Quantifying the Load-Retention Benefit of Preset Belleville Washers

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Where preload goes: preset vs. non-preset Belleville washers in bolted joints

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Symbols: F_P preload · A root area · E modulus · L_B active bolt length · dT joint compression · h deflection-to-flat · N springs in series · R joint relaxation · s fractional set · δ total spring set · dL^f fastening-system deflection

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1. Why Preset Matters

As a Belleville washer is loaded, stresses build throughout its cross section. On first loading that stress may drive localized yielding and the spring permanently loses free height, called set. Presetting (scragging) compresses the spring to or slightly past flat before shipment, taking the plastic deformation out at the factory and reversing the ID residual stress to compressive. The result is a spring whose free height is stable from the first cycle.

In a bolted joint, any loss of spring free height is mechanically indistinguishable from joint relaxation, since it removes elasticity from the system and therefore removes preload. Whether that loss actually occurs, however, depends entirely on whether service conditions drive the spring into its plastic range. This paper quantifies the benefit of preset and, equally important, identifies the applications where that benefit is real versus those where it is zero.

2. The Governing Relationship

Preload loss is governed by a single ratio. If R is the dimensional relaxation removed from the grip and dL^f the elastic deflection stored in the fastening system:

$$\Delta F / F_P = R / dL^f$$

Read dL^f as a reservoir of elastic length stored in the fastening system, and R as the length taken back out of it. The fraction of preload lost equals the fraction of the reservoir consumed. A rigid assembly holds a small reservoir, so even a modest R takes a large fraction. A Belleville stack holds a large reservoir, so the same R barely moves the load. With N sets in series:

$$dL^f = F_P L_B / (A E) + dT + N h$$

3. Preload Allocation: Where the Load Goes

Figure 1 shows how the assembly preload of 18,180 lbf is allocated in each of the three configurations after all relaxation has occurred. Two mechanisms remove load: joint relaxation R, common to every configuration, and, for non-preset springs, the additional set δ = s·N·h taken on the first load cycle when the spring yields. Spring rate is unaffected by presetting; the only difference between the second and third bars is whether there is Belleville yielding (δ) present.

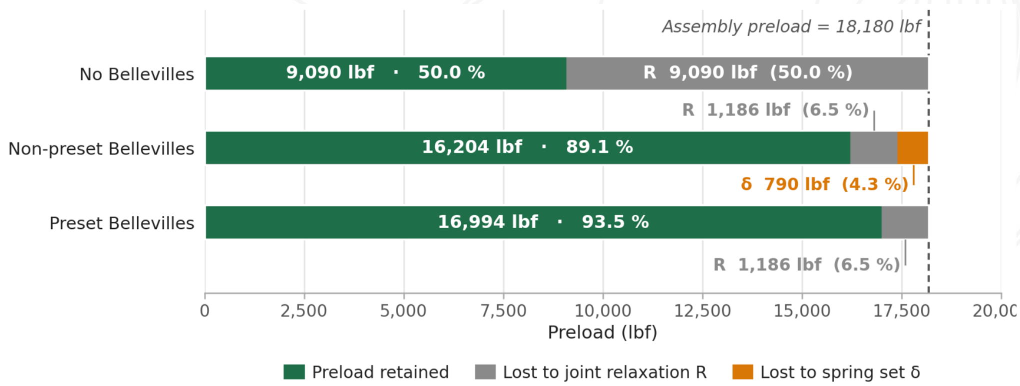

Figure 1: Allocation of assembly preload after all relaxation, DTE-loaded regime with R = 0.0030 in. Green shows load retained; gray shows load lost to joint relaxation R; amber shows the additional loss to spring set δ. The Bellevilles do the heavy lifting in both cases; preset removes the last amber segment.

4. Quantifying the Set Term

Set is reported as a percentage of deflection-to-flat h. For N springs:

$$\delta = s \cdot N \cdot h \qquad \rightarrow \qquad \Delta F / F_P = (R + s\,N\,h) / dL^f$$

Where s is the fractional set; δ and R enter the numerator identically.
For a preset stack s ≈ 0, reducing to R/dL^f. The penalty attributable purely to the absence of preset is therefore:

$$\Delta F_{preset} = F_P \cdot (s\,N\,h) / dL^f$$

This term is independent of R: a fixed deduction taken on the first load cycle, before any joint relaxation occurs.

The value of s is application-dependent.
Set occurs only if the spring is stressed into its plastic range in service. The value of s is therefore not a fixed property of a non-preset spring, but a function of what the joint does to the spring after assembly. Four regimes cover most bolting applications:

s ≈ 0: spring stays elastic. If the spring is never loaded beyond the stress at which yielding begins, no set occurs and preset provides no load-retention benefit. A moderately stressed spring operating at or below its assembly load remains in this regime.

s ≈ 0: load only falls after assembly. In joints where service unloads the fastening system, such as cryogenic applications where the joint contracts relative to the bolt on cooldown, the spring never sees a load higher than assembly preload. Nothing in service can drive it into yield, so a non-preset spring performs identically to a preset one.

s ≈ 0: spring flattened at assembly. Where the stack is sized so that assembly preload drives the springs to (or slightly past) flat, any first-cycle yielding occurs during tightening rather than in service. The nut simply turns a little further, the target preload is still reached, and the plastic deformation is complete before the joint is put into service, so the assembly operation is itself an in-situ presetting operation, and s ≈ 0 in the post-assembly loss budget. This holds provided preload is controlled by torque, tension, or measured bolt elongation rather than by a turn-of-nut count calibrated on an elastic system; a final verification pass after the springs have gone flat is good practice. Two qualifications: the deflection left to absorb relaxation is the post-set value (1 − s) N h, marginally less than the published h implies; and a spring already flat has no travel remaining in the loading direction, so any subsequent load rise is carried at the full un-sprung rate. Flattening at assembly therefore removes the set term, but it does not remove the need to check that the stack can accommodate whatever the joint does next.

s relevant: highly stressed spring, load rises after assembly. When differential thermal expansion (DTE) increases bolt load above the assembly value, in a hot joint whose members expand faster than the bolt, a highly stressed non-preset spring can be pushed past yield on the first thermal cycle. In this regime, values of s on the order of 2–8% of h are representative, and 5% is used as a planning figure below. Consult the manufacturer for data on a specific part number, material, and stress level.

