MATERION

# PREVIEW:

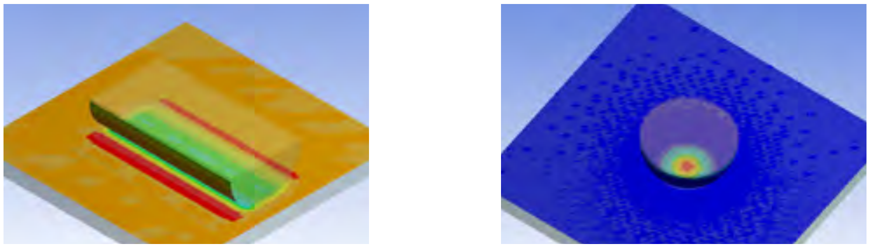
# Connector Engineering Design Guide

A comprehensive guide to design, modeling, analysis, testing, and production of reliable connectors and other conductive springs utilizing Materion's high performance alloys.

# Connector Engineering Design Guide

**Material Selection in the Design of Spring Contacts and Electrical/Electronic Interconnections**

## Figure IV-4 Contact Stress Distribution



**Cylinder on Flat**

**Sphere on Flat**

**Crossed Cylinders**

**Flat on Flat**

**Figure IV-4 – Contact Stress Distribution**
This is a representation of the stresses in the contact areas as calculated by finite element analysis. In the images on the right, high stress areas are in red and low stress areas are in blue. On the left side, high stress areas are in blue and low stress are in red. The sphere on flat configuration in the upper right and the crossed cylinders on the bottom left show the highest contact stress (and most deformation), while the flat on flat configuration on the bottom right shows the least.

## Figure IV-5 Effect of Contact Profile on Contact Pressure

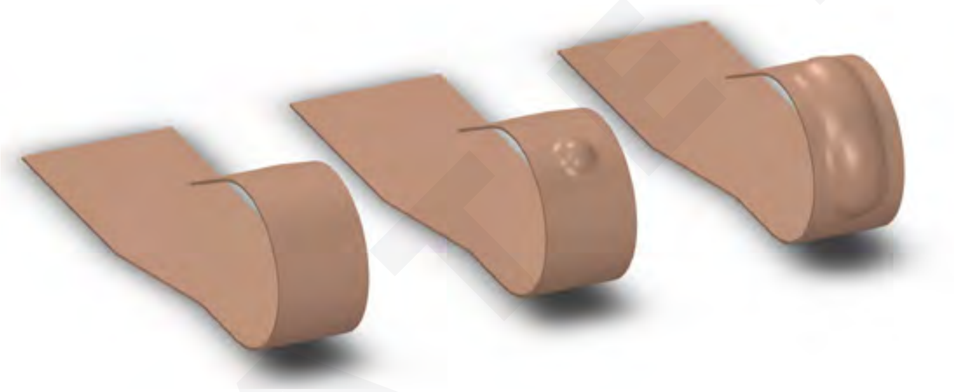


**Figure IV-5 – Effect of Contact Profile on Contact Pressure**
There are ways to use the contact profile to locally increase the contact stress on connectors, usually by stamping embossments in the contact area. The configuration on the left approximates the cylinder on flat line contact, while the other two approximate the point contact of sphere on flat.

### Insertion & Extraction Forces

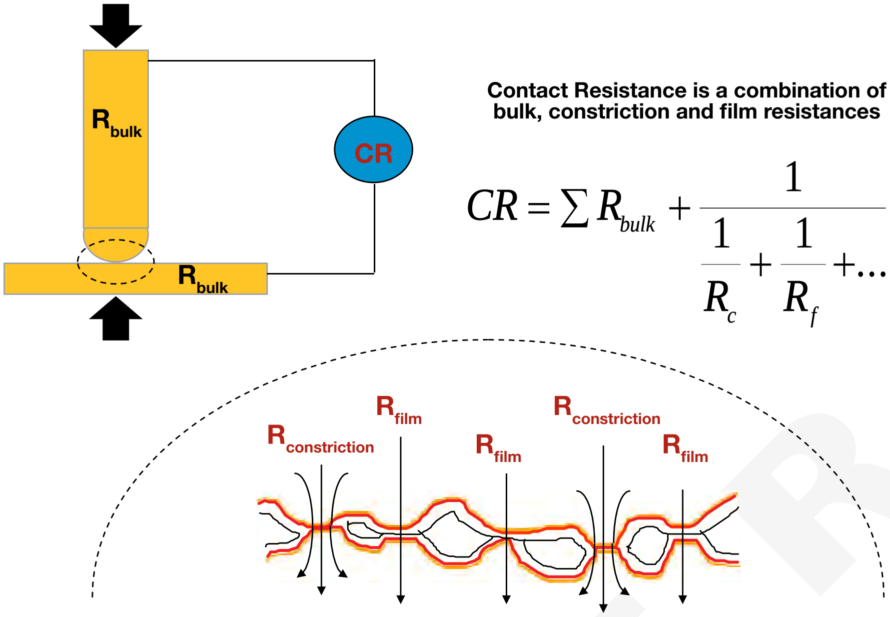
The force required to mate and unmate two connectors is the insertion and extraction forces respectively. Do not confuse these forces with contact force. The insertion and extraction forces are proportional to the normal force and the coefficient of friction. Wear concerns, contact force, number of contact points, coefficient or friction, lead-in angle of the mating part and design requirements determine the allowable number of insertion cycles. Ergonomic issues during mating and assembly determine the total mating force. Connector mating forces of more than 50 to 75 N (11 to 17 lbs) often require mechanical aids, and are frequently specified by governments as the maximum permissible insertion force for manually mated connectors. Lubrication lowers the insertion force and inhibits oxidation and corrosion. Non-sulfur containing lubricants are a requirement. The high temperature stability of the lubricant also is a consideration. (Section VII-Materials for other Connector Components contains more information on connector lubricants.)

