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How much variation can you tolerate? - This discussion will explain why tolerances are important in connector design.

- **Material Tolerances**
- **Manufacturing Tolerances**
- **System Tolerances**
- **Stack Tolerances**

The next issue of Technical Tidbits will include an informative discussion about system tolerances and tolerance stack-up issues.

The Cumulative Effects of Tolerances on Connector Performance – Part 1

In the early 1900's, Henry Ford introduced the Model T to the world and initiated a new era in personal transportation. In the same way, Ford's invention of the continuously moving assembly line set the stage for modern manufacturing through the use of standardized and interchangeable parts. Theoretically, if one of these parts works in an application, its siblings should work as well, no matter where, when, or how it was made. However, in the real world, engineers have discovered that there is usually some amount of variation in identical production parts. Therefore, designers have specified tolerances, or maximum allowed variations, in specific characteristics of the designed part. In the design of electrical connectors, there are three types of tolerances that are important: **material tolerances**, **manufacturing tolerances**, and **system tolerances**. System tolerances are design limitations created by the interaction of several components, and will be discussed in the next issue of Technical Tidbits. Additionally, tolerances may interact by superposition creating another source of variation known as **stack tolerances**.

Material tolerances are tolerances associated with the raw material input into a manufacturing process. These tolerances are usually specified by the material producer. When performing finite element analysis (FEA) or other stress and force analyses, designers usually assume average values for a metal's properties. However, the elastic modulus, yield strength, tensile strength, elongation, conductivity, formability, etc. either falls into some specified range or meets some minimum requirement. Most metal suppliers will have sufficient process control in place to keep property variations to a minimum. However, the slight property variations always appear from coil to coil, and even from point to point within a single coil.

Input materials will also have dimensional tolerances in addition to the aforementioned property tolerances. As you would expect, variations in the dimensions of strip material (length, width, thickness) will also affect its performance. For example, in cantilever beam style contacts, the variation in contact force is proportional to the cube of the variation in strip thickness. This is why material suppliers pay strict attention to thickness tolerances.

Manufacturing tolerances are tolerances that are specified on part drawings. These are intended to provide some degree of control over the final shape of the stamped contact since there are so many sources of variation in the stamping process. For example, punches and dies dull over time, slowly changing the shape of the contact throughout the production run. Stamped angles may experience varying degrees of springback, depending upon, thickness, modulus, yield strength, and whether the forming bend is smooth, coined, or irregular in contour. The residual stress left in the contacts from the rolling and slitting of the strip and from the stamping operation differs from contact to contact. This difference in residual stress creates differences in how the contacts perform under load. Since designers assume optimum dimensions and material properties, tolerances are used in an effort to insure that no single characteristic of the contact strays too far from optimal.

A connector exhibits optimum performance when all its characteristics fall at the midpoint of its tolerances. If one or more tolerances are not met, unacceptable performance may result. Generally, if all tolerances are met, a connector will operate within acceptable parameters. However, there is still a chance that acceptable variations may interact in such a way that a connector will not function properly.

Figure 1 illustrates a simple battery contact with specified dimensional tolerances. (Please note these tolerances are not necessarily realistic, but for example purposes only). Suppose the battery contact is made with a material that has an elastic modulus of 20,000,000 psi and an elastic limit of 100 ksi and must generate at least 100 grams of contact force. Table 1 shows that when all the dimensions fall at the nominal

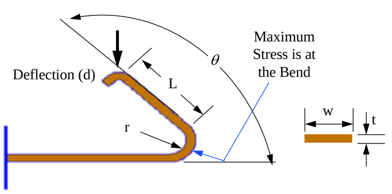
Cumulative Effects of Tolerances on Connector Performance – Part 1 (continued)

value (midpoint of the tolerance), the contact produces the required contact force. It also shows that the stress is well below the elastic limit. Since this is a low cycle application, fatigue is not an issue. To further complicate matters, any contacting or adjoining parts are subjected to their own tolerances. This is accounted for by the variation in the deflection.

Table 1 also indicates how a contact may fail to meet performance requirements even if all dimensions fall within tolerances. In the low force column, all the dimensions fall at the ends of the tolerance ranges, which produces inadequate contact force. If the material were to have a lower-than-average elastic modulus, the force would be further reduced. In the high stress column, the dimensions fall at the opposite ends of the tolerance ranges, producing excessive stress. With either combination of dimensions, a part would certainly yield. The amount of permanent set would be worse if the elastic modulus were higher than average or if the elastic limit were lower than average. The connectors in these worst case scenarios may pass inspection as acceptable if dimensional tolerances were the only attributes checked. This makes performance testing of the contacts a necessity.

Therefore, tight tolerances are essential for ensuring adequate operation of the connector. Tolerance ranges should be as small as possible while still remaining realistic from the stamper's point of view. There are innumerable sources of variation in the production of the raw materials, individual components, and finished products. Strict process control at every step helps to minimize variation in the final product.

In summary, material properties may be chosen to minimize the effects of tolerances. Since electrical connectors must be designed to provide adequate force without being overstressed, they should be designed to provide the minimum contact force under the worst case conditions. Materials with high yield strengths and good resistance to both fatigue and stress relaxation are better able to handle unintentional overstressing which may result from tolerance variation. Minimum property variations in the base metal will also minimize variation in connector performance.



$w = 0.070 \pm 0.0005$ $L = 0.250 + .0005$ $r = 0.040 \pm .002$

$t = 0.008 \pm 0.00025$ $d = 0.050 \pm .0075$ $\theta = 140° \pm 2°$

Figure 1. Design Example

Effects of Tolerances on Performance			
Varible	Low Force (Worst Case)	Nominal Values	High Stress (Worst Case)
d	0.0425"	0.050"	0.0575"
t	0.00775"	0.008"	0.00825"
L	0.2495"	0.250"	0.2505"
w	0.0695"	0.070"	0.0705"
r	0.038"	0.040"	0.042"
θ	138°	140°	142°
Force	74 g	106 g	140 g
Stress	69 ksi	90 ksi	110 ksi

Table 1. Design Example

Written by Mike Gedeon of Brush Wellman's Alloy Customer Technical Service Department. Mr. Gedeon's primary focus is on electronic strip for the telecommunications and computer markets with emphasis on Finite Element Analysis (FEA) and material selection.

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Brush Wellman Inc.
6070 Parkland Blvd.
Mayfield Heights, OH 44124
(216) 486-4200
(216) 383-4005 Fax
(800) 375-4205 Technical Service

BRUSH WELLMAN ALLOY PRODUCTS

Reference:
Pitney, Kenneth E.
Ney Contact Manual
The JM Ney Company
Bloomfield, CT 1973

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