# Tensioning the Critical Bolted Joint

**Considerations for the Optimal Solution**

The failure of critical bolted connections and closures often results in expensive downtime and is a costly and time-consuming problem to fix. As bolt tensioning becomes the preferred method of tightening many of these connections and closures, users gain the benefits of accurate bolt loading, repeatability and safety for personnel. Equally important is reduced downtime expense and maintenance headaches associated with older bolt loading methods such as torquing. However, since the requirements of different bolting projects vary greatly, it is crucial that the tensioning tooling match the specific requirements of the project to achieve optimal results. "Off-the-shelf" tooling, while perhaps initially attractive from the standpoint of cost and availability, often fails to provide the most cost-effective result. This article examines some of the key considerations that must be made when specifying stud tensioning equipment, considerations that can ultimately determine the success or failure of the bolt tensioning procedure.

**Required Bolt Load**

The stud tensioner initially applies a direct, or tensioning, load to the bolt or stud hydraulically. While the tensioner maintains the tensioning load, the nut is seated. The tensioning load is then released, and the load introduced by the tensioner is transferred to, and held, by the nut. The resulting load in the bolt, or residual load, represents the desired end loading of the connection, typically expressed in pounds of load or a unit load expressed in pounds per square inch. The residual load achieved in a given connection is generally a function of:

- The tensioning load applied
- The length of the bolted connection (referred to here as the "joint length")

Tensioners typically available off-the-shelf are designed to produce residual bolt stresses of 40,000 to 50,000 psi, roughly half the minimum yield of many commonly used bolt materials, and are designed primarily for use with pipe flanges. However, some tensioning applications use high strength bolting materials with higher residual loading requirements, often up to 80 or 90% of the bolt's minimum yield. In addition, many applications feature relatively short joint lengths that require higher tensioning loads. Clearly, standard tensioner designs are inadequate for these situations. Careful analysis must be performed to ensure that the proper bolt loads are safely achieved.

Structural bolting applications often require high bolt loads. One such situation recently addressed by Biach Industries included 1-1/4" ASTM A490 bolts requiring a residual load of approximately 115,000 pounds, or 88% of the bolt material's minimum yield point. Since the length of the joint dictated a tensioning load of 138,000 pounds, or 20% higher than the required residual load, it was clear that a standard tensioning tool would not have sufficient load capacity. In addition, a special tensioning procedure needed to be developed and tested so that the 115,000 residual bolt load could be achieved without exceeding the minimum yield point of the bolt material. A solution was provided when Biach engineers designed a custom, high capacity stud tensioner equipped with geared nut seating. The tensioner was designed to hydraulically load the bolts to a point just below the required residual load, and reach the residual bolt load with the application of 100 ft. lbs. of seating torque applied to the nut. The loading procedure was refined and verified through extensive testing, using strain gauged 1-1/4" bolts. The tensioners provided were thus able to safely, accurately, and consistently load the bolts to the required residual load.

**Tensioner Sizing Considerations**

Just as load requirements vary between bolt tensioning applications, geometry, and therefore available space, for the stud tensioner can vary greatly as well. Bolt spacing may be very close, walls or gussets may be positioned closely adjacent to the bolts, or overhead clearance may be minimal. It is not uncommon for all three situations to coexist in a single bolting application. Analysis of the application must be undertaken to confirm the actual amount of space available, and a tensioner configuration chosen that will fit in the available space and provide the correct amount of load. If the bolts are to be unloaded with the tensioner, allowance must be provided for additional tensioner capacity.

Often, analysis reveals that standard tooling is incapable of fitting the application, much less providing the necessary load capacity.

Understanding and accounting for the unique geometry of each tensioning application is crucial to the success of a tensioning procedure. Simply put, if the tools don't fit, they can't be used, and the benefits of using the stud tensioner can't be realized. Often, however, precise information about a given bolting application's geometry is not available, or available information differs significantly from as-built conditions. In these cases, and depending on the criticality of the job, it may be appropriate for the tensioner designer to inspect the application to develop a complete understanding of any issues of fit that may exist.

As an example, during recent routine generator maintenance at a power plant in Queens, NY, it was determined that the through-bolts securing the core assembly required retensioning. Although drawings existed for all the components involved, none precisely matched the as-built conditions in the generator. Since the time allotted for generator service work was limited, it was crucial that the bolt tensioners fit the application and perform perfectly. During a visit to the site, the tensioner designer thoroughly examined and sketched all relevant portions of the generator core assembly, noting dimensions of potential obstructions. Prior to manufacturing the bolt tensioners, a plastic model was made, and placed in each of the through-bolt locations to verify fit. Once tensioner fit was verified with the model, the tensioners were manufactured and provided within 10 days. Tensioning was easily accomplished within the allotted service window, without delays.

