How Stencil Manufacturing Methods Impact Precision and Accuracy

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1. Happy Tuesday everyone, and welcome to today's webinar, "How Stencil Manufacturing Methods Impact Precision and Accuracy." Our presentation is based on the white paper written by Ahne Oosterhof, Oosterhof Consulting, & Stephan Schmidt, President of LPKF Laser & Electronics North America.

2. Live from LPKF studios in Portland, Oregon we have presenting today the esteemed Mr. Oosterhof himself, with me, Shane Stafford, playing the humble role of host. And I would like to thank everyone for attending today.

3. If you have any questions throughout the webinar, for either Ahne or myself, go ahead and submit them via the Questions Submit Form as seen here on your screen. I will be monitoring questions throughout the webinar and will field them during the end of the presentation. Well, let's go ahead and get started.

4. So, there is an old phrase that you can see from the old photograph: "I can make a bad stencil on any laser and a good stencil only on some lasers." So, that can bring a lot of things to mine: "What is a good stencil?", "How do you know if you have created a bad stencil?", or even "Do you know how well your suppliers process and methods work?" So with that, I would like to propose to you a quick poll:

5. "Which of these factors do you think is the most important in manufacturing a "good" stencil?"

6. So, I think you'll see on your screen here a poll and you can select your choice. So, there are your results right now on the screen and from here I'm going to hand it off to Ahne. So, Ahne, what do you think of these results? Number one is 40% - correct aperture location and that I fully agree with. The paste regardless how much has to land on the pad where you want it. The next one is good paste release. The poll is very close to what I would say. So we do agree on that particular aspect of stencil pads used for stencils and printing. So, let's talk a little bit about how to get a good stencil pad used for stencils and printing

6. The process to make stencils depends a lot on the machines they use, how you use the machines in the processes, the manpower that is implementing all these and the materials that are being used to make a stencil. And then some very specific items we'll be discussing are: temperature differences that happen during processes and the change in tension in the materials.

7. Topics that we'll be discussing: little bit of the history of stencil technologies, then we'll take look at the most prevalent processes that are in use today, I've already mentioned the effects of tension and temperature on the stencil during the process and I will take a look at the number of stencils that I have acquired to put some actual numbers on these questions of quality.

8. So, originally, stencils were being used to solder paste. Silk screens were being used. And as the apertures and the amounts of paste went down in size the little wires in the silk screen got in the way so that the other processes were necessary. So chemical etching was the first solution for that. When you chemically etch stencil from one side you end up with a very cup shaped aperture which was not desirable. The alternative to that was etching from both sides. When you etch from both sides you have to have a very tight control of process to prevent ending up with the ridge in the middle of the aperture which would hamper the release of the paste.

Further developments led to electroforming of stencils which is very nice process but it also has its negative aspects which we will find in the subsequent tests that we are running. In the early 90s laser cutting became the next process to be used and it has by now become the number one process that comes to making stencils. I will take a look at it a little bit more. The first one came to laser printing which was lasers which were lamp pumped and pulsing. We can see here the results of pulsed metal. In the middle you can see the flow pattern in there but when we look at the actual magnification this is quite acceptable stencil and it has worked for a long time, except that now the apertures get even smaller and the demands on paste release have been much more stringent.

12. The newest lasers that are being used are diode pumped fiber lasers and a big plus of those are very much higher frequency and pulsing which in a smaller beam size leads to smoother aperture walls which in turn get you better paste release.

13. Looking at the two processes, one the electroforming process, it starts with accepting the data from the customer, processing it, and producing a film. The film is then used to transfer the image onto the mandrel. After the image has been transferred the mandrel is put in the chemical bath and a nickel layer is being grown on the mandrel except for the little islands where you want an aperture. Once the thickness has been reached that you want the mandrel is removed from the bath and the layer of nickel is pilled after mandrel after which it is mounted on the frame.

14. The laser cutting process on the other hand is much shorter. You again process the data but immediately after processing it goes to the laser system. You cut the metal and depending on the machine you mount it in frame or the metal was already melted on the frame and it was cut in the frame, which has advantages which we will be discovering later.

15. So, the laser cutting process is really rather straightforward. You have the laser beam which is a collimated beam, which is guided to the laser head or is focused onto the metal into the very small spot which give you very high energy density together with very high pressure air flow the metal is being cut, the liquid metal is being blown away and you end up with nice apertures.

16. Going back a little just to understand this pulsing of the laser imagine that you have a laser beam being pulsed rather slowly you move the metal around it and it may look like postage stamp almost, corner of which you can see at the picture. Of course, no laser was ever used to get this bad result. The next step is you can compare to perforated paper, laser cut paper, which you can see next to it and you can still see the scalloping that relatively speaking looks like your original lasers where you still could see a little bit of the scalloping in the metal. The next step was the diode pumped fiber lasers with much higher frequencies and smaller beam and now the bottom line shows no hardly any scalloping at all. A knife like edge.