# Electrical Requirements

### Connector Resistance

The contact resistance of the separable or non-separable interfaces and the bulk resistance of the contact spring comprise the total connector resistance.

## Figure IV-6 Contact Resistance



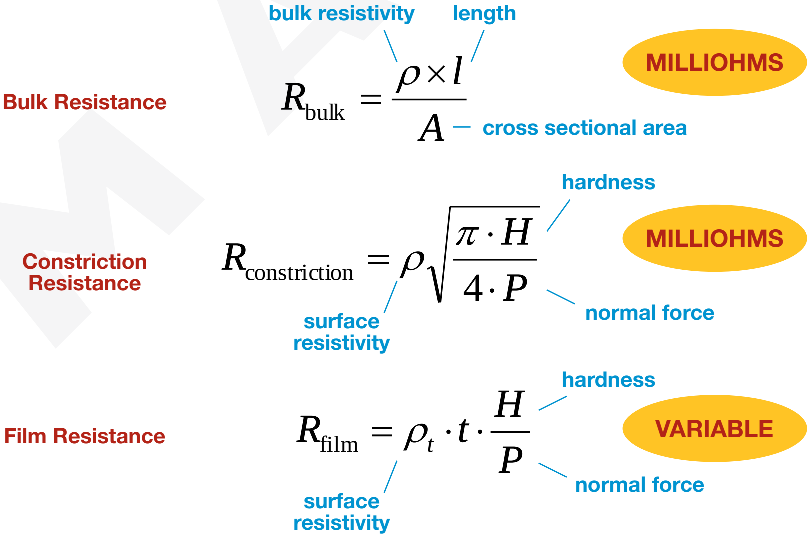
$$CR = \sum R_{bulk} + \cfrac{1}{\cfrac{1}{R_c} + \cfrac{1}{R_f} + \ldots}$$

**Figure IV-6 Contact Resistance**
Bulk resistance is the overall resistance of the metal in the contact. Constriction resistance occurs as the electrical current must squeeze through the asperities to cross the interface. (A smaller cross sectional area for the current to flow through means greater resistance.) Film resistance is created by thin layers of oxides and other contaminants that form on material surfaces. These have higher resistivity which requires more effort for the signal to travel through the film. The overall resistance is the bulk resistance in series with the interface resistance. The interface resistance is the sum of all the constriction and film resistances in parallel.

### Contact Resistance

Contact resistance is the electrical resistance of the interface between the two surfaces in contact. It is influenced by normal force, geometry, physical properties, and corrosion resistance of the contacting surfaces. Contact resistance further breaks down into constriction resistance and film resistance (Figures IV-6 and IV-7).

## Figure IV-7 Contact Resistance



$$R_{\text{bulk}} = \frac{\rho \times l}{A}$$

$$R_{\text{constriction}} = \rho \sqrt{\frac{\pi \cdot H}{4 \cdot P}}$$

$$R_{\text{film}} = \rho_t \cdot t \cdot \frac{H}{P}$$

**Figure IV-7 Contact Resistance**
These are the classic formulas derived by Ragnar Holm for calculating the various resistances. Mostly they are functions of the normal force and the hardness & resistivity of the contact surfaces. Higher forces and softer interface layers decrease the resistance, although softer interface layers may be prone to wear and other problems.

