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Establishing a Precision Stencil Printing Process for Miniaturized Electronics Assembly

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Abstract

The advent of miniaturized electronics for mobile phones and other portable devices has required the assembly of smaller and smaller components. Currently 01005 passives and 0.3 mm CSPs are some of the components that must be assembled to enable these portable electronic devices. It is widely accepted that about 65% of all end of the line defects occur in the stencil printing process. Given all of the above, it is critical that a precision stencil printing process be developed to support miniaturized electronic assembly.

This paper is a summary of a significant amount of experimental data and process optimization techniques that were employed to establish a precision SMT printing process. Our results indicate that the industry standard stencil aperture area ratio requirement of > 0.66 is an excellent rule of thumb. However, by optimizing printer setup with vacuum support, foil-less clamps, squeegee edge guards etc and assuring cleanliness and squeegee and stencil quality, we have been able to obtain acceptable stencil printing results with area ratios of 0.5 with Type III solder pastes. The work that was performed to achieve these results will be discussed in detail in the paper.

Introduction

One of the most important approaches to characterize a stencil printing process is measuring the level of variation in transfer efficiency. Even a small deposit of solder paste can form a solder joint. However, variation in the amount of adjacent deposits for a single component will inevitably alter uniform shapes and sizes of adjacent solder joints. Assembly line defects occur with such excessive variation in solder paste deposits.

As we look back on a global electronics industry trend to increase circuit density, major improvement factors for solder paste transfer efficiency have come from **tooling** and **process control**. These improvement factors can be recognized in SMT PCB assembly transitions during the 1990s, and most significantly since 2000. For examples, we can cite technology transitions such as: fine pitch, ultra fine pitch, no-clean paste, BGA assembly, lead-free, 0.5 mm pitches CSP, etc. During each transition, new assembly line practices fashioned improvement through better tooling and increased process control. Consequently, success with 0.3 mm pitch assembly necessarily should be expected to include innovative DFM for tooling (stencils/squeegees) and re-training for process control.[1] As OEM management guides pad design changes for new printed circuit board designs, the assembly process engineers must observe **key elements** about specifically how assembly tooling and process control will be challenged by the 0.3 mm pitch design.

Importantly, circuit board assembly management should expect a demand for tooling and process control change. In the transcendence to 0.3 mm pitch assembly, there will be a need to throw off many common process control freedoms and come to know the 0.3 mm pitch process through insight and experience. The rapid pace of this latest technology change will now create another new fashion for miniaturized electronics assembly. With transcendence to 01005 and 0.3 mm pitch assembly will come much renewed emphasis on further perfecting one's stencil printing process.

Discussion of Methodology

This paper provides a summary of projected process development demands for examining a precision ultra fine pitch stencil printing process. We will examine stencil printing by considering various paste print trial measurement results. The measurement data are actual results of application experiments done as case studies for solder paste customers. In most case studies there are several considerations, but always there is the desired goal for achieving a low level of variation in the transfer efficiency. Typically there are at least two paste products to be compared, a paste product used in current production, and candidate (experimental) paste products. A strategy for experimental paste product print trials begins by first understanding a current paste product's level of variation in transfer efficiency and then following a plan to systematically examine various experimental paste product prints until the set goal (low variation) is reached.

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[1] Steudel, H. J., and Desruelle P., "Product Design and Development," Manufacturing in the Nineties, 1992, Van Nostrand Reinhold, pp. 80-84.

The data from paste print trial experiments will provide the opportunity to quantitatively observe factors that contribute to the final yield of the assembly process. Among these factors is the stencil selection. There is a subtle assumption that the reader of this paper is cognizant of the importance of an area ratio sensitivity analysis in improving print performance.[2] While a case study focused on miniaturization will concentrate efforts for smaller aperture openings, selection of the test vehicle and analysis of print data typically include a broad examination on a range of aperture sizes and pad designs. There exists a major challenge to control the assembly process conditions during print trials. However, subsequent quantitative reporting approaches of the findings (in addition a significant challenge) will also be shown. The aperture sizes and pads will range from 6-40 combinations. These print trial examinations aim at process development of miniaturized electronics assembly. Data collection, tabulation, analysis and reporting will include the results of variation in transfer efficiency not only from the multiple combinations, but also the changes in the variation for various tooling and process attributes. All of this emphasis on further perfecting the stencil printing process includes using statistical tools for quality planning and analysis. Juran and Gyrna offer a well-written book on treatment of statistical and technological activities related to analysis techniques.[3]

The first step before any report of print performance is prepared is to establish measurement assurance that the variation in transfer efficiency is acceptable for decision making. This step demands a thorough evaluation of the measurement system. For the case study examples in this paper, automated solder paste inspection equipment is programmed for each test board and each test stencil. The inspection program is then tested by collecting paste measurement data on the same printed board 32 times. The results for each and every stencil aperture and board pad are individually examined statistically to characterize precisely how much variation exists in the paste measurement system. This variation is later summarized for different deposit sizes and shapes, but the repeatability of every individual aperture/pad combination gets observed. The relationship between the measurement precision and the paste deposit tolerance are expressed as a precision/tolerance ratio (P/T ratio)[4] for every aperture in the stencil. The measurement system is routinely re-checked to establish its stability over time. Copies of the measurement assurance study are available with every case study. It should be noted that repeatability results from the measurement system are excellent for every shape and size. The exercise is tedious, but the overwhelming assurance of measurement acceptability gives credibility to ensuing decision-making.

