WHY BOLTS WORK (AND WHY SOME DON'T)

GEORGE DAVET, BSME, MBA | CHIEF ENGINEER & VP | SOLON MANUFACTURING CO.

With bolting, there are three important points to remember:

1. Bolts stretch
2. Bolted joints lose load
3. If the loss of load is too high, then this could result in failure of the joint

BOLTS STRETCH

When a bolt is loaded, it will stretch. The amount it stretches is a fairly simple calculation:

$$\Delta L = \frac{P * L}{A * E}$$

where,

ΔL = bolt stretch or elastic displacement
P = Bolt load
L = Active bolt length. This is the portion of the length that actually stretches.
$A = \frac{\pi*(0.93*d)^2}{4}$ = Active bolt area. For a fully threaded coarse thread bolt, this can be estimated by using 0.93 times the nominal bolt diameter.
E = Elastic modulus of the bolt material

If the bolt stress (σ) is known and since stress is P/A, the formula could be simplified to,

$$\Delta L = \frac{\sigma * L}{E}$$

Looking at the formula, it's easier to see that in order to increase stretch, either the load or active length could be increased. We could also use a material with a lower area or elastic modulus. However, it is important to note that this formula works within the elastic limits of the bolt. Increasing the load or decreasing area will increase the stress on the bolt or the joint. This increase is limited and will eventually lead to failure of one or both. The modulus is established by material type and unfortunately, low modulus materials do not have adequate strength to be used for bolts.

As an example, let's consider the following joint:

The joint has a ½" stainless steel bolt and the joint comprises of two 3/8" thick plates. Assuming a 5000 lb preload, we can estimate the bolt stress as follows:

$$\sigma = \frac{5000}{\frac{\pi}{4}(0.93*0.5)} = 29{,}441 \text{ psi}$$

> *"Increasing the load or decreasing area will increase stress on the bolt or joint."*

Now, the bolt stretch can be calculated:

$$\Delta L = \frac{29441*.75}{29000000} = .00076 \text{ in.}$$



BOLTS LOSE LOAD

Bolts lose load due to many factors such as embedment relaxation, differential thermal expansion, elastic interactions, vibration loosening, bolt creep, component yielding, etc. While it is important to be aware of these factors, it is more critical to understand why these phenomena cause the bolts to lose load.

It is important to think of a bolted joint as a *system* of springs. By definition, springs deform elastically to some degree. Springs may also deform plastically. Even a very light coil spring may not completely "bounce back" if it was overloaded or exposed to excessive temperature under load.

In the case of the previous example, the bolt is acting as a spring because its stretch provided elasticity to the fastening system. The joint also provides some elasticity although it may be negligible because the effective area is greater than the bolt.

Now, assume that some yielding or plastic deformation occurs in the bolted system. If the amount of yielding is known, then predicting the load lost is simple. It is equal to the ratio of yielding to elasticity. In the example, if yielding (R) is

$$\Delta P = \frac{R}{\Delta L} = \frac{.0005}{.00076} = .66 = 66\%$$

In this case, a very small yield leads to a large change in load because the elasticity of the bolt is relatively low. While the bolt is a spring, it is a very stiff spring. In this case, the only ways to reduce load lost would be to either reduce the yielding or by increasing the elasticity of the system.

IF THE LOSS OF LOAD IS TOO HIGH, THEN THIS COULD RESULT IN FAILURE OF THE JOINT

Bolts nearly always lose some load. That assumption cannot be denied by any designer. The critical question should be, "Will the loss of bolt load exceed the threshold where risk of failure of the joint becomes unacceptable?" If the answer is no, then the design is sound and nothing additional needs to be done. If the answer is yes, then something must be done to improve the bolting system.

One option would be to attempt to improve the elasticity of the bolts. Remember the equation for bolt stretch is:

$$\Delta L = \frac{P * L}{A * E}$$

Therefore, we could increase load or length, or decrease area or modulus. Assuming that the bolt load is based on the joint's requirements, increasing load could lead to overloading the system. Increasing active length is commonly employed by using sleeves or washers but improvements are proportional and may not be adequate. Assuming that the bolt is sized based on the loading, decreasing the area would increase the stress on the bolt leading to possible overstressing. Decreasing modulus is often not practical since lower modulus materials are either very costly or do not possess adequate strength for bolting applications.

> ***"Will the loss of bolt load exceed the threshold where risk of failure becomes unacceptable?"***



Another option is to add elasticity to the fastening system by using Belleville springs. Bellevilles are conical washers that deflect as they are loaded.

In our example, the deflection for a ½" Belleville may be .020 in. at 5000 lbs. Therefore, .020 in of *elasticity* would be added to the bolt stretch to estimate the loss of load. If *s* is the deflection of the spring at load, then the equation becomes:

$$\Delta P = \frac{R}{\Delta L + s} = \frac{.0005}{.00076 + .020} = .018 = <2\%$$

The addition of Belleville springs to the fastening system resulted in only 2% load lost in this example. Belleville springs maintain bolt preload in addition to increase the elasticity of the bolting system.

Solon Manufacturing Company offers a variety of application-specific Belleville spring washer selection tools that can assist designers in selecting the proper Belleville spring for their requirements, including:

- Electrical Connections
- Flange Connections
- Valve Packing
- PEM Fuel Cells
- PV Racking Systems

For additional resources and information, *visit www.solonmfg.com*.

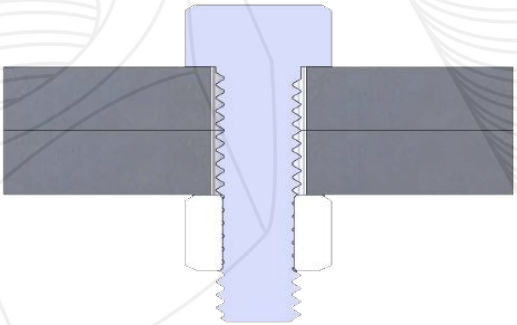


Figure 1: Electric bus assembly without Belleville springs

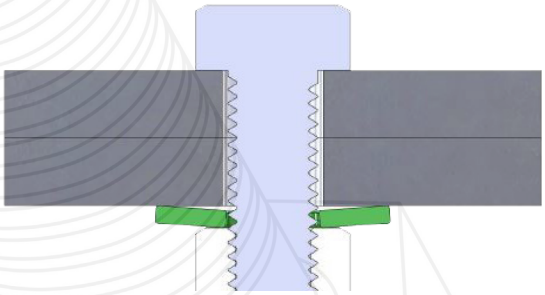


Figure 2: Electric bus assembly with Belleville springs



George P. Davet, BSME, MBA is Vice President, Chief Engineer and Owner at Solon Manufacturing Company and has written and published numerous articles on the use and application of Belleville spring washers. To learn more about Bellevilles and Solon Manufacturing, visit www.solonmfg.com, for technical resources such as case studies, white papers, product selection tools and videos.

Copyright © 2021. All Rights Reserved.

For additional information, please contact Solon Manufacturing Co.
800.323.9717 | sales@solonmfg.com | www.solonmfg.com