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Fastening Solutions Moving Forward

High Strength Bolted Joints

Section 4

High Strength Bolted Joints*

The design and application of high strength bolted joints is both art and science. Experience with a particular application is the best guide for future design of like joints. Reoccurring, or even sporadic difficulties with a fastener ion application require that the design and installation process be reviewed along with maintenance procedures. Presented here are some ideas, formulas and practitioner's tips on fastening with high strength socket products. When designing new bolted joints it is important to **TEST CRITICAL APPLICATIONS**.

The bolted joint is a clamping system in which it is necessary that the clamp, or fasteners, always offer greater useful load, than the material being clamped. The fasteners can also be termed a "spring" which stores energy. The energy is used to keep the mating materials compressed, and the bolt under tension, under both initial installation loads, as well as loads seen during the service life of the joint.

Tensile strength is important for carrying static or constant loads. Fatigue strength is critical in resisting dynamic or changing loads. Fatigue strength is, in part, dependent upon characteristics manufactured into the fastener and a sufficient amount of preload or clamping force.

The Design of Bolted Joints

The bolted joint should be designed to develop sufficient clamp loads to prevent the mating materials from separating, leaking or slipping. This should be accomplished while also preventing the fastener from failing, and determining the preferred fastener failure mode is it does become stressed beyond capacity.

The design process might proceed as follows:

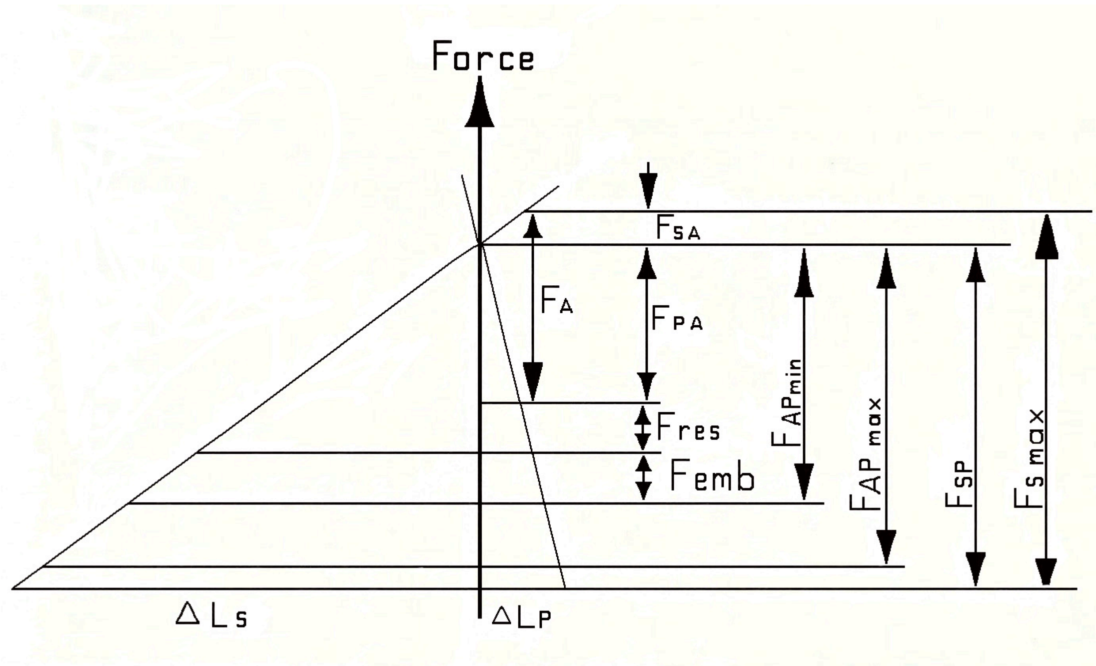
1. Determine the basic geometry of the joint, considering whether it is a single axis or multiple axes joint. Select joint materials.
2. Calculate the magnitude, direction and introduction point of the external forces acting upon the joint and if the forces are static or dynamic.
3. Determine the temperature range of the joint and the thermal expansion rates of the various components.
4. Select the fastener size, material, strength level, drive style, and thread type.
5. Estimate the required clamp load required to keep the joint functional. Develop a force diagram for the joint.
6. Calculate the clamped material's capacity to resist embedment while considering other setting force losses.
7. Calculate the safety factors desired for various functions of the joint.
8. TEST.

