

SOLDER PASTE STENCIL MANUFACTURING METHODS AND THEIR IMPACT ON PRECISION AND ACCURACY

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ABSTRACT

Stencil positional accuracy is a function of the manufacturing process (Machines, Methods, Materials and Men). The various parameters that influence positional accuracy will be discussed. These include different laser systems, various metals and processes, temperature variations and the effect of mounting a stencil in a frame. The total effect will be shown with measurement results from a number of stencils made according to today's practices using available laser systems and processes. Additional problems may arise when stencils are not used correctly in the printing process. There are several parameters that influence the matching (or mismatching) of the location of the solder paste bricks coming from the stencil with the location of the pads on the circuit board.

In the past stencils were chemically etched and before that silk screening was used, but those processes have been replaced by more modern ones. These days most stencils are either laser-cut in stainless steel using an infra-red (IR) beam or electro-formed from nickel. Stencils have also been manufactured using polyimide, cut with an ultra-violet beam (UV) or IR. [Ref #1]

Key words: solder paste stencils, lasers, laser-cutting, electro-forming, scanner

STENCIL MANUFACTURING

For each method used to manufacture the stencil the important parameters are: (1) the quality of the equipment used to manufacture the stencil, (2) the control over the process to fabricate the stencil, (3) the quality and behavior of the metal during the manufacture, (4) the temperature differences during the various processes and (5) the varying tension on the materials in the different process steps.

LASER CUTTING

The machine used to cut the stencils consists of two systems, the laser and the moving mechanism. It is very important that the laser has a small and very stable beam. The size of the beam determines whether very small details can be cut faithfully. If the beam is not stable in size and the main power concentration moves around, the kerf will not

be exactly where it is supposed to be, circular apertures are not round and straight wall apertures will have wavy sides (see fig 1).

Most of these lasers produce a stream of high power pulses to cut through the metal. Early lasers were pulsing at low frequencies, resulting in a scalloped cut when the metal was moved too quickly. Present day lasers employ a much higher pulse frequency, allowing higher cutting speed without resulting in a scalloped cut line.

To verify that the laser beam is stable and produces constant power, close examination of the aperture size, shape and wall is required.

With a 40 to 100x microscope it is easy to see whether the walls of an aperture are properly formed.

Various designs of the movement system exist. Early systems had a stationary laser beam while the table holding the metal sheet or stencil frame moved in both X and Y-axis. In some of the later systems the beam moves in X-axis and the table moves in the Y-axis. The next step is to hold the metal stationary and move only the beam in the X and Y axes.

The reduction in mass that has to be moved makes it easier to increase the cutting speed without sacrificing the ability to faithfully reproduce the detailed shapes of the stencil apertures.

In each design it is very important that X and Y-axes move perpendicularly to each other and that both move in a perfectly straight line (see fig 1). And of course the movement system has to be perfectly calibrated to assure control over the amount of movement to within a few micrometers.

Most laser systems advertise location precision of 5-10um over a given distance.

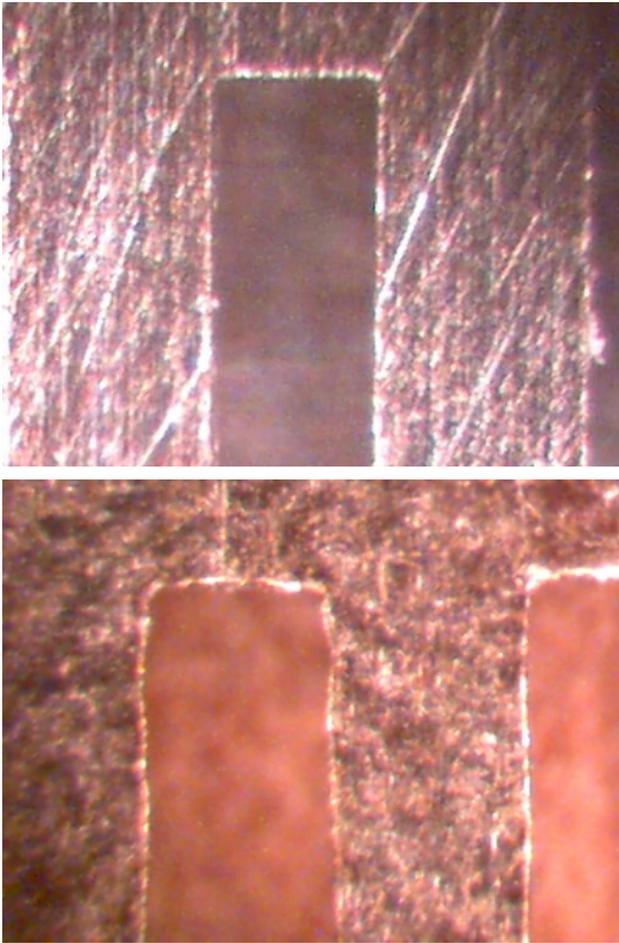


Fig 1: Stencil cut using a laser cutting system with stable and non-stable positioning system.

