report

In your memo style report, briefly describe what you did so that the reader can generally understand your procedure. Be sure to mention any particular features or circumstances that may have impacted your data or results.

Summarize your measurements and results. Make separate scatter plots of preload vs. applied torque for each of your six tests. Draw best-fit straight lines on your plots and measure the corresponding gradients. Record and compare the gradients for the six tests, also the maximum load. Also upload your gradient and maximum load results to the course website for later in-class statistical analysis.

Comment on your findings, particularly unexpected ones. Suggest possible causes of discrepancies and explain your reasoning, don't just cite "experimental error". Suggest possible changes in the experimental procedure to rectify the issues that you identify.

As part of your commentary, discuss the relative merits of preloading a screw using torque and turn-of-the-nut methods. Note also the differences between lubricated and dry bolts, and explain why they occur. Suggest examples of applications where each method should be used based upon their relative advantages and disadvantages.

Appendix A

Material Specifications

Spec.	Grade	Yield Strength[2]	Ultimate Tensile Strength[3]	Proof load stress[3]
SAE J429	2	57,000 psi	74,000 psi	55,000 psi
$E = 30 \times 10^6$ psi	5	92,000 psi	120,000 psi	85,000 psi

Fastener Dimensions

Size	Bolt Dia.[4]	Tensile Area[4]	Thread Length[2]	Head Height[2]	Threads Per inch
5/16-UNC	.3125 in.	.0524 sq. in.	.875 in	7/32"	18

$$n = \frac{F L}{A E P}$$

Thread Dimensions [5]

		Bolt			Nut		
Thread Size	Class	Major Dia. (in.)	Minor Dia. (in.)	Pitch Dia. (in.)	Minor Dia. (in.)	Major Dia. (in.)	Pitch Dia. (in.)
5/16-UNC	2A	.3113 .3026	.2431	.2752 .2712	.252 .265	.3125	.2764 .2817

Friction Factors (steel on steel)
"Marks" [6]

Materials	Static		Sliding	
	Dry	Greasy	Dry	Greasy
Hard steel on hard steel	0.78	0.11 (a)	0.42	0.029 (h)
		0.23 (b)		0.081 (c)
		0.15 (c)		0.080 (i)
		0.11 (d)		0.058 (j)
		0.0075 (p)		0.084 (d)
		0.0052 (h)		0.105 (k)
				0.096 (l)
				0.108 (m)
				0.12 (a)
Mild steel on mild steel	0.74		0.57	0.09 (a)
				0.19 (u)
Hard steel on graphite	0.21	0.09 (a)		

(a) Oleic acid; (b) Atlantic spindle oil (light mineral); (c) castor oil; (d) lard oil; (h) stearic acid; (i) grease (zinc oxide base); (j) graphite; (k) turbine oil plus 1% graphite; (l) turbine oil plus 1 % stearic acid; (m) turbine oil (medium mineral); (p) palmitic acid; (u) rape oil.

[2] Bickford, John H., *An Introduction to the Design and Behavior of Bolted Joints,* 2nd ed., Marcel Dekker, Inc., New York, 1990.
[3] *Fastener Assembly,* Premier Industrial Corporation
[4] *Machine Design,* Nov. 1977
[5] Machinery's Handbook, 20th ed., Industrial Press Inc., New York, 1977
[6] *Standard Handbook for Mechanical Engineers,* 7th ed., McGraw-Hill