Among the tools for quality planning and analysis, it appears essential to use those which visually present data in figures (graphs). The data must be formatted in carefully planned tables. The second step in preparation for a paste print trial is listing the key control attributes during the printing activity. Typically these include identification of the stencil, the squeegee, board support, print speed, print pressure, separation conditions, aperture count, squeegee overhang, inspection time, date, times, paste identification, alloy, powder size, metal %, room temperature, relative humidity, under screen cleaning setup/frequency, paste date of manufacture, paste lot #, and details of controlled pause times in the experimental procedure. At the conclusion of the print trial, the raw measurement data is immediately extracted from the paste inspection system so that a data table can be created in a statistical software program. Usually tabulation activity involves proper insertion of attribute columns that associate the control attributes to the measurement data so that each individual board data result can be distinguished. A standard file format for the columns in the data table allows for comparative analysis of the transfer efficiency among print trials. Attribute columns for individual stencil aperture size and shape are inserted, as well as, a column for area ratio of each aperture, and often a column with some designation to describe the pad design.

One of the subsidiary aims for using a visual presentation of the transfer efficiency variation will be to help anyone who sees printing process results to be able to both (a) simulate the experiment application (ultimately in a production setting), and (b) duplicate replicate figures (graphs and analysis) from similar transfer efficiency data collection. The critical parameter used to quantitatively confirm printing process results have been duplicated is the variation in transfer efficiency. The precision of the stencil printing process will be judged by the changes in variation of the transfer efficiency (for any of the combinations of aperture sizes and pad designs). Ultimately (in a production setting), any printing process will not be sufficiently precise, if variation increases and causes more assembly line defects to occur.

In this paper, box plots will be used to show variation in transfer efficiency. Box plots are an effective visual summary of the data.[5] Several approaches can be considered for axis settings on the box plots. Learning about transfer efficiency variation for a stencil thickness is important. In a 0.5 mm pitch stencil printing process, the box plots include specification limits on the axis settings. For example, 100% transfer efficiency is shown, suggesting that 100% transfer efficiency is a standard axis target for each aperture size and pad combination. When specification limits are set at 150% for the UCL and 50% at the

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[2] Anglin, C., “Improving print performance using area ratio sensitivity analysis,” Global SMT & Packaging, Vol. 8, No. 5, May 2008, pp. 16-20.

[3] Juran, J.M., and Gyrna, F.M, Quality Planning and Analysis, 1993 McGraw Hill.

[4] Speitel, K. F., “Measurement Assurance,” Handbook of Industrial Engineering, 1992, John Wiley & Sons, Inc., pp. 2246-2250.

[5] Juran, J.M., and Gyrna, F.M, Quality Planning and Analysis, 1993, McGraw Hill, pp. 193-194.

LCL, then the axis setting on each box plot figure will be conveniently standardized at 0-25-50-75-100-125-150%. In this manner, it becomes readily easy to see how closely transfer efficiency data surrounds the (100%) target value.

Placing a standard deviation chart below the box plot will help the reader gain insight about the level of transfer efficiency variation in the box plot. A good print has a standard variation less than 10%.[6] The axis setting on the standard deviation chart will be standardized at 0-10-20%. Observations of standard deviation below the (10%) mid-line will represent good print quality. Consistent observations below the (10%) mid-line will represent consistently good print quality. Changes in the observations will signal changes in the consistency of print quality. These consistencies or changes will show how significantly an attribute responds with changes in various tooling and process attributes, such as aperture area ratio, pad design, or print speed.

As sufficient insight about the character of print quality is gained for multiple tooling and processes, a precision stencil printing process may be established. The box plots and standard deviation charts can later be useful for determining that the ideal tooling and process has indeed been followed. Variation in the transfer efficiency that does match earlier print trials could indicate that the print operation is precisely under control.

Since it is expected that there will be a need to throw off many common process control freedoms, as we come to know the 0.3 mm pitch process we should expect incremental insight and experience with newly introduced product design. The message of some individual aperture variation may not necessarily signal the precision process needs further optimization. Clearly, the concept for comprehensively presenting visual variation of the stencil printing process for 40 aperture size and pad design combinations can help characterize the challenge. However, activity for comparing multiple trials suggests using multiple sets of 40 box plots and 40 standard deviation charts. The task of collecting all of this data and making all of these figures is daunting in itself, but trying to compare multiple sets of this many apertures becomes overwhelming.

