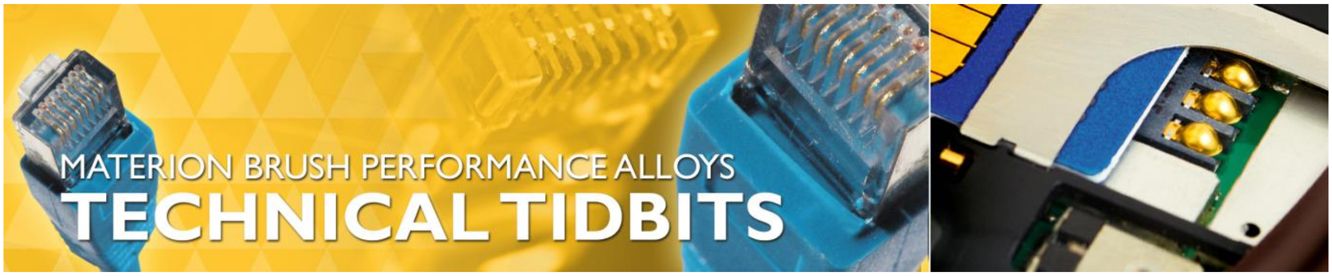

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Springs that can handle the pressure. – Bellows and diaphragms are often used in pressure sensing applications.

- **Bellows**
- **Convolutions**
- **Diaphragms**
- **Corrugations**

Spring Types Part 7 – Bellows and Diaphragms

This series of six or so (OK, now at least 8 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 complete the above list by talking about diaphragms and bellows. Next month we will discuss some miscellaneous spring types that do not quite fit any of the above categories.

Bellows feature **convolutions**, or repeated, small scale waves or serpentine bends. The local and repeated small-scale deformations of these features provide a very predictable and precise relationship between pressure and force loads and deformation. As such, they are more often used as sensors or actuators than simply as springs.

Bellows are interesting in that they can provide stiffness in axial extension and compression, as well as accommodate bending and lateral deflection (parallel offset. Each of their many individual convolutions may only see a small amount of incremental deformation and strain, but when summed up the whole bellows can see significant deformation.

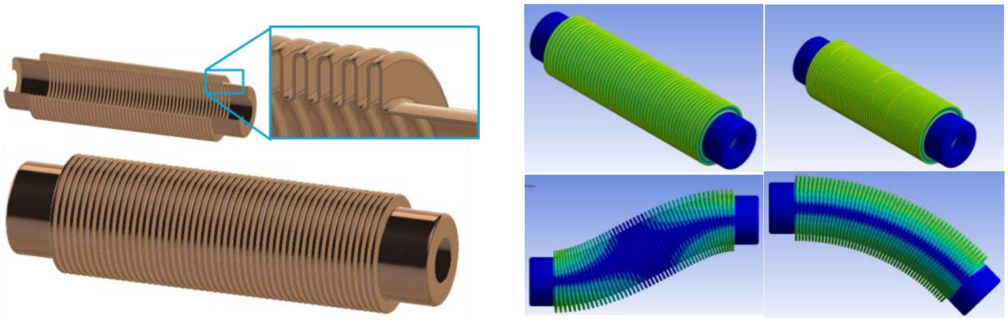

Figure 1. Metal Bellows. On the left side is a typical bellows, with cutaway view and a close-up of the convolutions shown above it. On the right side are the four deflection modes (clockwise from top left: axial extension, axial compression, flexure, and lateral deflection). Note, axial compression has an additional potential failure mode – namely, buckling.

An internal pressure load will cause the bellows to extend axially, and the convolutions keep a precise relationship between pressure and extension. Bellows are therefore quite useful as pressure sensors.