17. Little improvements in the laser system: the original machines had a stationary laser and a table with the metal on it was moved below the laser to form the individual apertures. The improvement on that was to have a laser with metal and it was moved in one axis and the laser head was moved in the other axis. The result is that your moving is less mass and it becomes easier to move the laser head. With the reduction in mass you can improve the acceleration and deceleration and thereby increase the cutting speed.

19. The newest laser the table is stationary while the laser head is moved, so this is a minimum amount of mass and allows maximum acceleration-deceleration and cutting speed. So, here we have a one of the most modern lasers. It

shows the machine which is much simpler to operate, it gives you the high speeds, and we also see that it gives you higher precision in the location of the apertures.

20. This is what the machine looks like at the laser head, and we can even make it move this time. So, metal is stationary, laser head does all the movements.

21. So, what makes these machines better? What is required for the good laser? First of all the beam has to be small and stable. The laser beam is like a miniature tool, and the larger the tool the larger the curve that you are cutting in the metal. It also means that corners are more rounded of a square aperture. And when the beam is not stable and fluctuates in size the curve changes in width and you end up with irregularly shaped apertures. The other part is the moving mechanism of the machine moving either in the older machines the metal, or in the newer machines the laser head. It has to be very stable and predictable and you have to have close control, tight control of the amount of movements and how far it moves.

22. There is an example (the bad example and the good example) of what you can do with the laser. On the first picture you can see that the walls are irregular, not straight while on the second picture the walls are straight and the corners are nice and square.

23. Talking about the tension in the middle. In the older machines it was normal to cut the stencil out of a sheet of metal and then mount it. In the machine that metal was tensioned in one direction only. After it got mounted in the frame the tension was significantly different. And now the tension is applied in both directions. The need for a tension is to keep the metal flat while you are printing. But the tension also stretches the metal and with the chance that wears potentially seeing from 0 to 35 N/cm and elongation over 50 cm in stencil can be as high as 65 micrometers or 2,5 mil. In the older applications, older circuit boards, 2,5 mil was not an unacceptable amount (not desirable, of course) but in today's processes 2,5 mil become significant. So, if the stencil is cut in the frame there is no chance in tension and no elongation after the stencil has been cut.

24. When I measure the aperture locations in the very large stencil you can see that in the middle of the slanted graph the apertures are close to what they are supposed to be. But on the edges they are significantly away from this angle. When the stencil is cut in the frame all the apertures are near where they are supposed to be located. These stencils (that are used in this test) were purchased from the different companies, cut on different machines, some were cut in the frame, some were cut as a sheet. They were ordered just like anybody would order the stencil without implying any particular goal on how this stencil was going to be used, other than we are going to print it on the very large circuit board. This particular circuit board is almost 50 cm in one direction, so it is not a very common board but at the same time small boards are made in panels, so again having a large panel is very common. So, this elongation over 50 cm distance can be significant for small boards in the panel or for large board as I had been using in these tests.

25. The other aspect, as I mentioned before, is the temperature. If the stencil is cut in a room with other machines and the machines heat up the room a little bit more than normal, let's say the temperature is going to be 25◦ C, but is used in the nice air conditioned room when you are printing the stencil, say 20◦ C, this 5◦ seems insignificant but when you look at the coefficient of thermal expansion of the material either steel in most sense labs' laser cut stencils or nickel in electroformed stencils you can calculate elongation over that distance of 42 µm in steel and 32 µm in nickel stencil. In itself these numbers are not very significant but when they all get added up they become very significant.

26. So, first of all, even the most modern laser has some tolerance. The best ones – 4 µm, the tension variations that we discussed can give you variations of up to 65 µm and the temperature can add another 42 µm and when you add it all up you are well over 4 mil just from this kind of errors, over 100 µm. So, with today's tight tolerances or small apertures, small pads on the circuit boards closely located and near each other the formula error can become significant. So, when you see the stencil how do we know it is manufactured correctly before you use it and discover that it doesn't work very well?

27. The way I've been doing it is using a large flatbed scanner where all stencils fits on and in the few minutes all the apertures have been measured and the size and location have been calculated and compared to the design goal.

28. So, we can look at this particular image that it is not easy to see. The blue areas represent the light that is shining through the stencil and received by the cameras and then converted to series of pixels. Green line around it is the design goal. So, this particular area of the stencil looks like to be very good. The light that comes through the stencil illuminates the pixels and computer calculates from the number of pixels the area of the stencil and we can compare it to the design goal. And it can also calculate the center of the aperture and again compare that to design goal. So, I know the deviation from the necessary location of the aperture.

29. Some problems that sometimes show up the bringing of the aperture can impact the calculations and skew the results.

30. But I can take a look at the data and see that in this particular aperture one side has maybe a hair or something like that in the aperture. From the shape I can conclude that this is not a laser problem. It is a system problem when I measure. And it will cause the centroid of the calculated centroid of the aperture to be off. In the data presentation at the bottom of this picture I can sequence the errors and then visually exclude errors like being shown in this particular image. The remainder I use for further analysis if necessary.