For short-term decision-making using many data sets of 40 box plots would be prohibitive, but fortunately a short-cut method can put entire sets together on a single page. Consider that the (100%) target value of the axis setting on the box plots indicates the transfer efficiency data could have a 1:1 relationship with the variance. This is because the standard deviation is the square root of the variance. Consequently, good print quality will have a transfer efficiency variance value less than 100%. To compress the massive amount of information from multiple print trials, the variance-to-mean ratio (VMR) can be taken from the measurement data for each combination of aperture size and pad data design. There could then be a set of VMR values plotted on a line chart. Points on the line would represent the aperture size and pad design combination. Points that remain below 1.0 indicate that the print quality is good. An entire line below 1.0 will serve to visually indicate that the entire combination of apertures and pad designs has good print quality. Several lines on the VMR line chart can represent an alternate attribute in the process, for example, stencil separation conditions, room temperature, or under screen wiping. Entire VMR lines that remain close will show similar print quality. VMR lines or points on a VMR line that diverge can show precise differences in the stencil printing process.

At times the transfer efficiency specification limits may be unknown. An example shown is a 0.5 mm pitch process using a 5-mil stencil thickness. In a production setting, an adequate volume of paste is present from a 75-85% transfer efficiency on 305 µ (12 mil) circular apertures. The true target may not be 100% transfer efficiency implied in the box plot, but instead 75-85% with low variation. The VMR line charts will be used to show qualitative and quantitative differences. The actual volume, SPC specification limits, and other information remain important knowledge to clearly characterize the 0.5 mm pitch process. However, the VMR line chart technique for precision stencil print process comparison will show its benefits for characterizing attributes for smaller assembly designs.

Test vehicle (board) layout and stencil aperture design selection for miniaturized assembly can easily be judged to have both too much opportunity available, or too little. The test vehicle can contribute to excessive variation in transfer efficiency if it has also been designed for SIR, pin-in-paste, wave soldering, or large-scale components that require a stencil thickness greater than 4 mils. There is likely to be interaction variation from unnecessary printing features during the data collection process. The test vehicle dimensions should at least be similar to new product introduction designs with 01005 and 0.3 mm pitch components. The important consideration is to recognize not only attributes available on the test vehicle, but also those that may be unavailable. For example, determine the location of representative 0.3 mm pitch aperture sizes and pad dimensions on the test vehicle. Recognizing the opportunities available, as well as, the opportunities unavailable on the test vehicle can help in planning the method used to characterize the results. Showing variation data from an unrepresentative location of component pad features may differ from those that are in a dissimilar location because of inherent tooling and process.

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[6] IBM, "CBGA Surface Mount Assembly and Rework," User's Guide, May 23, 2002, p. 17.

The test vehicles used in case studies from which transfer efficiency data results are shown in this paper are from data collected using customer test vehicles. A common feature of customer test vehicles is to offer a range of pad sizes and spaces. In this manner, the aim for variation in transfer efficiency is to capture the acceptable process and tooling window from a range of sizes and shapes. Unacceptable variation results of the larger sizes (or small spaces) and the unacceptable results from the smaller sizes (or large spaces) could help determine the acceptable range of sizes in the middle, as measured by the variation in transfer efficiency. At this writing, none of the customer test vehicle designs comprehensively captures the range of design criteria suggested in Figure 16. Figure 16 shows conceivable design proposal alternatives for 0.3 mm pitch.

One final comment about the method for reporting variation in transfer efficiency is that the sequence of the apertures in the box plots will not be arbitrary, random, or alphanumerically ordered. Clearly, the sequential order of the test vehicles should remain in consecutive order. This will allow for changes of variation in transfer efficiency to be observed over time. The sequence of apertures will be presented in descending order by area ratio, but in groups. This can offer advantages that are similar to the visual effect of a Pareto[7] chart. The first group is often rectangular aperture shapes, the second group is typically square apertures, and a third group is circular apertures. Within each group, solder mask defined (SMD) pads are a separate sub group, followed by non-solder mask defined (NSMD) pads. The general idea is to begin with the larger volume apertures, and descend to the smaller volume aperture. Anyone reading a report of variation in transfer efficiency gets lead down a benchmark of acceptability until the smallest aperture attributes show otherwise.

As a customer comes to better know solder volume optimization, clear production limits on transfer efficiency can be specified. Mathematical models have revealed techniques for estimating the formation of soldered connections – optimal solder volume.[8] However, from paste print inspection, representative calculated Cp, Cpk and DPMO tables can be formed from actual transfer efficiency measurement data on paste deposits. These tables can be done specifying 150% as an UCL, and 50% as a LCL, and then later updated as production yield determines acceptable process tolerance for defects.

Stencil Printing Process Data – Results of Variation in Transfer Efficiency

The data and results are given here in visual format. These figures are actual results from the raw data collected during paste product print trials. The explanation of each figure is focused on the variation present in the data. The outliers are often most interesting because these data points will be the print deposits that simulate inevitable assembly defects.

