Torquing Threaded Fasteners
Torquing Topic Goals

1. Discuss the factors that should be considered when determining the amount of joint preload required.

2. Discuss the primary properties associated with selecting threaded fasteners to achieve a desired joint preload.

3. Explain the importance of preload increments and sequencing to obtain a properly assembled joint.

4. Determine proper torquing sequence patterns for round and rectangular shaped flanges.

5. Discuss the factors that affect the Friction Coefficient of threaded fasteners.

6. Use a torque chart to determine proper torque specifications for various threaded fasteners.

7. Discuss the selection of a torque wrench for a given application.
Introduction

Numerous components and systems within an industrial plant are subjected to high pressures and extreme temperature changes. Many parts of these components and systems are joined mechanically to facilitate inspection and repair.

Mechanical joints normally consist of 2 flange halves, a gasket, and a threaded fastener assembly. The flange halves are attached to the component, the gasket assists with the restriction of fluid flow between the flange halves, and the fastener assemblies hold the flanges in place and compress the gasket material to assist it in stopping the fluid flow. To attain and maintain joint integrity, the threaded fastener assemblies (usually nuts, bolts or studs and washers) must be installed to the correct tightness.

In order for the fasteners to perform their assigned duties, they must be manipulated to set up the correct amount of internal stress. This internal stress is attained by “stretching” the fastener out of its relaxed state and not allowing it return. The force that the fastener applies trying to return to its relaxed state (spring back) is the “Preload” that is applied by the fastener to the joint.

JOINT PRELOAD

The threaded fasteners are installed by applying a tension load (preload) on the fastener acting to hold the flanges and gasket together. The total clamping force that threaded fasteners exert on a joint after tensioning is complete is termed “Joint Preload”. The behavior of the joint, whether it leaks, slips or vibrates apart, depends largely upon the total amount of clamping force (Joint Preload) applied to the joint.
Joint preload should be high enough to ensure that the compressive force reacting from the Bolt Preloads is high enough to overcome the hydrostatic end forces (system fluid pressure trying to separate the flange surfaces.) The increasing and decreasing of external forces can cause a fastener to continually stretch and relax. This action will fatigue the metal and cause it to prematurely fail. However, when the bolts are correctly preloaded, the internal tension will be greater than the applied external forces and the bolt will no longer be moving and will not “WORK HARDEN” and fail.

The amount of Joint Preload required for a given application is determined by the greater of:

- The force required to prevent the joint from moving due to the internal/external forces applied by the application. If the joint moves during operation, damage could occur to fasteners and joint material.

- The force required to cause the gasket material to flow a pre-determined amount. If the gasket material (when used) is not compressed enough to ensure it flows into the joint material, a leak-tight joint may not be achieved.

The size, location and number of fasteners of a joint are designed to allow the application of the required amount and location of required preload. For example, some pump flanges have larger bolts in areas where higher pressures exist in the pump.

Total clamping force is indicated in pounds of force.
**BOLT PRELOAD**

Bolt preload is the tensile force in the bolt after it has been properly tensioned and before joint operational forces are applied. The unit of measure for bolt preload is either pounds per square inch (psi) or thousand pounds per square inch (ksi).

Bolt preload requirements for a given application can be determined using plant procedures and/or manufacturer’s literature. Improper torquing can cause:

- Nut or thread deformation/breakage
- Assembled parts to warp.
- Bolts & nuts to work loose.
- Flexing of the joint

**PRELOAD SEQUENCING**

When preloading a flange, it is necessary to use the right sequence in order to bring the joint together uniformly/evenly. The objective of torquing and loosening a flange in a particular sequence is to avoid excess pressure at one point on the component, known as single point loading.

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**SINGLE POINT LOADING**

FIRST BOLT STRESSED TOO HIGH A LOAD

PIVOT POINT

GASKET IS CRUSHED

WHEN SECOND BOLT IS TENSIONED
FLANGE WILL FRY ABOUT PIVOT POINT,
CAUSING FLANGE DISTORTION
For a round flange, the task is easily accomplished by a criss-cross, quartering technique. When loosening a round flange, it is very important that a sequence be followed. The order can be the same as the tightening sequence or it can be reversed.