The force diagram in step 5 is shown on the following page.

*Thanks to Bengt Blendulf for allowing use of The Design of Bolted Joints material from his seminar"Fastening Technology and Bolted/Screwed Joint Design".

High Strength Bolted Joints (continued)

Joint Design – Main Force Diagram



Symbol	Explanation	Symbol	Explanation
F_A	External Force acting on Joint	$F_{AP\ min}$	Min. assembly preload to keep joint functional
F_{PA}	Portion of F_A acting on Clamped Parts	F_{AP} max	Max. assembly preload due to α A
F_{SA}	Portion of F_A acting on Screw	αA	Tightening Factor, ratio $F_{AP\ max}/F_{AP\ min}$
F_{SA}/F_A	Force Ratio Target 0.1	F_{SP}	Screw force at design level
F_{res}	Residual Force in Joint after unloading and set	$F_{S\ max}$	Maximum force in screw
Δ LS	Change in length Of screw	Δ LP	Change in length Of part

High Strength Bolted Joints (continued)
Material Selection Considerations

At both the design and application levels, consideration of materials to be joined is important. Issues such as thread stripping, embedment, galling, temperature changes and galvanic corrosion must be accounted for.

Suggested thread engagement depths in common materials such as steel, cast iron and aluminum are outlined in Section 3, Threads and Materials.

Embedment can be avoided to a great extent by choosing the correct strength level of fastener, one not too rigid when compared to the clamped material. Choosing preload levels properly and using a sensible tightening pattern will also aid.

Galling, commonly seen in stainless materials fastened by stainless screws, can be avoided by plating or coating the screw.

Galvanic corrosion occurs when 2 dissimilar metals are in contact and in a liquid capable of carrying electrical current. The anodic or least noble metal corrodes, while the cathode, or more noble metal, is not attacked.

Galvanic Series

Anodic or Least Noble

Magnesium
Magnesium Alloys
Zinc
Aluminum
Cadmium
Iron and Carbon Steel
4-6% Chrome Steel
Stainless Steel (not passivated)
Lead Tin Solder
Lead
Tin
Nickel (active)
Inconel (active)
Brass
Copper
Bronze
Copper-nickel Alloys
Monel
Silver Solder
Nickel (passive)
Inconel (passive)
Stainless Steel (passive)
Silver
Graphite
Gold
Platinum

Cathodic or Most Noble

High Strength Bolted Joints (continued)
Material Selection Considerations (continued)

Temperature changes in application affect both the clamped part and the fastener. The formula for expansion of metals due to temperature change follows:

$$L_1 = (L_O)\ (T_H - T_L)\ (C)$$

L_1 = increase in length in inches
L_O = original length in inches
T_H = the higher temperature in degrees Fahrenheit
T_L = the lower temperature in degrees Fahrenheit
C = coefficient of thermal expansion, in inches per inch per degree Fahrenheit

Elevated temperature applications above a certain temperature, approximately 450 or so degrees Fahrenheit may also adversely affect the strength characteristics of a heat treated alloy steel fastener, such as a socket head cap screw. A steel producing equipment manufacturer did some tests on standard SHCS. They concluded that socket cap screws lost about 30% of their tensile strength at 700 degrees Fahrenheit. Other end users have seen similar results.

Fastener Selection Considerations

Strength, corrosion resistance, drive style, availability, soundness of manufacture, and costs are just some of the factors involved in selection of the best fastener for the intended application. Static and dynamic load carrying capability must both be considered.
Two points must be kept in mind: First, the fastener should only see about 10% of the total external forces acting on the joint. Second, the endurance limit of the fastener, its ability to withstand cyclic loading is only 10-15% of its static load carrying capability.

