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By Mark Finstad

The Straight Truth About Bend Ratios

Ask the Flexperts is a new *CircuiTree* column where you can present your most controversial questions on flex circuit technology to Joe Fjelstad, Mark Finstad, and Mark Verbrugge, flex designers with a combined 80 years of experience. Have a question for the "flexperts" or a comment on this column? If so, email it to stephanie@circuitree.com.

Q: ***IPC has recommendations for minimum bend ratios (circuit thickness to bend radius). Is it possible to safely bend a flex circuit tighter than that which IPC recommends?***

A: Yes, it is done on a regular basis. When the IPC guidelines were being written, IPC members writing the document had to be intentionally conservative due to the wide variety of materials, constructions, and processes that can be used when building a flexible circuit. In reality, most flexible circuits can be safely formed down to about half the minimum radius recommended by IPC, providing certain precautions are taken. These precautions assume that the flex will be formed to a bend angle of 90 degrees or less.

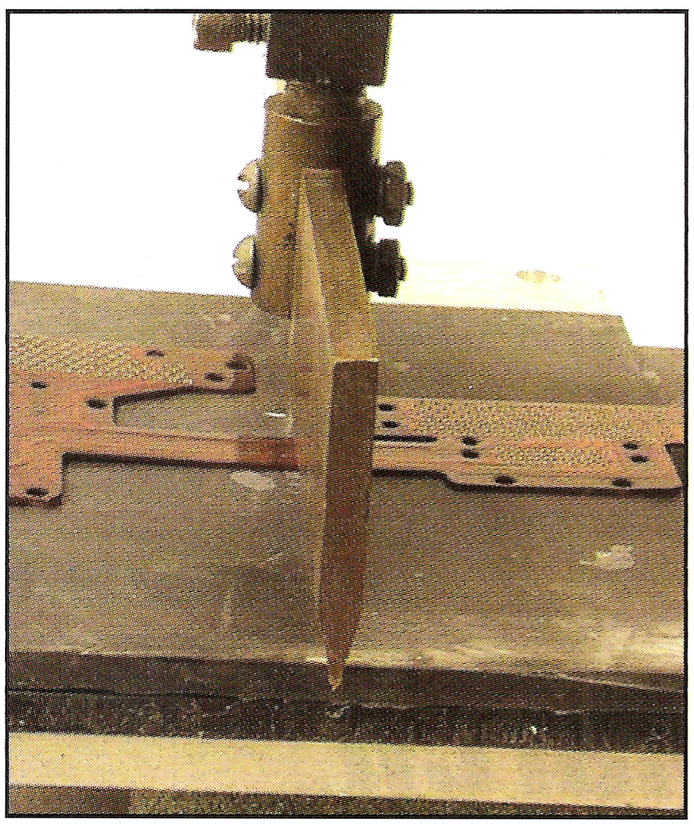

Figure 1 A Simple Forming Tool Will Make Forming a More Repeatable Process. In This Example, the Circuit Is Placed on Top of Two Layers of 0.250 in Sheet Rubber in an Arbor Press. The Forming Wedge Was Constructed With the Desired Radius on the Forming Edge