Stencil printing for extremely small apertures using extremely thin stencils requires minimal squeegee pressure or stencil damage frequency will increase. Most noticeably, there may be coining of the board pattern on the stencil foil. The best transfer efficiency performance results when the paste bead is able to roll uniformly across the surface of the stencil. To minimize variation in the uniformity of the paste bead roll, each print trial begins with a carefully measured amount of paste. For a 200 mm squeegee length, the maximum bead size has a diameter less than the 13.4 mm. This is because the blade face below the holder is 15 mm, and the squeegee blade angle is 60º. Use of a 45º angle blade is avoided because the bead size would need to be smaller, risking contact with the blade holder, and forcing more frequent replenishment of the paste bead. Edge guards on the blade holder help maintain a uniform sized bead as the paste rolls and as the bead becomes depleted. From experience, the typical amount of paste for the correct bead diameter (< 13.4 mm) is found to weigh 130-135g. Stiffer squeegee blades have not resulted in good performance results, so a more flexible blade is used.

Squeegee blade wear is a difficult tooling maintenance situation. The more flexible blade does not appear to be worn as its use increases. However, the data will indicate that there is a difference between forward and reverse squeegee strokes when the blades have reached maturity. Figure 1 is a common observation for worn squeegee blades. The data in this print trial proved to be erroneous for supporting the purpose of the printing experiment. The amount of variation appears to increase as the print trial progressed. The blades can be replaced and the print trial must be redone. Replacing worn blades will immediately eliminate the noticeable difference between forward and reverse strokes.

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[7] Steudel, H. J., and Desruelle, P., “Problem Identification,” Manufacturing in the Nineties, 1992, Van Nostrand Reinhold, pp. 89-92.

[8] Racz, L., and Szekely, J, “Estimation of Solder Volume,” Handbook of Fine Pitch Surface Mount Technology, 1994, Van Nostrand Reinhold, pp. 267-307.

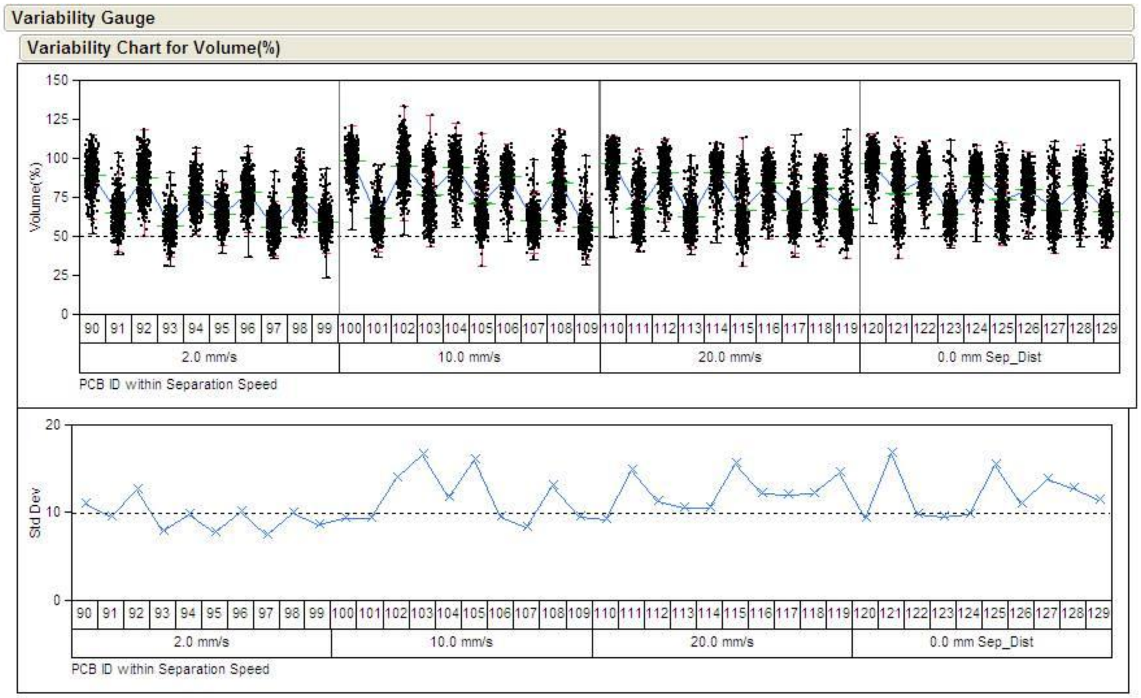

Figure 1. Squeegees Blade Wear Variability Chart

The results are from a circular aperture pattern with a 12 mil diameter. There are 54 x 15-pin arrays on each test vehicle. The minimum pitch is 0.5 mm. The stencil thickness is 5 mils. This is an area ratio of 0.60, which typically provides an average transfer efficiency of 85-92 %, with a standard deviation that is less than 10%. The signal for blade wear is (a) change in the transfer efficiency, (b) increase in variation, and (c) the difference between forward and reverse strokes.