METAL

The metal used for laser cutting has typically been stainless steel, type 302 or type 304, produced in a rolling mill. The resulting sheets are very uniform in thickness, but the specified thickness can typically vary by about 12 μm (0.5 mil). In order to improve paste release a number of post-processes have been tried, for example electro-polishing or chem-polishing, but not always resulting in improvements. Other metals are now being introduced like nickel sheets and very fine grain stainless steels. Especially these last ones have shown to bring significant improvements in the printing process. [Ref #2]

ELECTRO FORMING

Stencils made using the electro-forming (EF) process consist of pure nickel. The EF process starts with a film which represents the aperture pattern to be manufactured. Making the film introduces additional process steps with their inherent possibility of errors as the film material is both temperature and moisture sensitive. The film image is transferred in a photo process to a mandrel on which a metal layer is grown in an electro-chemical process. To get a uniform thickness stencil requires that the chemical actions in the bath are exactly the same over the full area of the stencil. This may at times be difficult, especially when the

aperture density varies greatly. Also the growth of the metal immediately around an aperture can be faster resulting in a small ridge or “dam” around the aperture. This dam has been used as a seal between the stencil and the pad on the board. However, if this dam is not exactly aligned with the pad or it gets damaged, paste can leak through, which may result in solder balls.

The process also has to be well controlled so that it can be stopped at the proper moment when the sheet has grown to the desired thickness. After that it has to be “peeled” of the mandrel without causing any damage to the sheet and then mounted in a frame.

TENSION

When sheets are laser cut, they are typically clamped and tensioned in one direction or they are cut already mounted in a frame.

If the sheets are mounted in the frame after cutting, the tension in both X and Y directions will often differ from the tension during cutting.

The same, but more so, is true for stencils made with the electro-forming process.

A stainless steel 125 μm (5 mil) stencil manufactured without any stress on the metal and then placed in a frame exerting a stress of 35 Newton/cm (common mesh tension) sees a strain (percentage change in length) of 0.0131%. For a stencil image (or panel image) where apertures are 0.5 m (20 inch) apart, this can cause an error of up to 65 μm (2.5 mil)

TEMPERATURE

Most stencil manufacturers produce stencils in air-conditioned rooms where the temperature is about 20° C (68° F). In non-air-conditioned, small rooms the temperature can easily vary by 5° C (9° F) or more. Similar variations can exist at the location where the stencils are being used. The coefficient of thermal expansion of steel is approximately 17 and of nickel 13 ppm/degree C. This number indicates the expansion or contraction of the metal in μm per meter for each degree C. If we have a stencil image (or panel image) where apertures are 0.5 m (20 inch) apart and the temperature difference between fabricating the stencil and using the stencil is 5° C, the change in dimension in a steel stencil can be 42 μm (1.7 mil). For a nickel stencil it would be about 32 μm (1.3 mil).

While laser cutting, the hot beam can cause a local temperature rise in the metal which can lead to discoloration (innocent) or even deformation through local expansion of the metal (troublesome). Proper control of the beam and cooling of the metal (airflow or liquid cooling) can minimize this problem.

IMPACTS ON USE

For newer components, such as CSP-s and very small passive components, the space between pads on the board can be less than 200 μm (8 mils)

To prevent significant errors as described above, it is imperative to employ the best stencil manufacturing equipment and practices possible. That also means working in a controlled environment, both at the stencil manufacturer and user locations. To prevent errors due to possible tension differences it is desirable to cut the stencil while mounted in the frame. In short, as a stencil user it is becoming necessary to know what equipment and what process is being used and what checks are being made by the stencil manufacturer.

Figure 2 shows an example of one stencil cut from a sheet and then mounted and another cut in the frame on the same laser. A definite change in the error trend can be observed.

