BELLEVILLE WASHER HYSTERESIS 101

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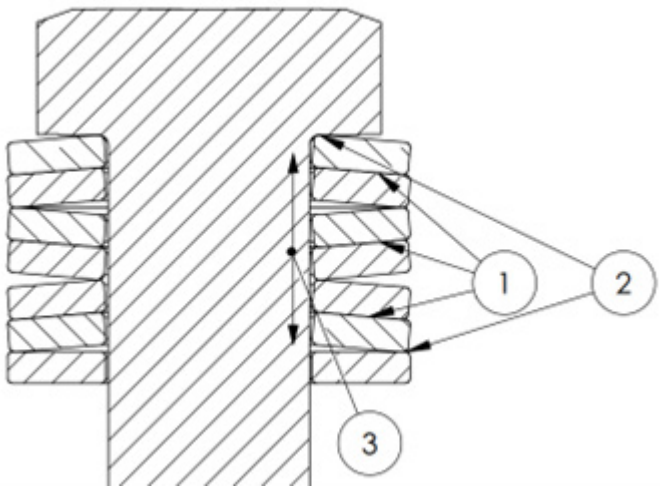
Friction may cause the actual measured load versus deflection for a stack of Belleville springs to be different than the calculated values. In general, friction is a result of relative "sliding" contact between loading surfaces. There are several measurable locations of friction on any given stack of Belleville springs (see *Figure 1* showing stack in selection):



1. Friction between parallel stacked springs.
2. Friction between the loading surfaces and the corners of the springs on each end of the spring stack.
3. Friction between the guiding surface and the guided corner of the springs in the stack.

Figure 1

Friction can be recognized in the difference between the loading and the unloading curves for the stack. Consider the following load versus deflection curve:

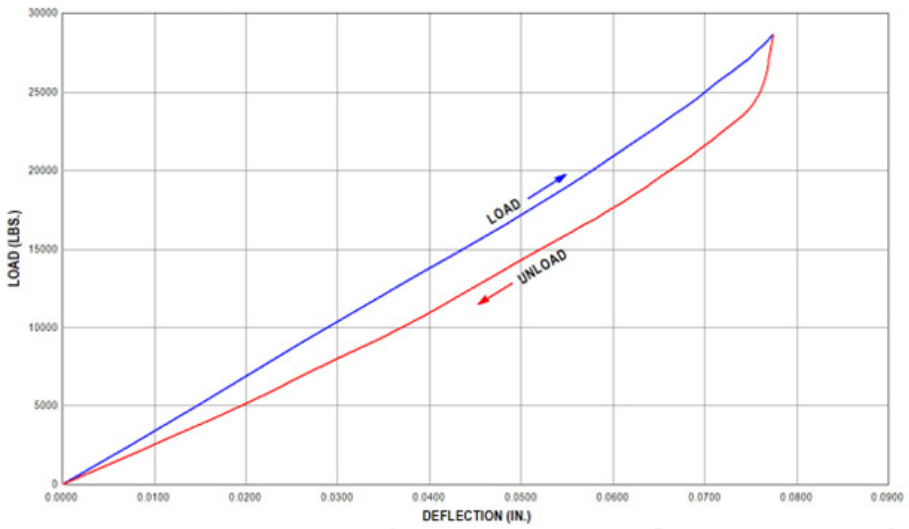


Figure 2

The top curve shows the load versus deflection as load is increasing (progressive). Conversely, the lower curve represents load decreasing (regressive). We call the difference between these two curves the frictional hysteresis. If loaded springs represent stored energy, then a way to quantify the amount of energy is to measure the area under the loading curve. In addition, hysteresis (shaded area in yellow in *Figure 3*) can be considered in terms of energy lost and it can be quantified by the area between the curves.