The product design for miniaturized assembly focuses attention on the smallest apertures. Typically, concern about transfer efficiency of the smallest apertures is outliers that fall below 50%, resulting with insufficient paste and open joint defects. However, larger volume deposits will remain part of the print process, complicating the challenge. Outliers for rectangular shaped apertures will sometimes occur. They can be observed in the results of data collection in Figure 2. This print trial contains rectangular aperture patterns and pad sizes that are oriented both horizontally and vertically to the direction of the squeegee print stroke. The rectangular apertures are 2 sizes, 9 x 50 mils, and 8 x 50 mils. There is opportunity to observe both solder mask defined (SMD) and non-solder mask defined (NSMD) pad designs. Note that the preponderance of outliers above the mean transfer efficiency is with rectangular apertures that are oriented vertically to the squeegee stroke, as opposed to those oriented horizontally. Also note that the NSMD pad designs show the greater amount of excessive outliers.

Under a microscope, these outlier deposit observations are commonly called “dog ears”. The print trial is conducted to identify whether an alternate paste product may change the concern about the dog ears. The current paste product print trial includes several timed print activity pauses. It is observed that outliers below the average occur at the first print after a pause in printing for all rectangular apertures. The alternate paste shows no significant improvement during the initial phase, and a decision is made to continue use of the current paste product. The customer should recognize for miniaturized assembly product designs, this set of common observations can become useful by planning new product designs using SMD for rectangular pads.

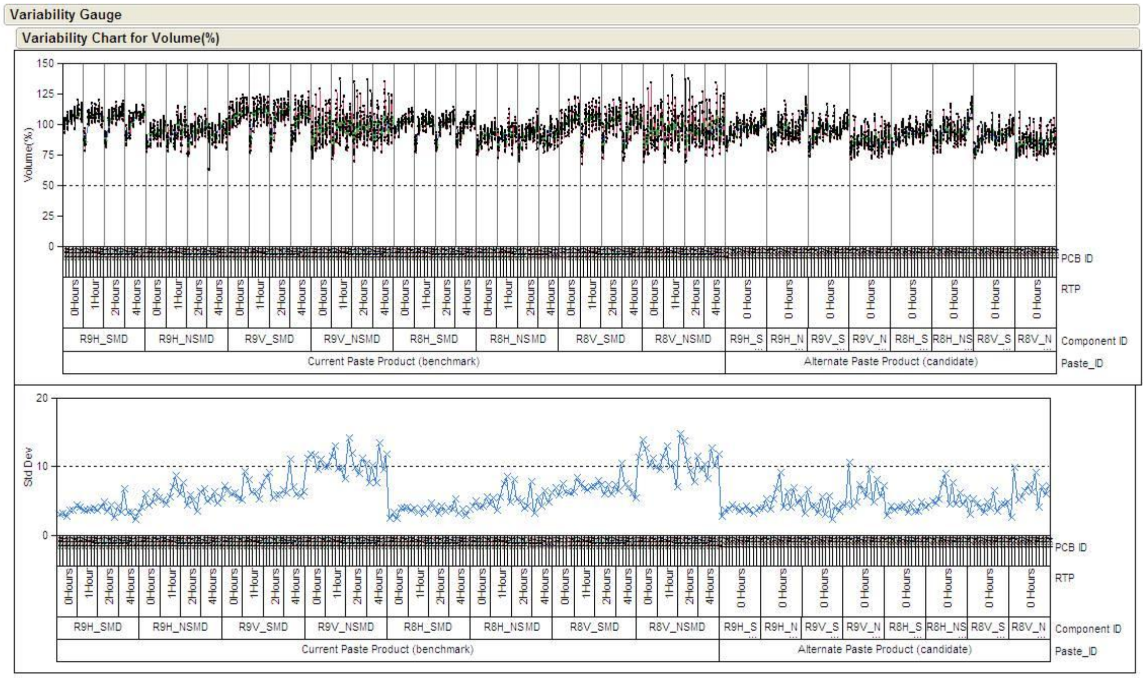

Figure 2 Rectangular Apertures - Dog Ear Outliers - 2 Paste Products

The results are from eight rectangular aperture patterns and pad design combinations. The rectangular apertures are 2 sizes, 9 x 50 mils, and 8 x 50 mils. Both solder mask defined (SMD) and non-solder mask defined (NSMD) pad designs are available. The orientation of the pads are both horizontally (H) and vertically (V) to the direction of the squeegee print stroke. The standard deviation of NSMD vertically oriented apertures appears unacceptable, but is often tolerated during actual production by accepting risk for increases in post-reflow rework activity.

Square apertures and circular apertures will have proportional area ratio for same-sized square sides and circle diameter. However, the volume of a square aperture is greater so while the transfer efficiency tends to be similar, more paste gets deposited using a square aperture. A common size square aperture and pad design pattern for both 0.4 and 0.5 mm pitch components is an 11 mil square. The small space between pads frequently results with a NSMD pad design. This situation presents a stencil printing challenge when there are pauses in the stencil printing activity. Figure 3 shows transfer efficiency results from six paste print trials. The first three trials are done using the same paste, but the print speed is varied. It can be observed that the slower print speed for the current paste product appears acceptable. During the trials with higher print speeds insufficient outliers occur. It appears that a higher print speed can result in greater opportunity for insufficient outliers, especially as the number of hour-long pauses increases. A new experimental paste is tried using the same print trial procedure, tooling and setup. The new paste product appears to withstand the test of timed pauses, and may even perform as well at the higher print speed as the current product performs at the slower print speed.

