SOLDER PASTE DEPOSITS AND THE PRECISION OF APERTURE SIZES

Ahne Oosterhof
Eastwood Consulting
Hillsboro, OR, USA

Stephan Schmidt
LPKF Laser & Electronics
Tualatin, OR, USA

ABSTRACT
Many articles have been published indicating that 60 to 75% of all board assembly problems stem from solder paste printing. The important outcome from the printing process is to get the correct amount of solder deposited in the right place. A significant part of that solution is the stencil and its correctness depends on how well its manufacturing process is controlled using proper machines, materials, methods and manpower (the 4M rule!).

The quality of the stencil can be measured a number of ways: smoothness of the cut wall, material quality, thickness and thickness uniformity of the material, proper aperture location, proper aperture size. This report will show that significant variability exists in aperture size precision between various stencil manufacturing sources.

REASON FOR THE TEST
The most significant predictor of paste release from stencils is the area ratio (AR). This is the ratio of the aperture area over the aperture wall area and the larger the number, the higher the paste release percentage. Therefore if the aperture area is off by a certain percentage it will directly influence the area ratio and thereby the paste release from the stencil.

Historically the lower limit for the area ratio has been 0.66. Below that the paste deposit was expected to be insufficient. How well the paste releases, even with a design limit of 0.66 or higher, depends for a large degree on the methods used and the performance of the equipment used to manufacture the stencil.

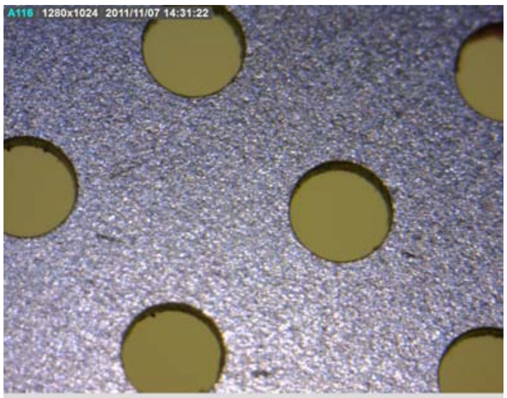

Figure 1 – Example of stencil cut on a modern fiber laser stencil cutter

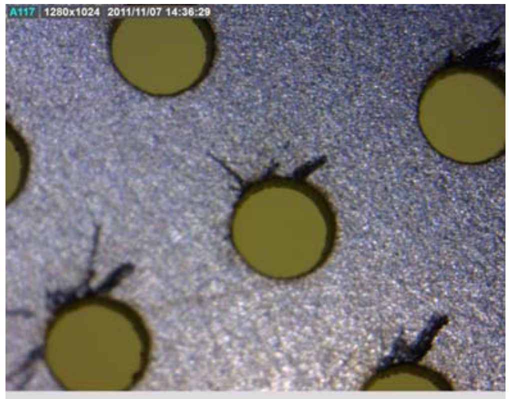

Figure 2 – Example of stencil cut on a legacy lamp-pumped stencil cutter

Figure 1 and 2 show apertures in different stencils made from the same data. The equipment, manufacturing method and process control of the operator can greatly influence the quality of the manufactured stencil, which in turn influences the accuracy of the solder paste deposit on the pad.

TEST

For this test a dozen stencils were acquired, manufactured using different equipment and methods (various laser brands and types, various manufacturing processes as well as electro forming). These stencils were produced using normal production processes, some cut as sheets, others cut in a frame, without the vendors being aware of their purpose.

All stencils were scanned and measured using a large, high-resolution (12,000 dpi) flatbed scanner (LPKF ScanCheck) and the resulting measurements were analyzed. Prior to use the scanner was calibrated and had a maximum error of +/- 5 µm. All stencils were stored at room temperature.

The information obtained from the scanner included aperture location (X and Y coordinates), aperture type, area, position error and size error. Some debris is often still present in a few apertures of a new stencil and the ScanCheck machine does pick up this debris. It causes the area calculation of those apertures to be smaller than actual. With visual inspection of the ScanCheck data it is easy to recognize such apertures and to exclude them from the analysis.

By far the most commonly used stencil thickness these days is 125 um (5 mil), as are the stencils used in this test. The metal used is typically available with a +/- 5 % or +/- 6.4 um (0.25 mil) thickness tolerance. The stencil used in this test has an image size of about 325 x 500mm and contains about 21,000 apertures; approximately 14,000 of those are circles. In this analysis only circles are used. For both the smallest circles and the smallest rectangles the area ratio (AR) was greater than 0.7.