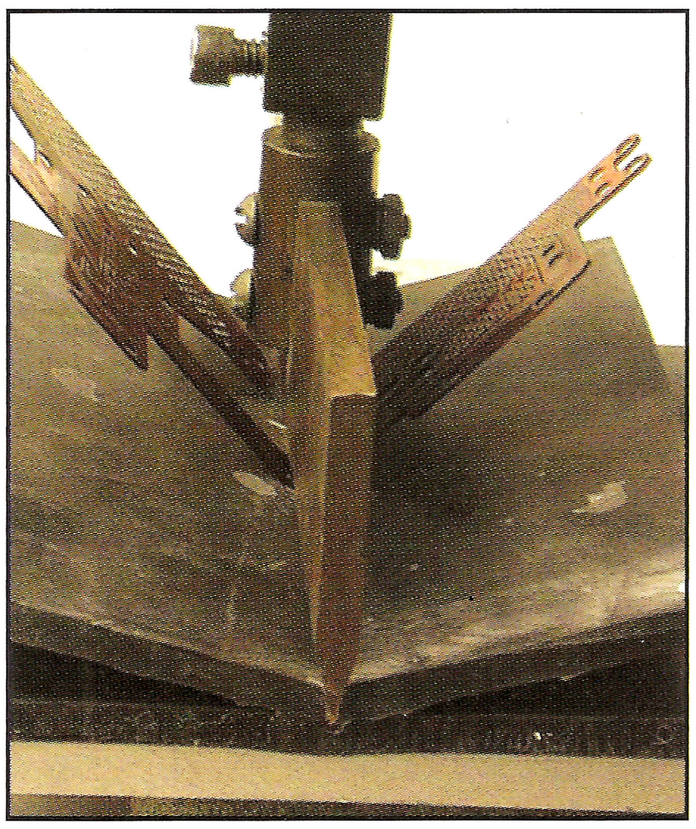

Figure 2 The Wedge Is Pressed Into the Circuit to Create the Form. As the Circuit Is Pressed Downward, the Rubber Exerts Pressure From the Backside to Reduce the Possibility of Cracks or Delamination

1. When forming a flexible circuit to a very tight bend radius, it is important to use a forming tool. A forming tool ensures each circuit is formed the same way and helps maintain consistency between operators that are doing the forming operation. Also, the proper radius can be built into the tool so that the circuits are not stressed any more than absolutely necessary.
2. Once a circuit has been formed to a tight radius, it should not be exposed to elevated temperatures. During the forming operation, the materials to the outside of the bend will be stretched, causing tension stress in the bend area. When the circuit is cold (approximately room temperature), the adhesive bond between the different materials is strong enough to overcome the tension created by the circuit-forming operation. However, if the circuit was to be exposed to elevated temperatures, the acrylic adhesive will soften slightly and the strength of the adhesive bonds will go down. When this happens, the tension in outer layers will cause the inner materials to ripple, buckle, and/or possibly delaminate.
3. After forming a tight bend, the circuit should not move (i.e., do not allow the bend to relax). The bend area must be constrained and not allowed to relax during the installation process. As mentioned previously, all copper and insulating layers to the outside of the neutral bend axis will stretch. The different materials in the circuit will react to this stretching in different ways. For the most part, the insulating materials (usually acrylic adhesive and polyimide film) are very elastic and will return to their original size and shape if allowed to relax. The copper conductors, however, behave much differently than the insulating materials. Most copper used on flexible circuits is fully annealed and very ductile. When a copper conductor is stretched, it will permanently elongate and will not recompress if the circuit form is allowed to relax. Instead, the conductors will tend to ripple. If the circuit is then reformed to restore the installation shape, the rippled conductors will work harden and become brittle. Once this happens, any further exercising or vibration in the bend area can cause the conductors to crack.

While most flex circuit designs can support a bend radius that is tighter than the IPC recommendations, there are some instances where these guidelines must be strictly adhered to. Some examples would be:

- The flex circuit has very small (less than 0.006 in) and/or plated conductors on the outside of the bend. Small conductors are going to be much more fragile than wider conductors. Also, plated copper typically is not capable of the same elongation as fully annealed copper. If the plating on the top of the conductor cracks, the entire trace will crack;
- The flex circuit is over six layers. Unless the bend area is unbonded, meaning not all layers are laminated together, a flex circuit with more than six layers is too

thick to safely drop lower than the minimum IPC guidelines. As circuit thickness increases, the stress on the different materials will also increase. While there may be some flex circuit designs of more than six layers that could be successfully formed to a radius that is less than the IPC guidelines, most cannot; and

- The flex circuit is being formed beyond 90 degrees. When the bend angle is greater than 90 degrees, it is possible that the copper conductors on the outside of the bend will be stretched beyond the maximum elongation limits. Fully annealed copper can usually tolerate at least 30 percent elongation before fracturing. When a circuit is formed to a tight bend radius AND beyond a 90 degree bend angle, the outer copper conductors can easily be subjected to 30 percent elongation or more, resulting in cracks.

It is important to emphasize that there can be significant differences in copper foils and copper plating and that some empirical testing be done on a few of the parts before preparing the whole lot to see how it is performing and if it will work. Also, it is possible to fold a flex circuit back on itself (i.e., 180 degrees), but both the copper and the flex circuit should be kept as thin as possible (ideally though one metal layer only), and the folded area should not be allowed to relax. It is normally a good idea to bond it permanently to itself in the area of the 180 bend in such cases.

> **In reality, most flexible circuits can be safely formed down to about half the minimum radius recommended by IPC, providing certain precautions are taken.**

Experience has also shown that 1 oz. copper (ra, no plating) is ideal for folded applications, as anything thinner or thicker can lead to cracked conductors. And remember, one layer only! ☐

The Flexperts are Mark Finstad and Mark Verbrugge