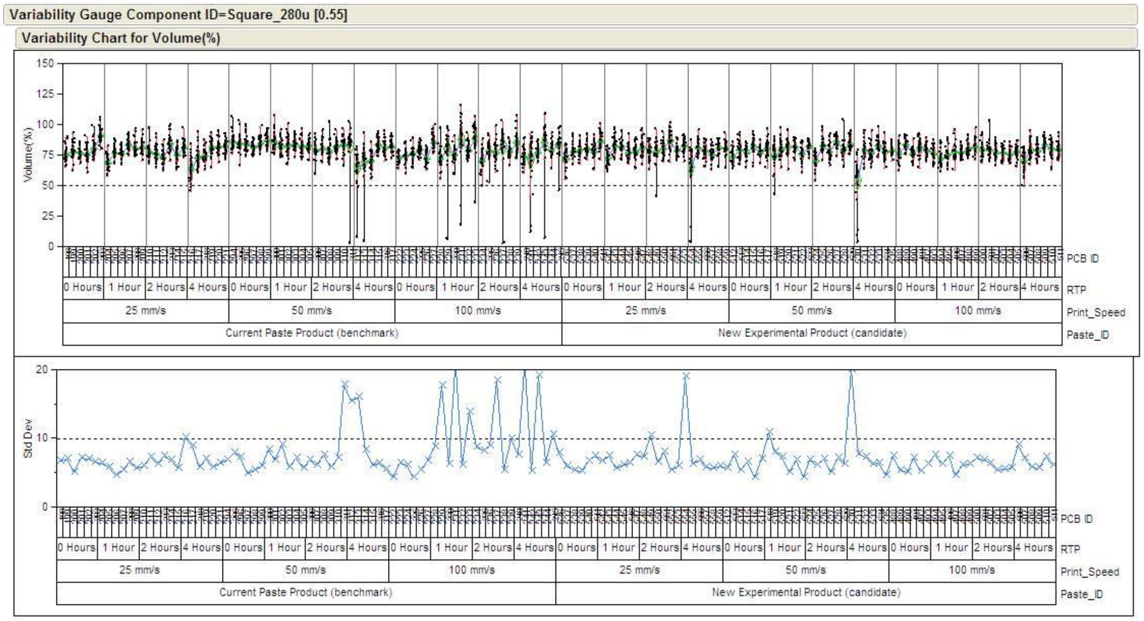

Figure 3 S11_NSMD Variability Chart - 2 Pastes - 3 Print Speeds

The results are for square apertures with 11 mil sides using a 5 mil stencil. The board pad is NSMD. The print speed can be slowed with the current paste to minimize insufficient outliers, or print speed may be increased in with a new candidate paste product.

Squeegee print pressure has been a difficult challenge in manufacturing settings. Often print pressure is increased to mask an unnoticed dilemma caused by general printer housekeeping, incorrect squeegee length, worn blades, improper support system, or a host of other process setup conditions. In a pristine stencil printing process setup, minimal squeegee pressure is required. Experimental results indicate that the interaction factor of squeegee pressure in a good setup is nearly nonexistent. However, maintaining a high print pressure will damage thinner stencils. The demand for area ratio increases to improve print transfer efficiency performance of miniaturized electronics assembly subsequently demands thinner stencils. Consequently, controlling minimal squeegee pressure will inevitably become necessary as customers experience production losses due to stencil damage (from excessive squeegee pressure).

As production control of squeegee pressure improves, production demand for high speed printing processes will be challenged. Higher print speed requires a higher print pressure in order to get a clean swipe across the surface of the stencil. A clean swipe helps control uniform paste roll and maximize transfer efficiency. The precision stencil printing process could be constrained by the challenge. New squeegee designs and innovative printer equipment capability could be a partial solution, but the demand for minimizing squeegee pressure is to be expected.

Figure 4 shows some results from print trials on four paste lots that have been done using a 4 mil stencil at a print speed of 100 mm/s. The print pressure is independently determined by the printer operator at the setup period for each print trial. The settings for the 200 mm squeegee length using this new experimental solder paste at 100 mm/s can range from 3.4 kg to 4.0 kg. The operator determines the minimum pressure by observing during setup whether a clean swipe and good paste roll are achieved. The paste bead has to be carefully measured so that it will not risk contact with the blade holder. For the setup for each lot, the trial starts with the operator using 130-135g of paste. The bead diameter will be kept uniform by edge guards, and it measures just below 13.4 mm.

The outcome of the results from this set of print trials is expected to help distinguish performance differences among the paste lots, to learn whether the transfer efficiency variation differs among paste lots. Nine aperture patterns and pad design combinations are presented. Clearly, the 0.56 area ratio apertures characteristically challenge the print process in all four lots. It can also be observed that 0.56 area ratio square apertures perform better than their circular counterparts. It is a tough call for the best referee. Another visual presentation from the same data is shown in Figure 5.

