Cumulative Stress & the Bauschinger Effect

In this age of miniaturization, the process of creating a robust connector design offers peculiar challenges. There are many operations necessary to turn coils of metal into contacts, including slitting, blanking, and forming. All of these processes leave their mark on the finished product. The residual stresses from these operations will combine in complex ways with the design stress produced during the operation of the contact. This may result in unexpected permanent set, stress relaxation, and loss of contact force, even when the design stress is well below the yield strength.

Finite element analysis (FEA) and other stress prediction techniques assume that the stress in a contact is only due to the operational contact deflection. However, in actual connector performance, the presence of residual stresses from forming operations in the material will affect the function of the contact. In particular, material properties will vary depending upon which way the contact is deflected. This induced directionality is known as the Bauschinger Effect. The main consequence is that contacts deflected back against the forming direction will experience a decrease in yield strength and less resistance to stress relaxation. This will result in a reduction in the contact force between a pin and contact that is critical for the passage of electrical signals. Figure 1 defines forward and backward deflection relative to the high stress 180° bend on the left side of the contact.

Figure 1. Preferred Bending Direction

Figure 2 shows the consequences of the Bauschinger Effect. In the forming step, the metal is deformed plastically into the desired shape. When the forming tools are removed, the metal springs back into a shape where all residual stresses in the contact balance. The yield strength may be slightly increased in the forward direction if the part has experienced strain hardening. However, the yield strength is substantially reduced below its original value in the reverse direction.

The Bauschinger Effect can be minimized through a combination of creative manufacturing and careful material selection. Since the Bauschinger Effect increases in bends with larger ratios of bend radius to material thickness and decreases with smaller ratios of bend radius to thickness,
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use the smallest recommended bend radius for the given material. Here, materials with better formability have an advantage. In addition, materials with higher yield strengths tend to show more resistance to the Bauschinger Effect. Higher strength materials can absorb more residual stress and design stress without yielding, therefore they will perform better during both forward and backward deflections.

A second alternative is to use an age hardenable material, or to give the contact a thermal stress relief treatment. Sufficient heat treatments virtually eliminate residual stresses, meaning that standard stress-strain curves for these materials will once again apply. These stress-relieved contacts will then behave much more predictably. Unfortunately, heat treatments can be expensive, and the residual stresses may cause the parts to distort during the heat treatment process unless they are firmly fixtured.

Another method to control the effect is to design the connector so that contact deflection occurs in the forward direction. If a reverse deflection is unavoidable due to space constraints, other methods may be used to limit the consequences of the Bauschinger Effect. A two-step process may be used to form the bend, as shown in Figure 3. In the first step, the material is given a much sharper bend than required. In the second step, the contact is bent back into its final position. This process tends to balance the residual stresses on both sides of the bend. The balance of stresses will minimize the Bauschinger Effect and help to control heat treating distortion. However, this does not eliminate residual stress and adds several degrees of difficulty to the forming operation.

In summary, age hardening or stress relieving heat treatments are the most effective means to eliminate residual stress in electrical contacts. If it is cost-prohibitive to heat treat the part, design the contacts to deflect in the forming direction, not back against it. If a reverse deflection is unavoidable, stronger materials will allow for higher stresses without yielding. Finally, the original forming bends may be made tighter or made with a two-step process. By utilizing these techniques and minimizing the stress in the contact, design engineers can avoid the unpleasant experience of watching an otherwise good design fail.

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