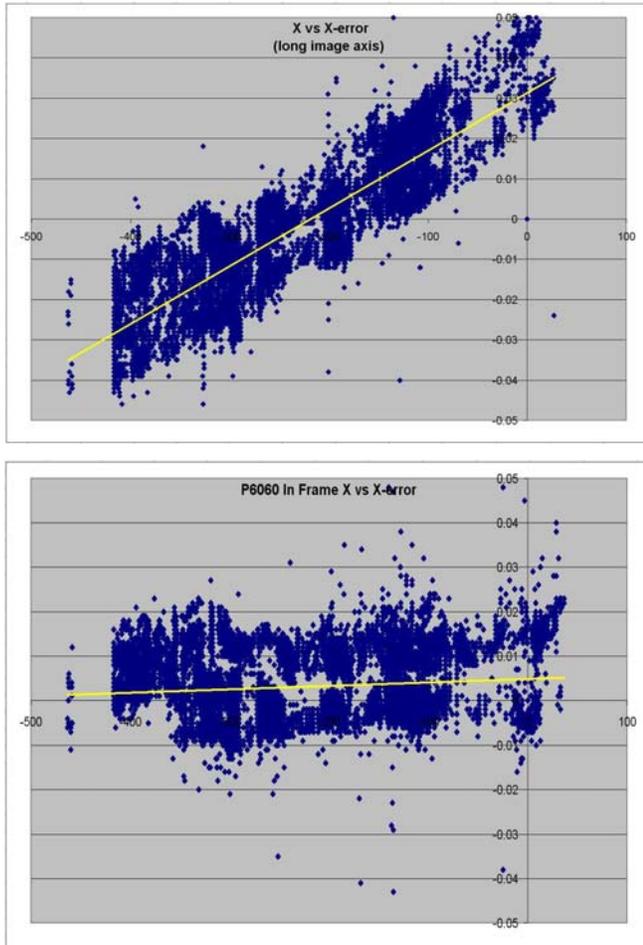


Fig 2. Stencil cut as loose sheet (top) vs. cut in frame (bottom)

STENCIL VERIFICATION

The simplest way to determine the precision of a stencil is to scan it and determine the location and size of each aperture. Systems are available allowing such a test to be made with high accuracy ($\pm 5 \mu\text{m}$ or 0.2 mil) within a few minutes. A computer program can determine the centroid and size of each of the scanned apertures and compare those to the original design. The resulting data can be used for an easy go-no-go determination or used to perform a statistical analysis.

The scanned, new, laser cut stencil may have remaining loose particulate in some of the apertures. This interferes with the centroid and area calculation but can easily be recognized and therefore excluded from the results. (see fig. 3)

A large stencil (about 460 mm x 300mm / 18" x 12") with about 21,000 apertures has been selected for these tests.

These stencils have been measured using a well calibrated scanner (ScanCheck) with a resolution of 6,000 pixels per inch (12,000 with interpolation). The resulting numbers are then compared to the cutting data and errors beyond a given specification are presented. All data that has been collected can be exported for further analysis, as is done in this report. For this analysis only the location errors along the long stencil axis have been used.

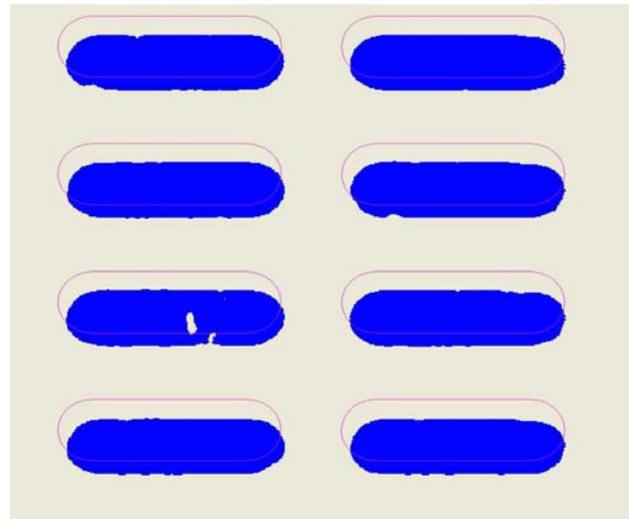


Fig 3. Apertures with some debris.

COMPARATIVE MEASUREMENTS

A number of stencils have been produced using different methods, machines and processes. These stencils were produced using the commonly available laser cutting and electro forming production methods. Four different laser system brands for a total of seven different types of machines were selected. Of these stencils five have been produced both as sheets and in a frame and two are only cut in a frame for a total of thirteen laser cut and one electroformed stencils.

The stencils were produced in several different commercial facilities and the environmental conditions were not recorded, therefore a temperature effect can not be established separately from the machine accuracy and tension effects.