![Diagram of a round flange torquing sequence](image1)

For a rectangular, square and oval types of flanges, there are special problems and should be addressed on a case by case basis. If manufacturers' literature or a procedure is available, it should be used to determine the proper sequence. If they are not available, the following guidelines will be helpful.

![Diagram of a rectangular flange torquing sequence](image2)

The objective, the same as in round flanges, is to prevent single point loading and distortion. This problem is more likely to occur with rectangular flanges. If torquing begins at the ends of a rectangular flange, the ends will become fixed and the middle of the flange from obtaining proper contact when torqued.

![Diagram of torquing from inside out](image3)

If the torque sequence begins at the mid position, the middle becomes fixed and allows for the ends to be drawn down evenly. When torquing is complete, there should be an even amount of clamping force throughout the flange.
When loosening a rectangular flange, it is very important to loosen in the REVERSE order of tightening. This will avoid distortion of the component. The principle is exactly opposite of the tightening. Start loosening from the ends and work toward the middle portion of the flange. Always use manufacturers' literature or a procedure if available.

Joint Gaskets

Joint integrity is accomplished by the selection and installation of the correct gasket material and design for the application and by properly preloading the joint.

Proper gasket selection depends on the following joint/gasket factors:

- The available joint preload for the gasket.
- Internal pressures and temperatures.
- Types of fluids or gases being sealed.
- Mechanical features of the joint.
- Gasket material and/or type required.
- Condition of the joint’s mating surfaces.
Preloading Threading Fasteners

Tensioning
One definition of tension is “load that is applied in line with the center line of a bolt that stretches it.” The bolt/stud is stretched by either pulling or heating forces. The nut is then adjusted to restrain the bolt from returning to its relaxed state.

Tensioning studs, for either tightening or loosening, is preferable to long wrench extensions or sledging operations for larger bolt diameters due to the extreme frictional and torsional stresses that would be developed. Mechanical tightening or loosening larger bolts/studs may cause galling of threads or scoring of the flange faces and nut faces.

There are two methods of tensioning studs, hydraulic tensioning and heating. The hydraulic tensioner is a special tool which seats against the joint, grips the bolt end after the nut, and using hydraulic fluid pressure the stud or bolt is pulled and stretched. This stretching causes Tensile Stress to be developed and results in tension being applied by the bolt trying to return to its original state.

The operation of a Hydraulic Tensioner would be to use the preload sequence to removal or install joint preload. This device attaches to a specially designed bolt/stud and has a base that rests on the flange surface. Hydraulic pressure is then applied to the device and “Stretches” it to a predetermined length. The nut is made up hand tight, hydraulic force is released and tension remains. Bolt elongations are usually measured with an extension meter or micrometer to ensure proper preload.
Some advantages of hydraulic tensioning are:

- The ability to preload larger fasteners
- The precise makeup (even loading)
- They reduce time required to preload especially large fasteners
- They extend equipment life (torquing produces friction or torsional loads)
- They can be used in cramped spaces when torque wrenches have trouble clearing or being used

Some disadvantages are:

- They require a special fastener and flange set up
- They require an outside energy supply (air or electric) to operate the hydraulic system
- The equipment can be quite expensive.
HEATING

When bolts are heated, they expand both radially and axially. When they are heated faster than the flange they are installed in, the axial expansion or elongation caused by the heating makes them longer than the flange due to the temperature differential. This elongation can be used to initiate or remove internal stresses of the fasteners by moving the nut up or down the threaded area while the differential exists. The amount of nut movement can be calculated and the desired preload can be installed or removed.

There are two methods of heating, gas and electric. However, gas heaters are not normally selected because of the risk of overheating the fastener and changing the heat treating and thereby the desired properties.

Electric Heating provides an even heating of the stud by using an electric heating element that is positioned inside a hole in the fastener designed to accommodate the heater.

Snug the nut and mark it for the predetermined movement. After heat is applied and the fastener expands, turn the nut to a predetermined mark that will place the bolt in tension. After heat has been removed, it will take time for the fastener and flange to normalize in temperature. This technique is used on the Reactor Coolant Pump flange bolts and the Main Turbine Shell at all three nuclear sites.