PRECISION OF APERTURES IN A LARGE STENCIL

The precision of the area of stencil apertures and the material thickness determine how close the paste volume will be with respect to the design goal. The dimensional precision of the aperture size depends on the stability, accuracy, use and maintenance regimen of the laser system. In the case of the electro formed stencil it depends on the exposure level of the film used, the exposure of the photosensitive material on the mandrel and the control of the chemical process.

TEST RESULTS

The distributions of the area errors of the apertures for each stencil are shown in figure 3. The vertical axis shows aperture quantities; the horizontal axis shows the percentage deviation from the aperture area design goal. The best results can be recognized by narrower distributions resulting in higher peaks near zero percent.

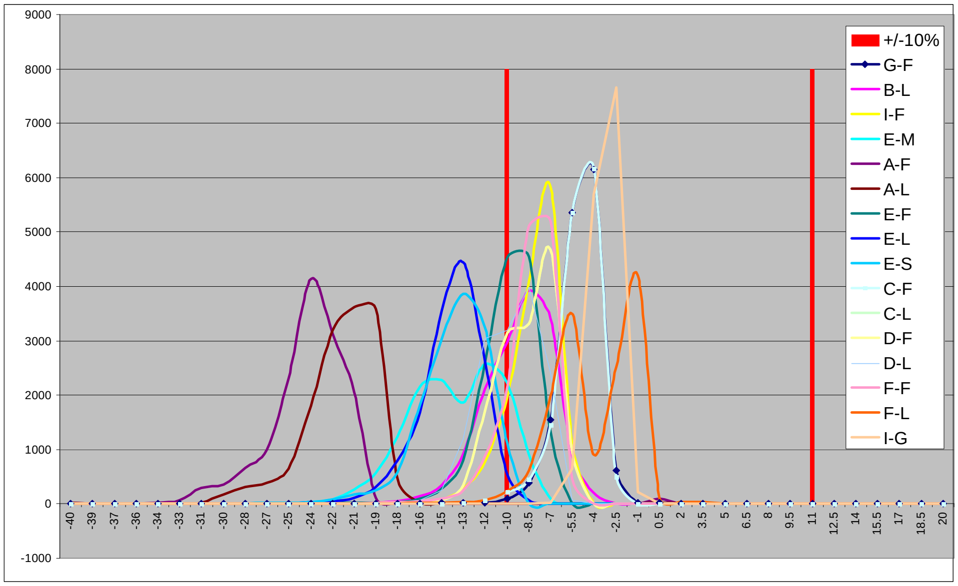

Figure 3 – Distribution of aperture area for each stencil

The data acquired from the ScanCheck system was analyzed and a tolerance of +/- 10% was chosen for area limits. This allowed calculating Cp and Cpk for the various stencils and the resulting distributions are shown in figures 4 and 5.

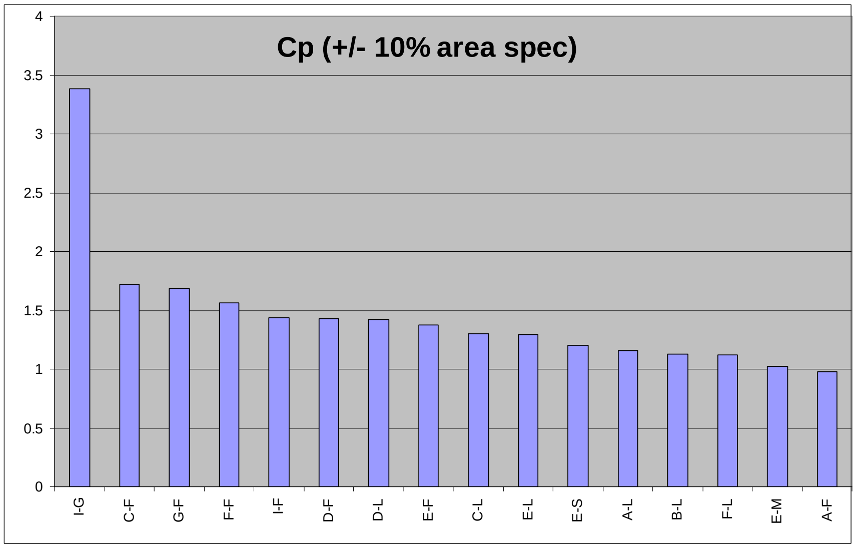

Figure 4 – Cp range for aperture area distribution

Figure 4 shows the distribution of Cp from a high of 3.4 to a low of 0.97. This indicates that the width of the aperture size distribution of these stencils ranges from near to much better than the width of the chosen spec limit, and the width distribution of the best performer is more than three times as good as that of the worst performer.