## Bending Stress (Continued)

Using classical beam formulas and section properties, the following relationship can be derived:

Bending stress, $\sigma_b = \dfrac{6PL}{wt^2}$

Bending or flexural modulus, $E_B = \dfrac{4PL^3}{wt^3y}$

Where: P = normal force
L = beam length
w = beam width
t = beam thickness
y = deflection at load point

The reported flexural modulus is usually the initial modulus from the stress-strain curve in tension. When available, take the value from a 4-point bend test. (For multi-layered composite materials, the flexural modulus is not equal to the tensile modulus, but can still be relatively easily calculated from the elastic modulus and moment of inertia of each layer. )

The maximum stress occurs at the surface of the beam farthest from the neutral surface (axis) and is:

$$\sigma_{max} = \frac{Mc}{I} = \frac{M}{Z}$$

Where M = bending moment
c = distance from neutral axis to outer surface where max stress occurs
I = moment of inertia (see Section XIII-Design & Analysis)
Z = I/c = section modulus (see Section XIII-Design & Analysis)

For a rectangular cantilever beam with a concentrated load at one end, the maximum surface stress is (Figure V-25):

$$\sigma_{max} = \frac{3dEt}{2L^2}$$

Where d = deflection of the beam at the load
E = flexural modulus/modulus of elasticity
t = beam thickness
L = beam length

One of the methods to reduce maximum stress is to keep the strain energy in the beam constant while changing the beam profile. Some additional beam profiles include trapezoidal, tapered and torsion.

Figure V-25 Maximum Surface Stress

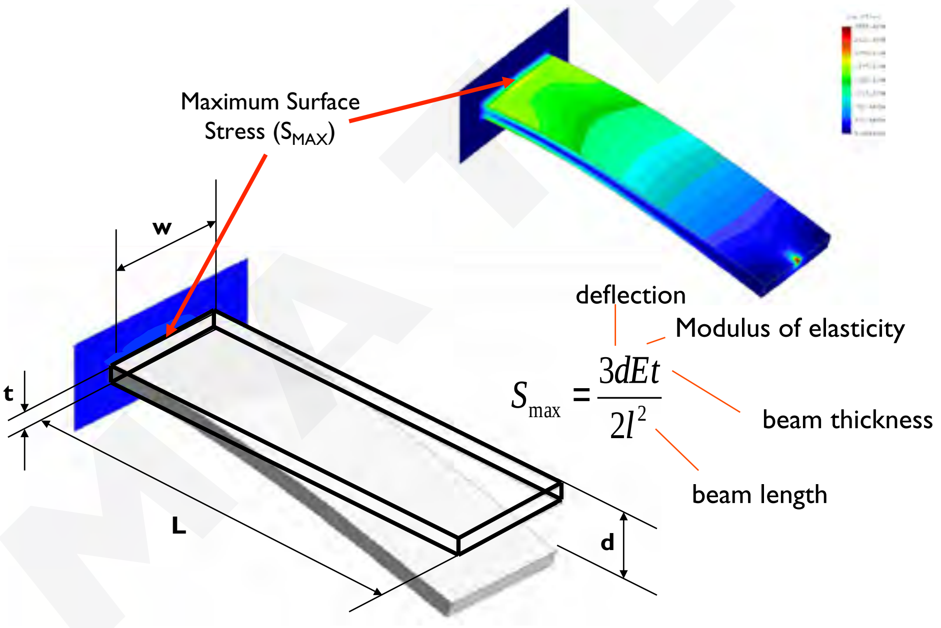


**Figure V-25 Maximum Surface Stress**
The maximum stresses in any beam will always be at the outer fiber. The maximum tensile stress will be on the elongated side (convex), the maximum compressive stress on the compressed (concave) side. In cantilever beams, the maximum stress is at the fixed end, tapering to zero at the point of loading (and beyond if the load is before the end of the beam).

# Yielding

For design purposes, yielding can be said to occur when the design stress exceeds the material's yield strength. Design stress is typically maximum surface stress (simple loading) or Von Mises stress (complex loading conditions). The Von Mises yield criterion states that yielding occurs when the Von Mises stress, $\sigma_V$, exceeds the yield strength in tension. Finite Element Analysis stress results use Von Mises stresses. Von Mises stress is defined as:

$$\sigma_v = \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2}{2}}$$

where $\sigma_1$, $\sigma_2$, $\sigma_3$ are principal stresses

The safety factor is a function of design stress and yield strength. The following equation denotes safety factor, $F_S$.

$$F_s = \frac{YS}{DS}$$

, where YS is the yield strength and DS is the design stress. Alternatively, for highly cycled applications the appropriate fatigue strength (see passage on fatigue later in this section) may be substituted for the yield strength.