Advantages of Heating
- The ability to preload larger fasteners
- Allows precise makeup (even loading)
- It extends equipment life (torquing produces friction or torsional loads)
- It is easy to use in cramped spaces
Disadvantages of Heating
- It requires a special fastener set up
- It requires a long period of time for the fasteners and flange materials to normalize to allow measuring of elongation
- It requires a special electrical supply (voltage and amperage)
- It may create changes in the metal if the heat is allowed to get too high

TORQUING

Torque is known as the torsional moment (Force X Distance) applied by a wrench to tension/detention a fastener. Torsion is the radial force that is applied to the head or the threads of a bolt when a nut is being tightened. This action applies a twisting force to the bolt due to the frictional forces encountered by the mating of the threads as the bolt stretches.
The threads of the fastener act as an inclined plane to cause the applied force to be increased and act in an axial direction. The resulting elongation causes internal tensile stress by the fastener trying to return to its relaxed state, thereby resulting in the bolt being “stretched” or pre-loaded. Think of tuning a guitar. Torque or twist is applied to the tuning pegs and tension or stretch takes place in the guitar string. The same basic principles apply to torquing a bolt.

Torque is commonly measured in:

- Inch-pounds (in-lbs)
- Foot-pounds (ft-lbs)
- Newton-meter (N-m)

Twelve inch-pounds or one foot-pound of torque would be created by exerting a one pound pull on a point of a wrench exactly 12 inches from the center of a bolt. When converting in. lbs to ft. lbs divide by 12 and to convert ft. lbs to in. lbs multiply by 12.

When torque is applied it goes to three places:

- Developing a pre-load force in the bolt.
- Overcoming friction at the threads.
- Overcoming friction between the nut and flange surface.

**FRICTION COEFFICIENT FACTORS**

The amount of torque required to obtain a predetermined preload on a fastener varies greatly with the Friction Coefficient of a fastener to be torqued. (Rotated.) The coefficient of friction includes many factors such as type of lubrication if any, contamination, and assembly practices.

Most of the torque goes into overcoming friction at the bearing surface which is the nut to flange interface. Keep in mind that torque values specified by manufacturers and plant procedures have already factored in the coefficient of friction.
The following are some “Rule of Thumb” assembly practices:

- Be sure to apply the correct type of lubricant to the threads and the sliding surface of the nut.
- Check to see if the grade of the nut matches the grade of the bolt. A low grade nut cannot support the load requirements of a high grade bolt.
- Look for galling on the threads or the flange surface.
- Remove any dirt or rust with a wire brush and file off minor burrs.
- The nut should always turn freely, if not, replace or repair.
- Repair cut threads with a tap (nut) and die (bolt). Keep in mind rolled threads should not be cut with a thread chaser.
- Remember approximately 80% of the force applied to a fastener may be lost due to friction, therefore threads and bearing surface must be CLEAN.

Good assembly practices would be to install the nut with markings (if applicable) up to reduce friction. Flange distortion can also increase friction.

Only use lubricants specified and approved by the Power Chemistry Manual. The lubricant must be compatible with the fastener material, the contained fluid, and the area it’s used in (radiation area). Chlorides, fluorides and sulfides are undesirable since they contribute to stress corrosion cracking. Each lubricant also has a recommended service temperature limit. Oil is not a very good lubricant since it is forced out of bearing surfaces at high pressures.

When bolts are received they will have some amount of lubrication, but remember, typically they will also have some dirt that needs to be removed. There will be times that a torque chart will specify “dry” threads and with no lubrication the bare metal will have very high friction.

Good lubrication techniques include lubricating the nut, bolt/stud threads and the bearing surfaces. Avoid over-lubricating by globbing lubricant on the parts, as this may reduce the efficiency of the lubricant. The best way is to apply a thin uniform coating of lubricant to the parts.