**Application Stresses**

Another important consideration in the analysis of bolt tensioning applications are stress levels that develop during tensioning. Of primary concern are stresses that develop in the stud or bolt, as bolt yield during tensioning is undesirable, and bolt failure during tensioning poses the risk of personnel injury or equipment damage. Analysis of the stud tensioner and application interface must examine the tensile and thread shear stresses that develop in the bolt during tensioning and detensioning. Another area of concern is the compressive stress that occurs between the tensioner and the flange. To avoid a situation where the tensioner "coins" into the flange, the analysis must examine the bearing stress that develops during tensioning. This condition is especially likely to occur when the flange is made from a relatively soft material or the tensioner has been configured in a way to fit a tight space, and therefore has a small "footprint" relative to its applied load. And of course, in the case of a custom-designed tensioner, the analysis thoroughly examines all stresses that develop within the tensioner, including hoop stresses, compressive stresses, shear stresses, and tensile stresses. Only through the careful review of all the stresses that are known to develop during tensioning can safe and efficient tensioner operation be ensured. In choosing off-the-shelf equipment, stress analysis of the tensioner/application interface may or may not occur, and therefore leaves open the possibility of unsafe conditions or equipment damage during tensioning. The end user of the equipment may be unaware that a potential problem exists until it occurs. Careful analysis of the tensioner/application interface prior to using the tools prevents these problems and the downtime or equipment damage that can occur.

**Special Features**

Often during application analysis and discussion with the client, special requirements become evident. Properly addressing special situations can assume paramount importance to the ultimate success of the tensioning operation, and may include:

- Applications where speed and/or ease of use is especially required
- Applications where the tensioning equipment is used continually as part of a manufacturing process
- Applications where an extra degree of bolt loading accuracy and repeatability is required
- Applications where tensioner handling is of particular concern, especially for very large tensioners, or where multiple tensioners must be handled simultaneously

In these cases, the tensioner is not simply a tool, but a solution to a special problem, and the designer of the tensioning equipment must work closely with the client to determine the optimal solution. Can special materials or configuration be used to reduce tensioner weight? Can a special lifting fixture be provided to safely and easily handle a large tensioner used in an inverted position? What features can be added to the tensioning system to ensure the fastest possible operation? How can the tensioner be designed, and a procedure developed, that provides the most accurate and repeatable bolt loading possible?

The best answers to these questions result from expertise, experience, and the ability to consider the entire problem and its optimal solution to rather than simply specify a tool. Unfortunately, in the case of standard, off-the-shelf tooling, special issues are often not examined at all, or the tooling supplier may not have the capability to properly address these crucial concerns.

Sometimes, a tensioning system must accommodate multiple requirements. In a recent case, a client needed tensioning equipment for use on an assembly line in a factory setting. Although the bolt tensioners themselves would be small, workers would be expected to handle them continuously, so issues of tooling weight, safety, and ease of use were paramount. An especially high degree of bolt loading accuracy and repeatability was required. Finally, because it was crucial to avoid assembly line downtime, the tooling would be required to operate almost continuously, with very little maintenance, for a high number of operating cycles.

To address all these requirements simultaneously, the entire tensioning system had to be evaluated. Weight calculations of preliminary designs indicated that the use of titanium would result in a tool weight of approximately three pounds, versus five pounds if standard materials were used. Titanium was therefore chosen as the primary material. Ergonomics and ease of use were considered, and a spring-actuated, automatic piston return feature was incorporated as an internal feature of the design to eliminate the need to manually return the piston after each tensioning cycle and maintain a cleaner outside profile for easier handling. To ensure safety in the event the tensioner was improperly connected to the bolt, a restraint feature was added to protect the operator and surrounding equipment. An adjustable torque handle, used in conjunction with a geared nut seating assembly, was added to enhance nut seating accuracy and repeatability, therefore maintaining bolt loading consistency. To minimize downtime, the system was designed to operate at relatively low hydraulic pressures, and long-life seals were installed. Finally, a special, electrically driven, table mounted hydraulic pump was chosen, with footswitch controls for ease of use.

This system has been in continuous use since the client received it. When last contacted, the client stated that the system had performed over 1.5 million bolt loading cycles without significant downtime. It is highly unlikely that off-the-shelf tensioning equipment could have matched this success. In this case and similar ones, a tensioning system specifically tailored to the client's needs is ultimately the most cost-effective approach.

As mentioned above, increasing downtime and maintenance costs have led to more widespread use of bolt tensioning for critical bolted connections and closures. To take full advantage of the benefits the tensioning process has to offer, and to achieve the most cost-effective result, each tensioning application should be carefully analyzed to ensure the best approach. Although in many situations standard, off-the-shelf tooling is appropriate, other situations warrant more detailed analysis and a customized approach to realize optimal results.

Since 1955, Biach Industries has performed the analyses outlined above for many critical bolting projects. With equipment used in the nuclear, petrochemical, construction, shipbuilding and aerospace industries around the world, and on such unique projects as the George Washington Bridge (and many other bridges), Alaska pipeline, the space shuttle, medical manufacturing and MRI machines, and many others, Biach has been called upon time and time again to provide the tooling appropriate for the project. With the right tooling, the project is completed smoothly, quickly and efficiently the first time. Downtime is not incurred to go back and fix the job. And the project isn't delayed due to "off-the-shelf" tooling that couldn't perform the job. Contact Biach Industries for an analysis of your special bolting project.

R. Gregory