For many years, it had been customary to set the design stress equal to 75% of the yield strength, for a safety factor of 1.33. Since the elastic limit of a copper alloy is typically around 70-80% of the 0.2% offset yield strength, this design stress level guarded against yielding. With the current widespread availability and predictive capability of finite element analysis (FEA), it is now common to see safety factors approaching and even falling below unity, if a small amount of permanent set can be tolerated.

Table V-5 lists the critical material mechanical properties of copper alloy strip.

**Table V-5 Strip Mechanical Properties**

| Alloy | Temper | Heat Treatment Required for Peak Properties | Modulus of Elasticity | | Yield Strength 0.2% Offset | | Tensile Strength | | Total Elongation |
|---|---|---|---|---|---|---|---|---|---|
| | | | ($10^6$ psi) | (GPa) | (ksi) | (MPa) | (ksi) | (MPa) | (%) min. |
| **Materion Copper Beryllium Strip Alloys** | | | | | | | | | |
| 25 | A | 3 hr at 600°F (315°C) | 18 | 124 | 30 - 55 | 200 - 380 | 60 - 78 | 410 - 540 | 35 |
| | 1/4 H | 2 hr at 600°F (315°C) | | | 60 - 80 | 410 - 560 | 75 - 88 | 510 - 610- | 20 |
| | 1/2 H | 2 hr at 600°F (315°C) | | | 75 - 95 | 510 - 660 | 85 - 100 | 580 - 690 | 12 |
| | H | 2 hr at 600°F (315°C) | | | 90 - 115 | 620 - 800 | 100 - 120 | 680 - 830 | 2 |
| | AT | Properties after Heat Treatment by User per Above Specifications | 19 | 131 | 140 - 175 | 960 - 1210 | 165 - 195 | 1130 - 1350 | 3 |
| | 1/4 HT | | | | 150 - 185 | 1030 - 1280 | 175 - 205 | 1200 - 1420 | 3 |
| | 1/2 HT | | | | 160 - 195 | 1100 - 1350 | 185 - 215 | 1270 - 1490 | 1 |
| | HT | | | | 165 - 205 | 1130 - 1410 | 190 - 220 | 1310 - 1520 | 1 |
| 190 | AM | Mill Hardened | 19 | 131 | 70 - 95 | 480 - 660 | 100 - 110 | 685 - 755 | 16 |
| | 1/4 HM | | | | 80 - 110 | 550 - 760 | 110 - 120 | 755 - 825 | 15 |
| | 1/2 HM | | | | 95 - 125 | 650 - 870 | 120 - 135 | 825 - 940 | 12 |
| | HM | | | | 110 - 135 | 750 - 940 | 135 - 150 | 930 - 1035 | 9 |
| | SHM | | | | 125 - 140 | 860 - 970 | 150 - 160 | 1035 - 1110 | 9 |
| | XHM | | | | 135 - 170 | 930 - 1180 | 155 - 175 | 1060 - 1205 | 4 |
| | XHMS | | | | 150 - 180 | 1030 - 1250 | 175 - 190 | 1205 - 1320 | 3 |
| 290 | TM02 | Mill Hardened | 19 | 131 | 95 - 115 | 650 - 800 | 120 min. | 820 min. | 14 |
| | TM03 | | | | 110 - 125 | 760 - 860 | 135 min. | 930 min. | 12 |
| | TM04 | | | | 115 - 135 | 790 - 940 | 140 min. | 960 min. | 9 |
| | TM06 | | | | 135 - 155 | 930 - 1070 | 155 min. | 1060 min. | 6 |
| | TM08 | | | | 150 - 175 | 1060 - 1210 | 175 min. | 1200 min. | 3 |
| 3 | AT | Mill Hardened | 20 | 138 | 80 - 100 | 550 - 690 | 100 - 130 | 685 - 900 | 10 |
| | HT | | | | 95 - 120 | 680 - 830 | 110 - 135 | 750 - 940 | 8 |
| 174 | 1/2 HT | Mill Hardened | 20 | 138 | 80 - 100 | 550 - 695 | 95 - 115 | 655 - 790 | 10 |
| | HT | | | | 100 - 120 | 685 - 830 | 110 - 130 | 750 - 900 | 7 |
| Brush® 60 | 3/4 HT | Mill Hardened | 20 | 138 | 95 - 115 | 655 - 795 | 115 - 135 | 795 - 930 | 11 |
| | HT | | | | 105 - 125 | 720 - 860 | 120 - 140 | 825 - 965 | 10 |
| 390 | HT | Mill Hardened | 20 | 138 | 135 - 153 | 930 - 1055 | 138 - 158 | 950 - 1090 | 1 |
| 390E | EHT | Mill Hardened | 20 | 138 | 138 min. | 951 min. | 143 min. | 968 min. | 2 |

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