After good lubrication techniques, the proper torque is required to ensure that mechanical preload is correct. A torque chart will be used when Station Procedure and/or manufacturer’s specifications are not available. Verify the chart and application are correct considering the gasket used in the joint, type of lubricant, fastener material and so forth.
Preparing to Torque

In preparation for torquing, the joint, determine bolt sequence and increments. Make sure the gasket and bolting materials are correct for the application. Clean and inspect the bolts/studs, nuts, washers, gasket and the gasket seating surfaces on the flange. After properly applying lubricant (when required), ensure flanges are parallel within 1/32” (0.031”) per foot of flange. If this condition cannot be obtained, request technical support/engineering assistance. The gasket should be centered in the flange and properly seated.

There is not a “one size fits all” process prior to torquing the joint. Once the bolts/studs have been installed and all nuts are finger tight, there are a couple of options. It will depend upon the gasket (metal, spiral-wound, red rubber) as to the method best suited for getting the joint ready for torque. Bringing the joint together to remove any clearance may be accomplished by 1) Hand tight the fasteners or 2) tighten fasteners to ~ 5% of the final torque. With spiral-wound gaskets the “rule of thumb” would be ~ 5% of final torque. At NO time with either method should the value of the first pass be exceeded. Should this occur, loosen nuts and start over. If the gasket has been damaged, replace it and start over. Follow plant procedures, charts, or manufactures recommendations and torque in specified sequence at least 3 equal passes till final torque is achieved. Continue torquing sequentially (check pass) around the flange at the final pre-load torque until no further nut rotation is observed.

Several precautions should be taken when torquing a flange joint.

- Maintain correct sequence to avoid “tight on one side, loose on the other” and putting excessive pressure at one point known as “single point loading.”
- Do not preload to maximum value on initial preload. Increase in small steps to required preload ensuring all bolts are preloaded to same value.
- If possible when torquing a bolt, hold bolt head and torque nut.
- Always remember to pull the torque wrench with a smooth, even action and don’t jerk. Jerking creates momentum and will result in the cap screw or bolt being over torqued.

Special precautions on torque sequence and increase in torque value between steps must be considered when torquing components that are easily broken such as a flat or column type sight glasses.

- Carefully finger tighten nuts/bolts before using a wrench.
- Cut increasing torque valves in half for each pass.
- Make a check pass on each pass to ensure even preloading.
The steps to disassemble or de-torque, are just as important as the assembly process. There is an enormous amount of elastic energy stored in a bolted flange. The joint, in effect, is a giant spring held compressed by the bolts. When removing the bolts, the stored energy of the flange loads the bolts still remaining in the joint. The joint can be distorted, and gaskets or flange surfaces can be damaged. In a few cases, the final bolts remaining in flange have actually been broken as they attempt to hold the expanding joint together.

For this reason, it is recommended that a joint be disassembled with the reverse procedure used to tighten it. Use several passes. Partially loosen each bolt before further loosening any of them. Remember to bag and tag all parts during disassembly. Always leave four (4) bolts in place until gasket seal is broken. This is to prevent injury to personnel in case the piping or vessel is still pressurized with hot or dangerous fluids.

**Torquing Tools**

Several tools may be used for torquing bolts/studs. The purpose of a torque wrench is to induce and measure the applied force to a bolt/stud and nut.

The Dial type indicates the amount of torque applied at any given moment. It is used for repetitive applications of different torque values. The dial does not have to be preset and usually comes available with a memory pointer.
The Click (micrometer) type indicates torque by an audible sound or “click” and a sudden release followed by a few degrees of free movement. As soon as the wrench has signaled that the desired setting has been reached, immediately release the handle pressure to allow the wrench to reset itself to the pre-selected torque setting. Torque setting is achieved by a micrometer adjustment on the handle. The handle is rotated to the desired setting and locked in place. When not in use, torque setting should be returned at lowest setting. This will prevent damage to the tension spring. A handle extension cannot be used unless the wrench is designed or calibrated for that application.

A Geared Head Wrench Multiplier does just that, takes the torque produced by a manual wrench and multiplies it. Typical ratios are 4:1 or 10:1. Due to friction losses in the gear trains they may be slightly inaccurate.
A Hydraulic Torque Wrench is another way to get a lot of torque when space is limited. This wrench uses hydraulics to actuate a piston to drive a short stubby ratchet through as many cycles as necessary to tighten a bolt. Torque is determined by using a conversion chart (PSI vs. Torque output) and may be used for applications ranging from 1500-ft. lbs. to 100,000-ft. lbs.