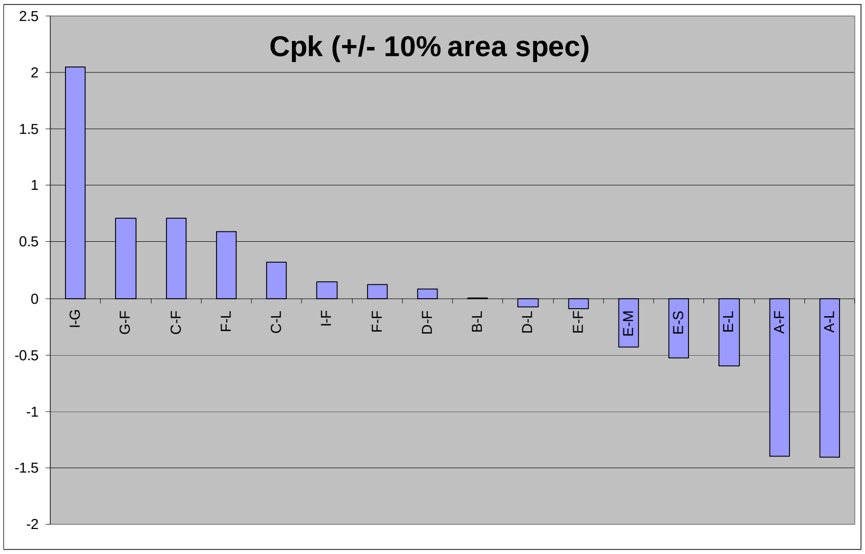

Figure 5 –Cpk range for aperture area distribution

Figure 5 shows the distribution of Cpk, which is the more significant quality indicator, as it shows how well the range of aperture sizes fits within the spec limits. Here and in fig 3 we see that all stencils tended towards the smaller end of the spec range with several completely outside on the low end. Again the quality of the best stencil far exceeded that of the worst stencil.

IMPACT

From the data we can see that the Cpk of the worst stencil indicated that all its apertures were well outside the spec limits. The Process Mean for this stencil's aperture area was -22%. The best stencil has a Cpk of 2.04, a Process Mean of -3.9% and with a Cp better than 3.38, very few of its apertures were outside the chosen area spec limit.

The smallest circular apertures in these stencils were 0.388 mm (15 mil), which for a stencil with a 125 µm (5 mil) thickness results in an area ratio (AR) of about 0.7. For the stencil with the worst process mean of -24% this means the AR is reduced to 0.53, which means that half the apertures have an AR of better than 0.53, but the other half is worse than 0.53. This is well below the historic limit of 0.66 and will result in poor print performance.

ROOT CAUSES

There are a number of root causes that are influencing the dimensional accuracy of an aperture in a solder paste stencil. The most significant source of avoidable inaccuracies in the industry is data processing. If the artwork file is processed without an exact consideration for the manufacturing method and knowledge of the laser system's performance this can lead to a significant impact on the Cpk.

Laser systems can operate with varying beam sizes, typically anywhere from 20 to 45 µm depending on laser technology, system condition and maintenance. In many cases artwork files are processed with a "standard" beam size, but remember, the laser beam is equivalent to the bit in a milling machine. The size of the bit determines where the cutting path should be in order to cut the proper opening. As the stencil could end up being cut on any of a number of different machines with varying laser beam sizes it is necessary to know the beam size when calculating the cutting path in order to get the correct aperture sizes. Lacking this information the result could be undersized apertures if calculating the cutting path using the large "standard" beam size but using a modern fiber-laser based system with typically a smaller laser beam. Similarly, oversized apertures would result if cutting on an older lamp-pumped laser with typically a larger laser beam after calculating the cutting path expecting to use a much smaller beam. To avoid these pitfalls it is important for a manufacturer to frequently monitor and adjust for the actual beam sizes of the equipment to be used.