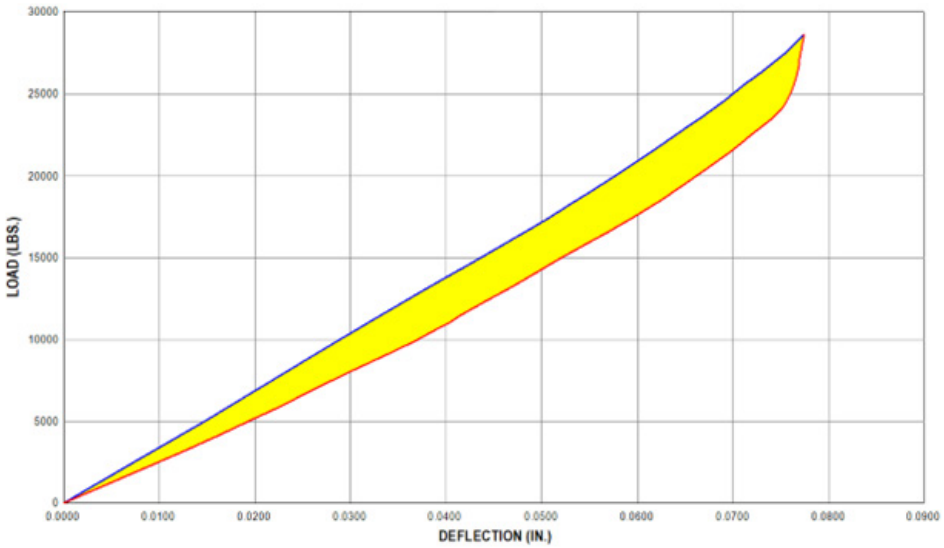


Figure 3

This is not desirable in most bolting applications since more friction results in greater load fluctuations relative to systems with less friction. Consider the following curves taken to extremes. In *Figure 4* below, the curve to the left shows a system with almost zero friction while the one on the right is one with very high friction. Now, assume that the preload in each case is 28000 lbs and after loading, the system is exposed to .010 inches of differential expansion that unloads the spring stack.

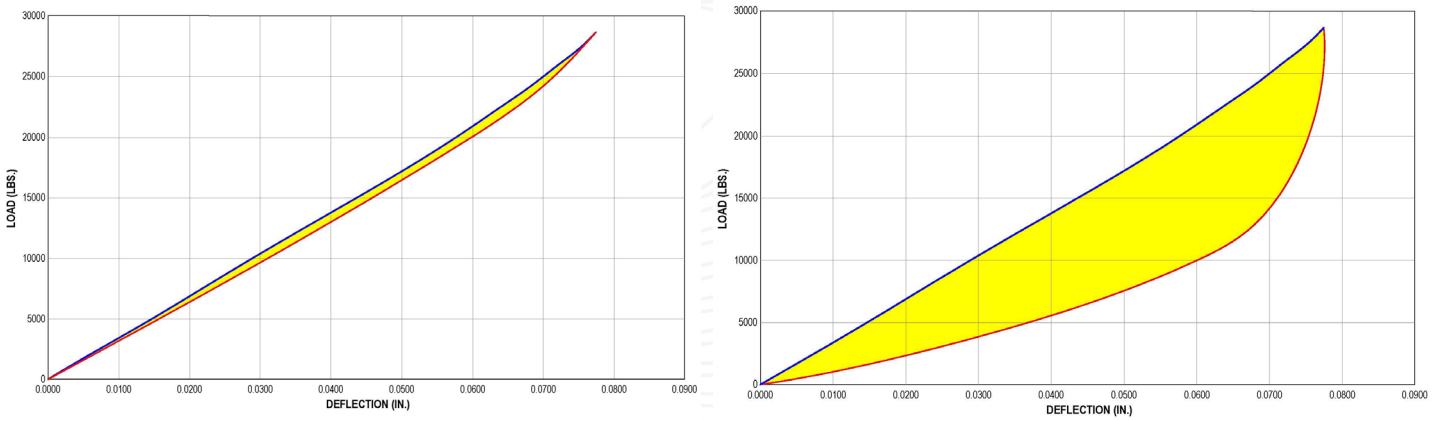


Figure 4

For the stack with low friction, the residual load would be approximately 23000 lbf.

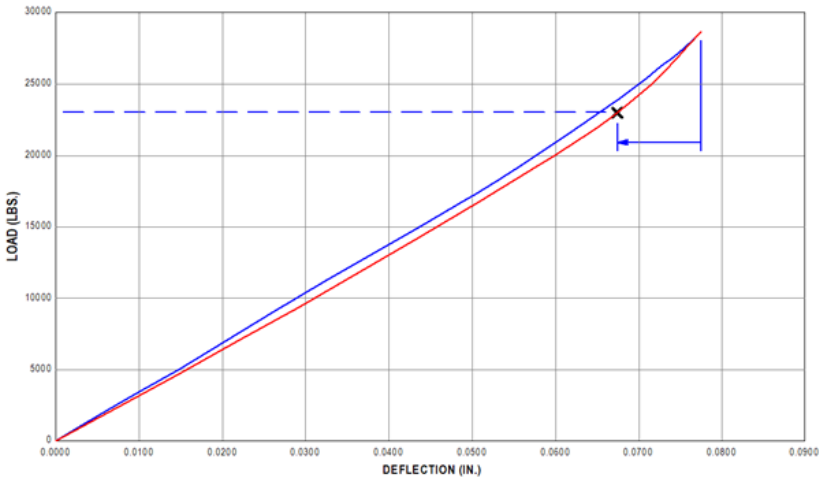


Figure 5

In the system with high friction, this residual load falls to 13000 lbf. While this is an extreme example, it does illustrate the reduction in performance due to friction. It should be noted that both of these systems perform far better than a system with no springs since a comparable differential expansion would likely lead to complete unloading.