31. The jagged line with the dots in it are the measured results for the location of each of the apertures. And my computer program can add a bell curve and for this particular test I established the spec limits of plus or minus 10 µm. So, I'd like to see all the apertures to be within 10 µm of where they should be. This particular stencil shows that almost all these apertures are within the spec limits, which means I have the Cp that is greater than one. If the distribution is wider Cp goes down and it means that more apertures are outside the spec limits then I'd like. Also if the curve shifts away from the center of the spec bands the Cp goes down. Most of these changes tell me something about the manufacturing of the stencil. If the Cp width of the spread of aperture locations is wider than the spec bands it typically means that the machine is not as good as it should be, the laser system itself, either the movement mechanism or some other factor in the machine is not optimum. If the Cp goes down meaning width of the bell-curve shifts away from center, most often it is operator problem, manpower problem. The data may not be prepared properly or the machine has not been set up correctly.

32. Here are some examples of different stencils. The first image shows the stencil cut in the frame and the stencil cut as an individual sheet. And you can see the spec band for the stencil that is cut in the frame is significantly narrower giving you a better sense on. The second image shows again the same stencils but now they are cut on different lasers. The same kind of a problem occurs with one laser gives you a good result and the other the variation in location is much higher.

33. After doing all these measurements and analysis for all stencils I can combine them and show you the huge variation in quality depending on how these stencils are manufactured. The wide bars show the Cp or the width of the distribution in aperture locations. The blue ones are stencils that were cut in the frame, the yellow ones are stencils cut on individual sheets of metal and then mounted in the frame. The blue one, the best one has a Cp that is greater than one which means its distribution is well within the spec band of plus or minus 10 µm and it is many times better than the worst one of these stencils. The brown narrow bars are the error range that I observed expressed in mm. And we can look the worst stencil and its errors that are close to 7 mil. In today's circuit boards a 7 mil error in printing location leads absolutely to problems. You'll have shorts and opens both due to printing disorder next to the pads, some of the pads instead of on the pads.

34. After the paste has been printed you also like to note that you get the right amount of paste and from the previous presentation I can show here the light blue line is the typical stainless steel stencil as was used. And the yellow line is the rule of thumb for area ratio acceptable area ratio. Area ratio is the ratio of the pad aperture as seen through the aperture in the stencil, the pad size over the wall size of the aperture. The pad essentially sucks the material, actually the paste material out of the aperture. The walls are the source of friction and the friction tries to keep the paste in the aperture. When the ratio between those two reaches .67, approximately .67, you can expect reasonable amount of paste release. So when you extend intersection of light blue line and yellow line to the left you can see that best results are the red line, and that intersection gets you an allowable aperture ratio around. 5. So, a significant improvement is obtained. This is the result, this particular test shows different materials and different paste that being used to discover which one gives you most paste release and, of course, from the previous information get it in the right location.

35. So, we mentioned that to get highly précised stencil you need absolute equipment, the machines that you are using have to be the right ones and have to be well maintained and the process has to be executed correctly. Changes of tension in the material and changes in temperature, cutting loose leaf v. cutting in frame again give you significant differences in quality of the stencil. So the conclusion is that the best stencil that you can obtain is cut with the proper machines in the frame. The second conclusion that comes right after that is if you want to know that you get one of the best stencils possible you have to know your vendor and you have to know how and what he is doing when he is cutting his stencil.

36. Thank you very much Ahne, you're very smart and that was a very thorough analysis. I am wondering if anyone has some questions in our audience today which had not been submitted yet during the presentation. Ok, thanks for the questions. In regards to whether a copy the presentation is available, we'll have a recorded copy of the presentation online in a day or two. And you can also download from the URL you have on your screen, the copy of the whitepaper which this is based on. We had a question from Louis H. He wanted to know: "When stencil is cut in the frame does it have to remain in that frame?" Ahne, why don't you tackle this? The most common way to obtain stencils is it can be glued in the frame and to remove them from it is not easy and it can be done and remounted if necessary. The other part is some reusable frames are available. And there the stencil should be cut in one of those reusable frames. It can be shipped without a frame and then mounted again in the frame. And I have tested that particular process and the changes in location accuracy are minimal as long as it is mounted in the similar frame with the

similar air pressure. Alright, thanks. Pretty much covers that. So, I just want to follow up if anyone else has any questions. So, we have another question coming from Sean. In our experience when we have a high aperture account and cut in the frame we have a high release in the foils. Any thoughts of this? I don't know how you have determined that my experience that once the stencil is mounted in the frame glued onto a mesh it is very difficult to measure the tension in the mesh afterwards. I have not seen very good methods to determine the tension but theoretically when the tension decreases there will be a chance elongation of the metal. So, the small chance in aperture location should be expected at that point. OK, again thank you Ahne and everyone who attended. If you have any more questions contact us or you can download the whitepaper which has some more info from the URL shown. On behalf of everyone here at LPKF North America, I wish you a good rest of the week and a fun filled, safe Memorial Day weekend. Thanks again.