Another cause of inaccuracies of aperture dimensions is the control and performance of the position system. Resulting errors typically show up as greater variance in aperture size and this is mostly impacting the Cp of the aperture dimension accuracy. Laser cutting systems for instance, come in a wide variety of models and quality levels. The accuracy and stability of the positioning system can vary greatly. Some lasers can also show beam shapes that are not round if not adjusted or maintained properly. This leads to a different size error in the X vs. Y direction. It leads to round apertures showing an oval shape and square apertures becoming rectangular. This is in most cases a maintenance issue which should not be present on a properly calibrated and maintained system.

The best performing stencil (graph I-G in fig 3) was manufactured using a modern laser which was well maintained and calibrated. The data preparation was done specifically for this laser with exact knowledge of the beam size and shape. The program used for CAD data processing allows for corrections to accommodate laser beam size and shape. Obeying the 4M rule does pay off.

Photochemical production methods such as e-form also require very tight process control to allow for higher Cp and Cpk values.

Laser systems have been in use to manufacture stencils since the mid-nineties and have improved significantly. To show continuous improvements, from the data above two stencils (I-F and I-G) are compared which are manufactured on the same brand, type and family of machines (Figure 6 and 7). However the second one is the more modern updated version.

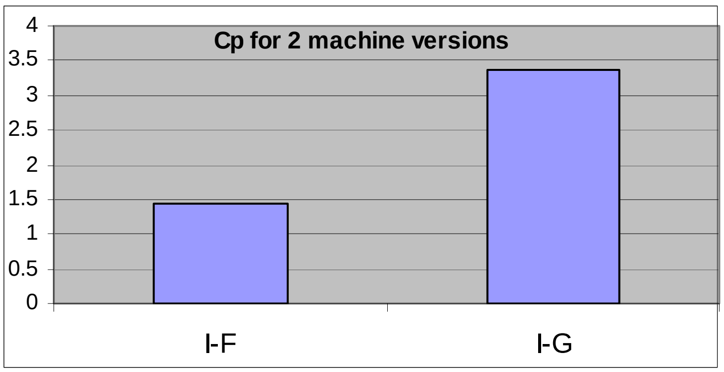

Figure 6 – Comparing Cp of 2 stencils made similar machines

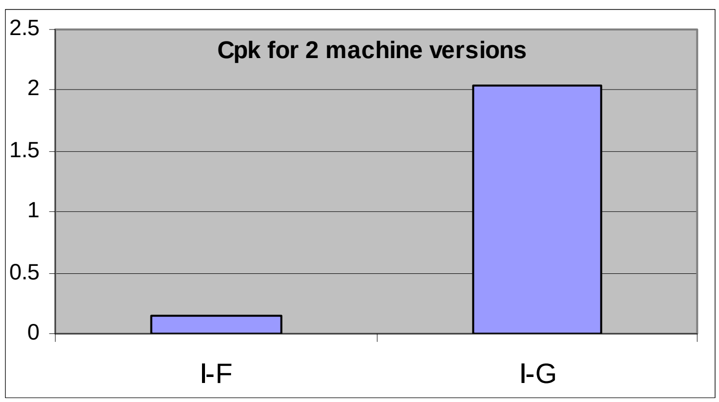

Figure7 – Comparing Cpk of 2 stencils made of similar machines and different beam size compensation procedures

CONCLUSION

The above measurement results indicate that without knowing the manufacturing method used to produce the stencil designed to meet an AR limit of 0.7, AR may vary between 0.7 and less than 0.53, likely resulting in very poor print performance.

However based on paste release test results (Figure 8 and Ref 1) with the best choice of stencil manufacturing method and stencil material it still may be possible to get acceptable paste deposits even with these lower AR values.