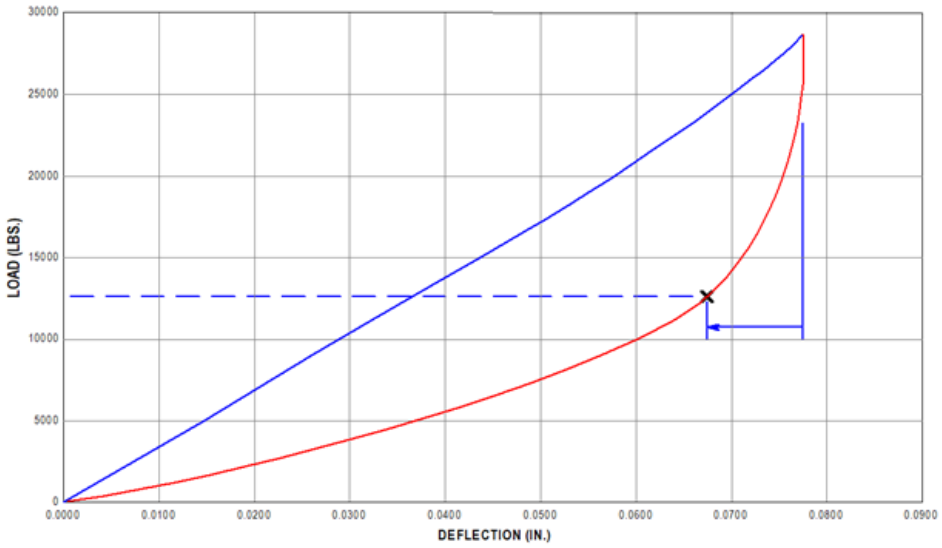


Figure 6

The magnitude of hysteresis can be affected by several factors such as surface roughness, lubrication, component materials, hardness of components, numbers of springs in parallel and series, etc. For bolted joints it is ideal for the hysteresis to be as small as possible. However, some methods to reduce friction are simple and inexpensive and others come at high cost. In order to evaluate the effectiveness of options, it is necessary to compare load curves using differing components, treatments, techniques, etc. This is not simple because of the variations between tests. However, the ideal case is that the regressive load curve is the same as the progressive curve. This could be restated that the area between the curves is zero. Conversely, the worst case would be that the load would immediately fall to zero as the stack is unloaded. In this case, the area of the hysteresis would be 100% of the area under the progressive load curve.

Rather than compare the area between the curves, it is more effective to compare the *ratio* of the hysteresis to the area under the progressive load curve. This value correlates to the energy lost with reference to the potential energy in the loaded spring stack. In the curve below, this would mean the shaded area in yellow relative to the yellow PLUS crosshatched areas.

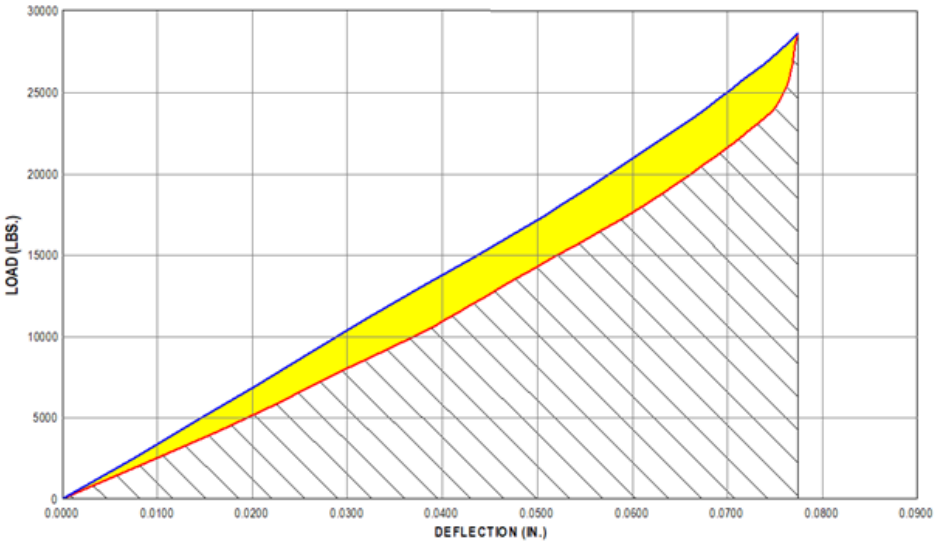


Figure 7

In summary, it is better for bolting applications to have less hysteresis than more. Several ways to reduce hysteresis include:

1. Avoid stacking in parallel when possible. Thicker springs stacked in series only will have lower hysteresis than stacks in parallel/series combination. This is because the contact surface area in a parallel stacking arrangement is very high.
2. Reduce friction on all sliding surfaces. This may be achieved with better surface finishes, hardened contact surfaces, lubrication, surface treatments, etc.
3. Stack more springs in series. This does not reduce the amount of friction at the loading surfaces. Rather, the total hysteresis will be a smaller percentage of the total energy stored by the spring stack.

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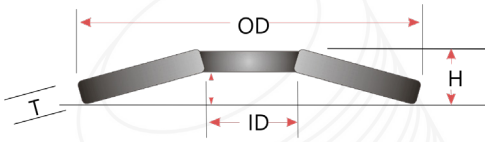
- *Flange connections*
- *Infinite Bolt Fatigue Life*
- *LNG / Cryogenic*
- *Valve packing*
- *PV racking systems*



Typical Belleville Diagram

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

ABOUT THE AUTHOR

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.

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