A specification of $\pm 10 \mu\text{m}$ was used and for each stencil the extent and the distribution of the location errors was calculated. This above mentioned specification limit is a commonly used value for allowable tolerance by many large EMS companies. The value of C_p indicates how often this distribution of the data fits between the specification limits.

(see fig. 4). For these very large and complicated stencils only one showed a Cp value greater than 1 (see fig. 5). In the individual graphs the short green bars represent the three sigma limits. At those points the error rate is 2,750 ppm. Of course more desirable would be using Six Sigma where the error rate would be only 0.002 ppm.

As the stencil can be shifted and aligned to the board in the printer, the Cpk value, which uses the worst half of the distribution and the deviation of the mean from the center of the specification, has not been determined.

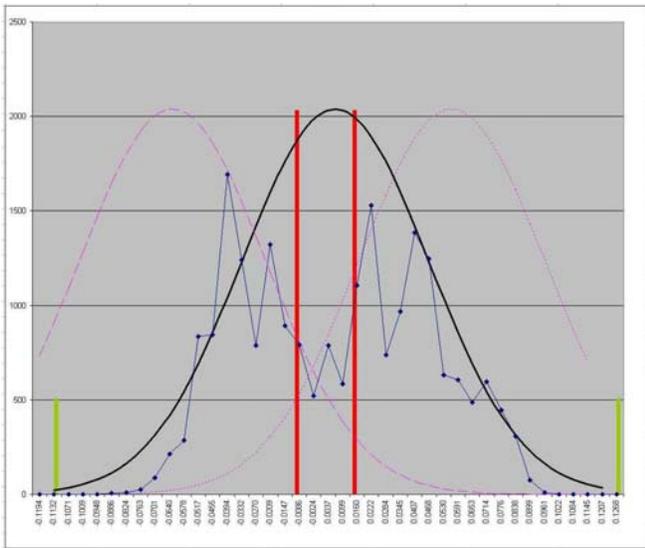
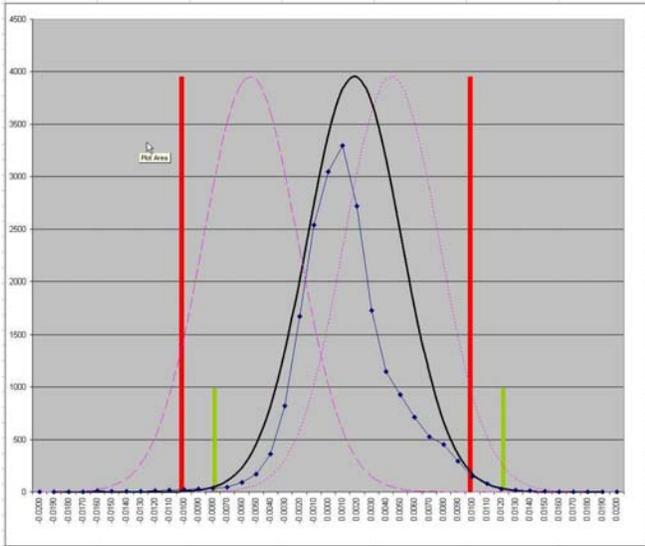


Fig. 4 Sample bell curve surrounding measured data. Red vertical bars show spec limits of +/- 10um.

RESULTS

The resulting Cp values for the whole group of stencils are shown in fig 5.

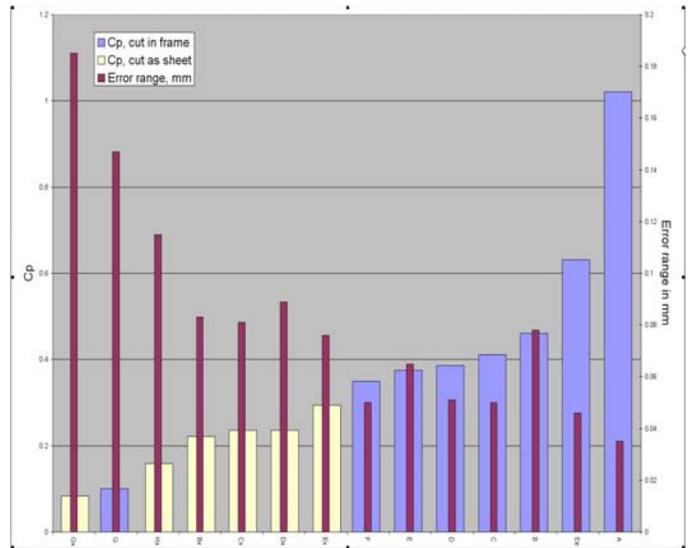


Fig. 5 Analysis of measurements.