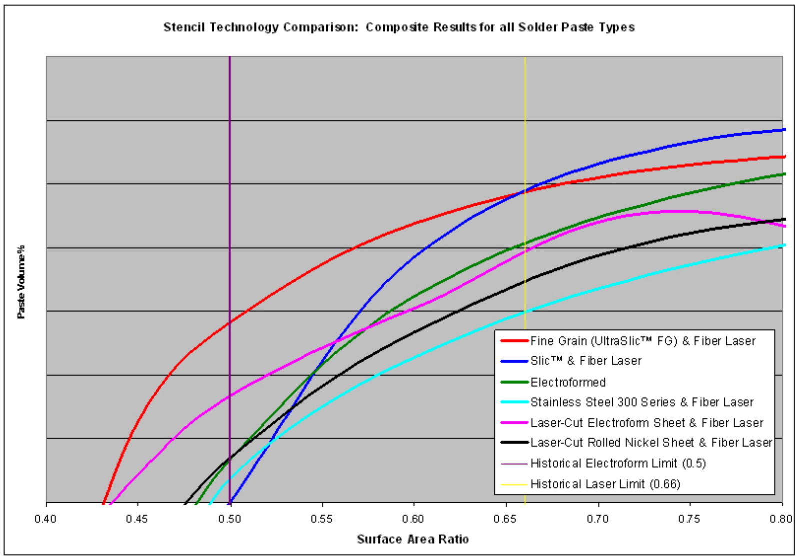

Figure 8 – Paste release test results

In print tests represented by figure 8 the vertical yellow line indicates the historic AR limit. Using the intersection of this line with the commonly used stainless steel (300 series) line (light blue curve) yields a given paste volume percentage. For the best material choice (fine grain stainless, red curve) that same percentage allows an AR of 0.52. This means that for the tests described above, with the worst aperture sizes it is necessary to choose the very best stencil material to even have a chance of obtaining acceptable paste release.

Now that we have learned that the size of the apertures can vary significantly due to manufacturing methods, previous reports (Figure 9 and Ref. 2) have shown that for the same reasons the aperture locations can vary greatly. For the same size and complexity of stencils location errors of up to 175 µm (7 mil) have been measured.

In short, it is necessary to know how a stencil will be manufactured and the user needs to have to ability to verify the stencil quality, especially measuring aperture size and location as with the above test results and the referenced results it is clear that poor print results are not out of the question.

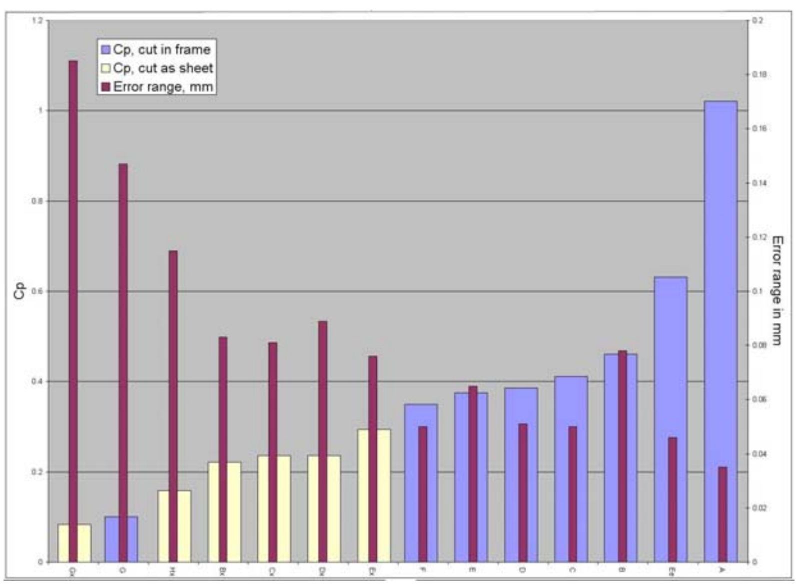

Figure 9 – Variance of aperture size

References

[1] *Robert F. Dervaes, Fine Line Stencil, Inc.; Jeff Poulos, Alternative Solutions, Inc.; and Scott Williams, Ed Fagan, Inc.,* "Conquering SMT stencil printing challenges with today's miniature components", Global SMT & Packaging, April 2009.

[2] *Ahne Oosterhof, Eastwood Consulting, Hillsboro, OR, USA.* *ahne@oosterhof.com*
Stephan Schmidt, LPKF Laser & Electronics, Tualatin, OR, USA. *sschmidt@lpkfusa.com*
"Solder Paste STENCIL Manufacturing Methods and Their Impact on Precision and Accuracy", SMTA Pan Pacific Conference, January 2011.

© Originally published in the Proceedings of the IPC APEX Expo, San Diego, CA, February 28-March 1, 2012.