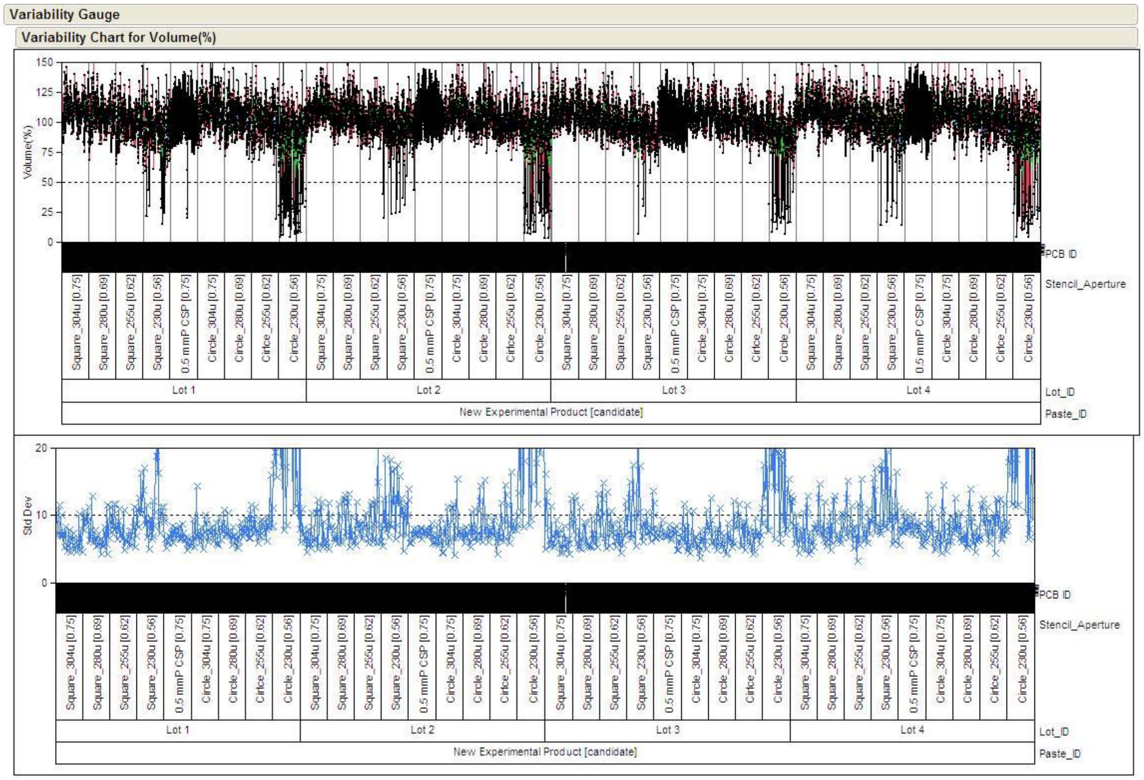

Figure 4 NSMD Variability Chart - 4 Lots - 100 mm/s

The variance-to-mean ratio (VMR) is calculated from the data for each aperture pattern and pad design from each print trial on the four lots of an experimental solder paste. It is important to note that a low VMR indicates better print performance in Figure 5. These values show in a concise format the precise performance differences among each paste lot. Clearly, paste lots #2 and #3 performed similarly, as did paste lots #1 and #4. Looking back at the box plots and standard deviation charts in Figure 4, it is easier now to distinguish the distinct differences among the lots. Additional information about the storage history of each sample will help a decision-maker understand whether its storage and handling history can have an impact on the product performance.

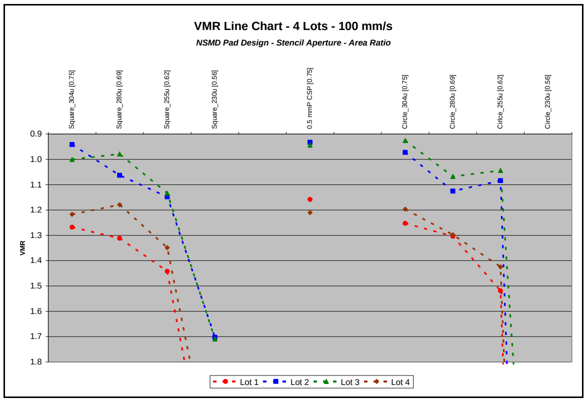

Figure 5 VMR Line Chart - 4 Lots - 100 mm/s

There exists a certain confidence among industry experts about the print performance with respect to solder mask design of the pad. These insights can assist with stencil aperture design modifications, allowing for even better production performance. Ironically, many experts have opposite views on the benefit of SMD versus NSMD. Data can be presented to support both sides of the same matter. Common attributes that filter into many of these SMD/NSMD situations is the board support and relative location of the pads under surveillance in the board layout. For example, rectangular pads with a definitively large area and aspect ratio may perform better using a NSMD pad design when positioned in the layout so that maximum support is provided beneath the sites. In another example, circular pads with an area ratio under 0.66 perform better using a SMD pad design when positioned away from the start of the print stroke, and given maximum support beneath the sites. Because each expert draws on case by case experience, it is difficult to reach any concrete conclusion.