The equations that govern the stiffness of bellows are rather complex and will not be repeated here, but only highlighted to show the key variables. For a detailed treatment, please see the reference listed on the 2nd page of this article. The equations for axial deflection (d) as a function of pressure (P) and as a function of axial force (F) are shown below.

$$d = 2 \cdot n \cdot \frac{P \cdot r^4}{E \cdot t^3} \cdot NDT_1 \qquad d = 2 \cdot n \cdot \frac{F \cdot r^2}{E \cdot t^3} \cdot NDT_2 \qquad NDT_x = f\left(\frac{OD}{ID} \text{ and } \nu\right)$$

Here, E is the elastic modulus, n is the number of convolutions, t is the material thickness, r is the outside radius of each convolution. There are also four non-dimensional terms (NDT_x) that are complicated functions of Poisson's ratio (ν) and ratio of the outside diameter (OD) of the convolutions to the inside diameter (ID). As in cantilever beams, deflection is linearly proportional to the applied force or pressure, and inversely proportional to the material stiffness (elastic modulus) and the cube of the thickness.

Bellows can be manufactured by roll-forming (large bellows), electrodeposition (small bellows), hydroforming, or by stacking a number of open-center **diaphragms** in series, and welding the edges.

The next issue of Technical Tidbits will continue the discussion on spring types, briefly covering some miscellaneous types.

Bellows and Diaphragms (continued)

Figure 2 shows some corrugated metal diaphragms. One major use of these diaphragms is in pressure sensors, where the sealed interior is filled with oil or some other inert fluid at a fixed reference pressure. The upper and lower disks will deflect inward or expand outward depending on whether the external pressure rises or falls, respectively. The key performance metric in this application is precise, predictable movement (i.e. spring rate) based on small changes in pressure. As is the case for the convolutions in bellows, the **corrugations** minimize local strain and deformation, which keeps the spring rate constant.

Diaphragms may also be made with flat (non-corrugated) surfaces. However, force/deflection or pressure/deflection curves become nonlinear after small deflections. A nonlinear force/deflection curve results in mechanical hysteresis, so the unloading curve does not match the loading curve. This limits their usefulness as a sensing element, as you would have to know which way the diaphragm is moving to determine which of the two possible loads corresponds to each deflection.

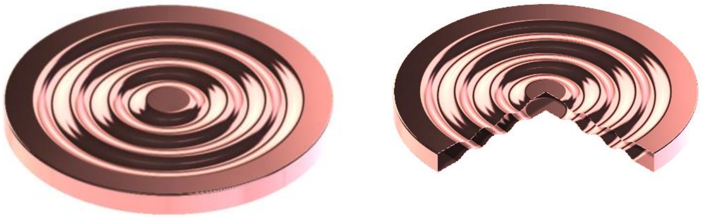

Figure 2. Diaphragm with Cutaway View.

The equations relating deflection (d) at the center of the diaphragm to the applied pressure (p) or applied axial force (F) are shown below. Note that this is not a linear relationship, as the deflection term appears twice, once in the first power and once cubed. The variables are the same (and even raised to the same power) as for the bellows case, with the exception that the non-dimensional term is a semi-complicated function of the ratio of the corrugation height (H) to the material thickness (t), and the number of corrugations does not explicitly appear.

$$\mathrm{P} = \frac{E \cdot t^4}{r^4} \cdot \left[NDT_1 \cdot \left(\frac{d}{t}\right) + NDT_2 \cdot \left(\frac{d}{t}\right)^3 \right] \qquad \mathrm{F} = \frac{\pi \cdot E \cdot t^4}{r^2} \cdot \left[NDT_3 \cdot \left(\frac{d}{t}\right) + NDT_4 \cdot \left(\frac{d}{t}\right)^3 \right] \qquad NDT_x = f\left(\frac{H}{t}\right)$$

The equations (not shown) for maximum stress are similar. Radial and tangential stress is directly proportional to the applied stress, the square of the ratio of outside diameter to material thickness, and a non-dimensional term that is also a function of corrugation height divided by material thickness. For a detailed treatment, if you are really interested in design of either bellows or diaphragms, please see the reference text listed on the upper right of this page.

Written by Mike Gedeon of Materion Performance Alloys Marketing Department. Mr. Gedeon's primary focus is on electronic strip for the automotive, telecom, and computer markets with emphasis on application development.

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Materion Performance Alloys
6070 Parkland Blvd.
Mayfield Heights, OH 44124

Sales	+1.216.383.6800	800.321.2076	BrushAlloys@Materion.com
Technical Service	+1.216.692.3108	800.375.4205	BrushAlloys-Info@Materion.com

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References:

Di Giovanni, Mario
Flat and Corrugated Diaphragm Design Handbook
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