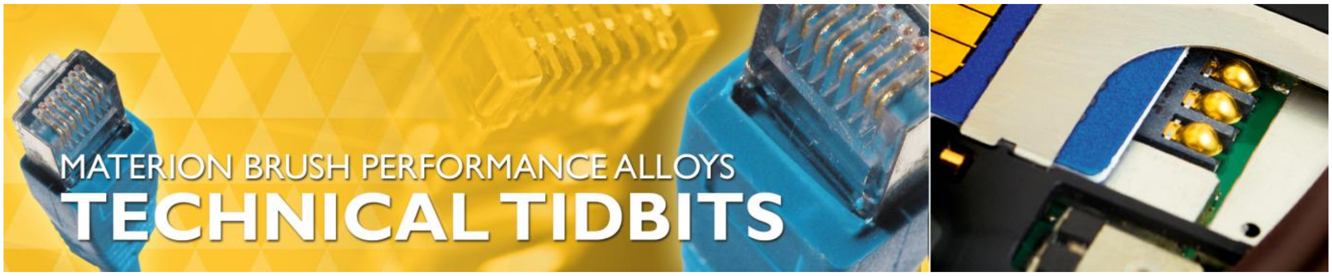

Issue No. 79 – July 2015 **New Publication**

Cones aren't just for ice cream and traffic school. – Washers that also function as contact springs.

- **Spring Washer**
- **Wave Spring**
- **Curved Washer**
- **Belleville Spring**
- **Free Height**
- **Series Stack**
- **Parallel Stack**

The next issue of Technical Tidbits will continue the discussion on Belleville washers, focusing on their unique stiffness characteristics

Spring Types Part 4 – Spring Washers

This series of six or so (now seven or so) editions of Technical Tidbits will discuss various types of springs used in electrical contacts or sensors, and group them into six broad categories of similar function (cantilever beams, simply supported beams, torsion bars, Belleville washers, coil springs, and bellows & diaphragms). This month we will focus on spring washers.

Spring washers are round springs that are typically designed to fit around a fastener, rod or some other cylindrical shaft, and provide force against two mating surfaces joined by the fastener. They may also fit inside a tube or cylindrical shaft to provide the same functions. **Wave springs** are aptly named, as shown in Figure 1. **Curved washers** generally fit on the outside of a large shaft with a smaller cylindrical protruding from the large shaft through the center of the washer. **Belleville washers** resemble the small, squat orange or yellow cones that you might find marking the boundaries of a makeshift football field.

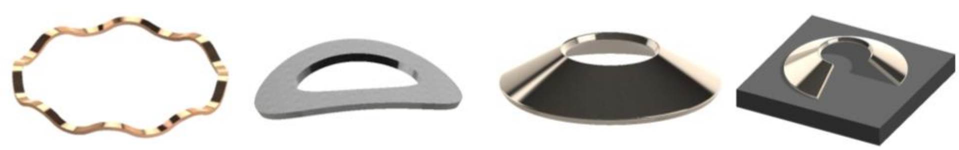

Figure 1. Spring Washers – Wave Spring (Far Left), Curved Washer (Near Left), Belleville Washer (Near Right), and Cutaway View of Belleville Washer (Far Right). The shafts around which and/or within which these springs washers sit are omitted for clarity.

The **free height** (*h*) is the vertical distance between the uppermost and lowermost points on the bottom surface of the spring. It is also the total height of the spring minus the thickness. If the spring is mounted on a solid surface to prevent snap-through, the free height is simply the maximum amount the spring can be deflected. The other geometric variables that govern force/deflection and stress/deflection behavior are the inside diameter (*ID*), outside diameters (*OD*), and the thickness (*t*). For wave springs, the number of waves (N_w), and spring width ($b = OD/2\text{-}ID/2$) are also important. In the equations in Table 1 below, contact force is designated as *P*, Maximum Stress as *S*, and deflection as *f*. Poisson's ratio appears as *v*.

	Contact Force (P)		Maximum Stress (S)	
Curved Washer	$P = \frac{4 \cdot E \cdot t^3 (OD-ID)}{OD^3} \cdot f$		$S = \frac{1.5 \cdot OD}{t^2(OD-ID)} \cdot P = \frac{6 \cdot E \cdot t}{OD^2} \cdot f$	
Wave Spring	$P = \frac{E \cdot b \cdot t^3 \cdot {N_w}^4}{2.4 \cdot [(OD+ID)/2]^3} \cdot \frac{OD}{ID} \cdot f$		$S = \frac{3 \cdot \pi \cdot [(OD+ID)/2]}{4 \cdot b \cdot t^2 \cdot {N_w}^2} \cdot P = \frac{3 \cdot \pi \cdot t \cdot {N_w}^2}{3.2 \cdot [(OD+ID)/2]^2} \cdot \frac{OD}{ID} \cdot f$	
Belleville Washer	$P = \frac{4 \cdot E}{M \cdot (1-\upsilon) \cdot (OD)^2}\left[\left(h-\frac{f}{2}\right) \cdot (h-f) \cdot t + t^3\right] \cdot f$		$S = \frac{4 \cdot E}{M \cdot (1-\upsilon) \cdot (OD)^2}\left[C_1 \cdot \left(h-\frac{f}{2}\right) + C_2 \cdot t\right] \cdot f$	
Belleville Washer Constants	$a = \frac{OD}{ID}$	$\mathrm{M} = \frac{6}{\pi \cdot \ln a}\left[\frac{(a-1)^2}{a^2}\right]$	$C_1 = \frac{6}{\pi \cdot \ln a}\left[\frac{(a-1)}{\ln a} - 1\right]$	$C_2 = \frac{6}{\pi \cdot \ln a}\left[\frac{(a-1)}{2}\right]$

Table 1. Contact Force and Maximum Stress as a Function of Deflection. Note that the equation listed here for the peak stress of the Belleville washer is for the lower edge of the ID. The maximum stress could occur at any corner, but there would be different equations for these locations. This provides another illustration of why finite element analysis is so popular. It is probably faster and easier to draw the model and simulate the deflection than to crank through the hand calculations, unless you like performing mathematical operations for recreational purposes.

Spring Washers (continued)

The spring force generated by these washers can easily be modified by stacking them in parallel (nesting them so that all springs have the same orientation), by stacking them in series (alternating the orientation in consecutive springs, top to top and bottom to bottom), or by some combination thereof. (Figure 2) Note that series stacking of curved washers is problematic, since there would be only two points of contact between neighboring springs, and the stack would be highly unstable.

Figure 2. Series Stacks (Top) and Parallel Stacks (Bottom).
The Belleville and curved washers are shown in cutaway view for clarity. Parallel (nested) stacks take up much less total height than series stacks. These stacks would either encircle and/or be encircled by a cylindrical surface to keep the springs in place.

Ignoring frictional effects, **parallel stacking** increases overall load per unit deflection (spring rate), but **series stacking** increases the overall deflection (resilience) without increasing the load. In all cases, the shaft of the rod or fastener in the center of the hole holds the stack in place and provides radial stability. Series stacked wave springs may be made in one continuous piece to provide rotational and tangential stability. Nested stacks are self-stabilized in the rotational/tangential direction. By combining series and parallel stacking, an infinite number of spring rates are possible, assuming that you have room to stack all the washers required.

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