To ensure ability to properly preload the fastener, one with a length to diameter ratio of 4:1 or greater should be selected. Resistance to thread stripping of the mating part SHOULD NOT be the only consideration. Remember, most high strength bolted joints fail in fatigue. Other fatigue resisting features in a fastener might also need to be considered: rolled threads and fillet, possibly after heat treatment, an elongated body or 'turned down shank".

Corrosion resistance can be accomplished by choice of fastener material or selection of a plating or coating. While today's modern coatings offer increased corrosion resistance over many plating choices, they usually require a modification to the allowance of the screw thread to accommodate them. A socket head cap screw with a standard 3A thread allows for only a ten-thousandth of plating or coating. The metric 4g6g thread is a little more forgiving, but the best alternative would be a 2A inch series or 6g metric series thread form.

High Strength Bolted Joints (continued)
Tightening and Assembly Considerations

As noted earlier, the primary purpose of the bolted joint is to clamp parts together. There are many more suggestions that can be offered to make the process go smoothly. Several are listed below.

To help reduce embedment and to spread out the external load seen by any given screw, flat washers can be used. Lock washers, thought to prevent vibration loosening, have been proven ineffective in steel to steel joints using hardened screws. Other devices such as stepped washers, disc springs, and anaerobic adhesives have proved valuable in vibration applications. They are most useful in addition to proper preload, not as a replacement for it.

Achieving Preload

There are several methods for achieving preload. One is direct tensioning of the screw, a method used in industries willing to spend the money and time to purchase and use equipment made for such purposes. Most industry still relies upon achieving tension through torque. The accuracies of various methods are outlined below:

Method Of Tightening	Accuracy Factor	Scatter %
Yield Point Computer Controlled Motorized	1	+/- 5-12%
Turn of the Nut (angle of rotation)	1	+/- 5-12%
Elongation Measurement Of calibrated screw	1.2	+/- 10
Manual Torque Wrench with experimental tests	1.4-1.6	+/- 17-23%
Same but w/o experimental tests	1.6-1.8	+/- 23-28%
Screw driver with Preset torque (friction, etc. estimated)	1.7-2.5	+/- 26-43%
Impulse Controlled Impact Wrench	2.5-4.0	+/- 43-60%
Hand Tightening	2.5-4.0	+/- 43-60%

The inaccuracies of certain tightening methods make preload determination even more critical.

High Strength Bolted Joints (continued)
Tightening and Assembly Considerations (continued)

Determining the correct torque to achieve the desired preload is most commonly done by using the short from torque equation:

$$T_{IN} = K \times D \times P$$

in which T_{IN} is the tightening torque,
K is the "nut factor", estimated or experimentally determined
D is the nominal diameter of the fastener
and P is the desired preload.

The nut factor is similar to, but not the same as a coefficient of friction. There are some 250 factors affecting the value of "K'.

For alloy steel socket head cap screws, lightly oiled, the "K" factor is between 0.18 and 0.22. Some other "K" factors are approximately as shown here:

--- Zinc Plated Screws – 0.25 to 0.34
--- Cadmium Plated Screws – 0.10 to 0.15
--- With Nickel based Compounds – 0.05
--- With Copper based Anti-seize – 0.08

High Strength Bolted Joints (continued)

Fastener Failure Worksheet

1. **Brand name or head marking on fasteners**
2. **Product type, diameter, and length**
3. **Lot Code**
4. **Failure location – threads, body, or Underhead**
5. **Lubrication – brand name, manufacturer and type, coefficient of friction**
6. **Plating or coating – type, process used, name of applicator**
7. **Installation method – for rundown, for final tightening**
8. **Installation torque – value if used**
9. **Service temperatures**
10. **Joint material – type and hardness**
11. **Recurring failure? Y/N, frequency**
12. **Details of joint design**
13. **Samples of failed screws**
14. **Other user provided details**