Due to an injury caused by a socket exploding under pressure, only sockets identified for use with the Hydraulic Torque Wrench should be used.
Torque Wrench Adapters and Extensions

When using a torque wrench with an extension, an adjustment in the reading must be made. Remember that forces multiplied by length equal torque. With an extension, the total effective length is the sum of the wrench length plus the extension length.

\[
\begin{align*}
\bullet & \quad T_w = \text{torque wrench reading} \\
\bullet & \quad A = \text{extension length} \\
\bullet & \quad T_a = \text{torque at end of extension} \\
\bullet & \quad L = \text{wrench length}
\end{align*}
\]

If a bolt has to be tightened to a specified torque using an extension, the following formula can be used to give the correct torque wrench reading.

\[
T_w = \frac{T_a \times L}{L + A}
\]

Example:

The equipment manufacturer indicates that a bolt has to be tightened to 200 foot-pounds. The torque wrench is 2 feet long and a 6 inch extension is used. By applying the formula above:

\[
T_w = \frac{(200 \times 2)}{(2 + \frac{1}{2})} = 160 \text{ foot-pounds}
\]

In other words, the wrench would have to be pulled until the dial read 160 foot-pounds, but the bolt would see 200 foot-pounds.

To determine what torque will be developed on a bolt by a given torque wrench setting, use the following formula:

\[
T_a = \frac{T_w \times (L + A)}{L}
\]
**Torque Chart #1**

The following torque chart indicates torque recommendations for SAE Grade 5 and Grade 8 carbon steel bolts either oiled or dry assembled.

<table>
<thead>
<tr>
<th>Thread Size</th>
<th>SAE Grade 5</th>
<th></th>
<th></th>
<th>SAE Grade 8</th>
<th></th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>Ft-lbs</td>
<td>Nm</td>
<td>Oiled</td>
<td>Ft-lbs</td>
<td>Nm</td>
</tr>
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<td>1/8-20</td>
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<td>9.8</td>
<td>6</td>
<td>7.84</td>
<td>12</td>
<td>19.6</td>
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<td>9.8</td>
<td>7</td>
<td>9.8</td>
<td>14</td>
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<td>19.6</td>
<td>13</td>
<td>19.6</td>
<td>24</td>
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<td>44</td>
<td>58.8</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Oiled</td>
<td></td>
<td></td>
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<tr>
<td>3/32-24</td>
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<td>27</td>
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<td>42</td>
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<tr>
<td>1/8-12</td>
<td>110</td>
<td>147</td>
<td>84</td>
<td>118</td>
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<td></td>
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<td></td>
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<tr>
<td>11/64-7</td>
<td>795</td>
<td>1078</td>
<td>610</td>
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<td>890</td>
<td>1186</td>
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<td>3550</td>
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</table>
Torquing Exercise

1. Use the torque chart provided above to determine the torque values for a 3 sequence torquing application for the following fastener sizes:

<table>
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<th>Fastener Size</th>
<th>1st pass</th>
<th>2nd pass</th>
<th>3rd pass</th>
<th>Check</th>
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<td>5/8-18, Grade 8, oiled</td>
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<tr>
<td>1/4- 28, Grade 5, Dry</td>
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<tr>
<td>1-1/4 – 12, Grade 8, Oiled</td>
<td>[ ]</td>
<td>[ ]</td>
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</tr>
<tr>
<td>3/4 – 10, Grade 5, Dry</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
</tr>
<tr>
<td>9/16-18 Grade 8, Dry</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
</tr>
</tbody>
</table>

2. Set the torque wrench provided to the following torque settings. Have instructor or classmates attest per classroom instructions.

<table>
<thead>
<tr>
<th>Torque setting</th>
<th>Verified by</th>
</tr>
</thead>
<tbody>
<tr>
<td>86 lb/inch</td>
<td></td>
</tr>
<tr>
<td>102 lb/inch</td>
<td></td>
</tr>
<tr>
<td>148 lb/inch</td>
<td></td>
</tr>
</tbody>
</table>