The yellow bars show the Cp values for the stencils that were cut as loose sheets and the blue bars show the range for the stencils cut in the frame. For the measured apertures we see an error range (brown bars) varying from 35 to 185 μm (1.4 to 7.3 mil).

The data shows a noticeable grouping based on the chosen manufacturing techniques. In general stencils that are cut in a mounted frame show significantly higher aperture positional accuracy then stencils that were cut as loose sheets and subsequently mounted into a frame.

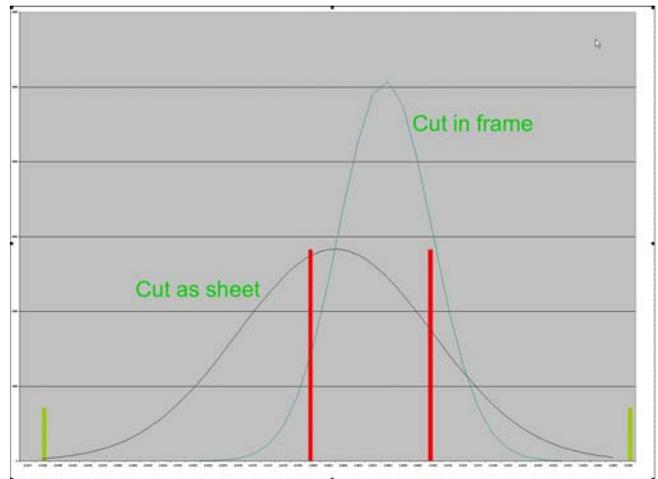


Fig. 6 Cutting in frame vs. cutting as loose sheet.

In fig. 6 the distribution of the data for a stencil cut in the frame and as a sheet using the same laser is shown. The noticeable change in the spread of the data shows the result of the change in tension between while cutting the stencil versus the tension after the stencil has been mounted in a frame.

Another factor for the change in positional accuracy is the choice of laser cutting system. In general we can observe that most newer generation systems (less than 3 years old) provide a higher positional accuracy compared to the older systems (3-15 years old). However even among new laser systems we can observe significant difference in aperture positioning accuracy between different laser systems. These differences are probably related to system architecture and calibration methods used. Fig. 7 shows the change in the spread of the data for two stencils cut in the frame on two different laser systems.

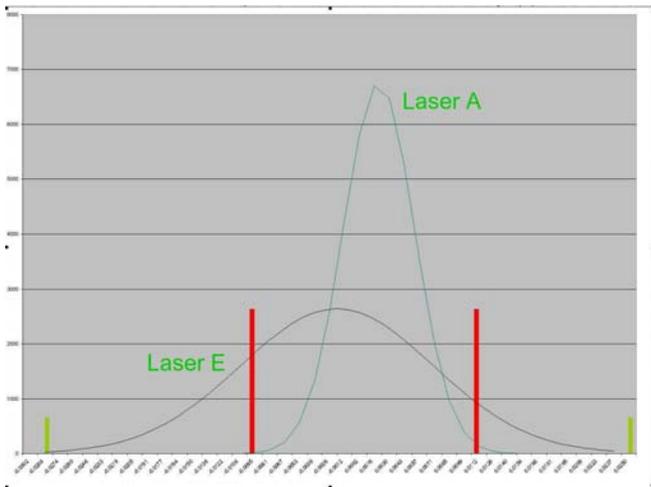


Fig. 7 Identical stencils cut on two different modern laser systems.

CONCLUSION

When printing on a board with components which have large pads and large spaces between pads, a significant alignment error between the stencil apertures and board pads may not cause serious issues. It is like a form of overprinting and many solders, in their molten state, will wick back onto the pad.

However, many of today's boards have tiny parts with very small and closely spaced pads where such errors might cause bridging. On top of that, today's lead-free solder does not spread as well as lead containing solders.

Therefore the size of the errors encountered in several of these stencil samples will lead to production errors at an unacceptable level.

For a stencil with optimum aperture positioning accuracy we can conclude that it is critical to choose the best manufacturing method based on three main factors: 1. Laser cutting shows better results than photo based processes, 2. Stencils cut in a frame show very little distortion and 3. Stencils cut on modern lasers showed significantly better positioning accuracy.

Note that additional printing errors can come from among others low mesh tension, inadequate squeegee pressure or insufficient board support.

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REFERENCES

[1] *Ahne Oosterhof, et al*, "Stencil cutting", *Industrial Laser Solutions*, June 2007.

[2] *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.