The worked example that follows therefore represents the regime where preset matters: a hot flanged joint with DTE loading and springs stressed near flat.

5. Worked Example

A 1″-8 ASTM A193 B7 stud in a Class 300 flange: 5.0 in active length, root area 0.606 in², preloaded to 30 ksi.

$$F_P = 30{,}000 \times 0.606 = 18{,}180 \text{ lbf} \qquad dL_B = F_P\, L / (A\, E) = 0.0050 \text{ in}$$

Joint compression dT = 0.0010 in. Two flange washers in series, h = 0.020 in each, flat load ≥ F_P. The joint runs hot with DTE that raises bolt load above assembly preload on the first cycle, stressing the springs past yield. Cumulative joint relaxation from embedment, gasket creep, and elastic interactions: R = 0.0030 in.

Case A: no Bellevilles. dL^f = 0.0050 + 0.0010 = 0.0060 in. $\Delta F/F_P$ = 0.0030 / 0.0060 = 50.0%. Residual = 9,090 lbf, half the clamp load is gone.

Case B: two non-preset Bellevilles. dL^f = 0.0050 + 0.0010 + 2(0.020) = 0.0460 in. δ = 0.05 × 2 × 0.020 = 0.0020 in. $\Delta F/F_P$ = (0.0030 + 0.0020) / 0.0460 = 10.9%. Residual = 16,204 lbf.

Case C: two preset Bellevilles. $\Delta F/F_P$ = 0.0030 / 0.0460 = 6.5%. Residual = 16,994 lbf.

Two observations follow. First, the dominant benefit comes from the Bellevilles themselves: even non-preset springs cut preload loss from 50% to 10.9%, retaining 89% of assembly preload. Second, preset recovers a further 790 lbf, or 4.3 percentage points of F_P, lifting retention from 89.1% to 93.5%. Expressed as a fraction of the load lost, the non-preset stack **loses 1.67× as much preload** as the preset stack under identical joint conditions.

6. Summary and Sensitivity

Within the DTE-loaded regime, the preset penalty is a constant 790 lbf regardless of how much the joint relaxes, so its relative weight is largest in well-behaved joints where R is small. Note that in all cases the non-preset stack still retains far more preload than the springless joint.

Table 1: Retention comparison (F_P = 18,180 lbf, R = 0.0030 in)

Configuration	dL^f (in)	δ (in)	Loss	Residual (lbf)
A: No Bellevilles	0.0060	—	50.0%	9,090
B: Two non-preset	0.0460	0.0020	10.9%	16,204
C: Two preset	**0.0460**	≈ 0	6.5%	16,994

Table 2: Preset penalty vs. joint relaxation, DTE-loaded regime (two springs, h = 0.020 in, s = 5%)

R (in)	Preset loss	Non-preset loss	Preset penalty	Ratio
0.001	2.2%	6.5%	790 lbf	3.0×
0.002	4.3%	8.7%	790 lbf	2.0×
0.003	6.5%	10.9%	790 lbf	1.7×
0.005	10.9%	15.2%	790 lbf	1.4×
0.008	17.4%	21.7%	790 lbf	1.2×

7. Design Implications

• Non-preset Bellevilles already deliver most of the available benefit. In the worked example they retain 89% of preload versus 50% with no springs; preset adds the final 4.3 points. For most joints, standard springs are sufficient.

• Reserve preset for joints where absolute maximum load retention is required, such as critical sealing services, joints with no retorque access, or applications where every point of residual preload carries safety or leak consequences, and where the service profile actually stresses the spring into yield.

• First establish which regime the joint is in. If the spring stays elastic, if assembly preload already drives it flat, or if load only falls after assembly (as in cryogenic service), $s \approx 0$ and preset buys nothing. The set term is only live in hot, DTE-loaded joints with highly stressed springs.

• If preset is required, specify it explicitly, since it is not universal across suppliers and is not implied by a dimensional standard alone.

• The set penalty scales with $N \cdot h$, not R. Adding non-preset springs in series in a DTE-loaded joint also multiplies the set term, partially canceling the added deflection.

• Preset does not change spring rate; flat load and h are unchanged, so sizing calculations are unaffected. It removes first-cycle set only, but it does not confer creep resistance in an overstressed spring.

8. Conclusion

The benefit of preset reduces to one added term in the standard retention equation: $F_P \cdot s\, N\, h / dL^{f}$, where s is nonzero only when service stresses the spring into its plastic range. In the regime where it applies, a hot, DTE-loaded flange with springs stressed near flat, the penalty for non-preset springs on a representative 1” B7 stud is 790 lbf, cutting retention from 93.5% to 89.1%. Both figures are dramatically better than the 50% retained with no Bellevilles at all: the springs themselves do the heavy lifting, and preset refines the result. Where no set is taken after assembly, such as elastic service, cryogenic and other load-falling applications, or joints in which assembly itself flattens the spring and so presets it in situ, $s \approx 0$ and preset offers no retention benefit. Preset is therefore best reserved for joints where the absolute maximum load retention is required and the service profile genuinely engages the set mechanism.

ABOUT THE AUTHOR

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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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