Figure 6 shows results of circular and square apertures on both SMD and NSMD sites. The aperture distance away from the start of the print stroke varies considerably. Three squeegee speeds have been used in the print trial. Other attributes of the print setup have been tightly controlled. The area ratio using a 5 mil stencil is 0.60. It is not clear whether a significant difference exists, except that the NSMD circular apertures did show more outliers than the square apertures. This phenomenon supports a common observation trend. For miniaturized assembly, however, the increased density of the smaller sized pads will result with predominantly NSMD pads in the print process. Additionally, there will be small area ratio apertures. For this reason, insufficient outliers could become a significant concern with production yield rates.

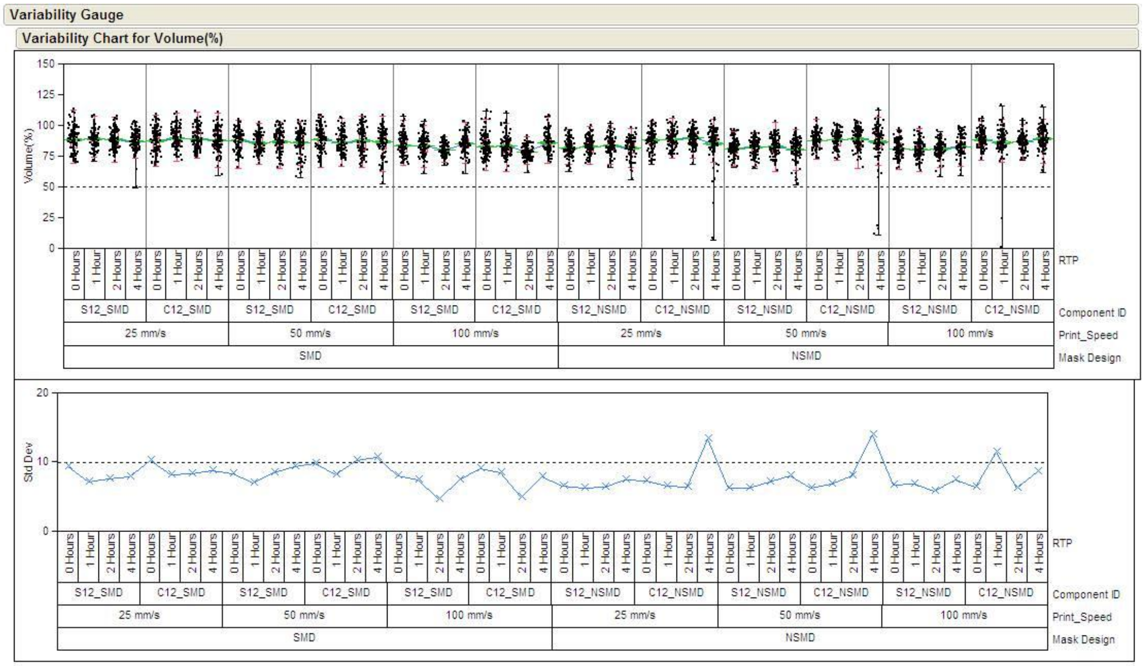

Figure 6 12 mil SMD and NSMD Variability Chart

A board support system for stencil printing can offer opportunity for variation in the print performance. Smaller features in the print process will dictate much tighter tolerance for the board support system. Paste print trial performance has shown improvement with routine housekeeping maintenance following and at the start of each print trial. Dedicated support fixtures are custom designed for every print test vehicle. These fixtures provide 100% support coverage of the bottom side of the board. Squeegee length (overhang beyond the edge of the board size) is less than 10 mm, providing maximum support while the squeegee travels over each aperture. The custom support box is vacuum equipped to hold the test board flat and in place. Minimum squeegee pressure minimizes potential shift in the board position during the print cycle. No print gap is permitted in the print cycle. The printer program is not set to over-compensate the board thickness so that the board is pressed into the stencil causing possible deformation of the flatness of the stencil.

Since no paste debris is ever left on the printer conveyor rails due to diligent housekeeping, the print gap (between the board surface and bottom side of the stencil foil will not inadvertently occur. The regular board clamps that have been traditionally used in the conveyor system have been replaced by a new clamp system. The regular clamps include a stainless foil to hold the board in place, clamping down on the board surface during the print cycle. Small apertures located within 20 mm of this clamp are at risk of having a print gap. Any print gap during the print cycle tends to alter the transfer efficiency performance, in part, because the stencil is moving while paste is rolling into its aperture. At a print speed of 100 mm/s it has be shown to adversely affect the transfer efficiency. Figure 7 shows two different stencil and two different test vehicles with similar circular 10 mil NSMD pads. The presence of insufficient outliers in the data is significant when using the regular clamps.

The variance-to-mean ratio line chart shown in Figure 8 is from a print trial that includes observation of 25 different aperture pattern and pad design combinations. Three paste product print trials were conducted during May, June and July. Two of the paste products used (Paste A and Paste C) are the same product but from different manufacturing lots. Paste B is a different product. The results show a performance difference between Paste A and Paste B at aperture sizes of 10 mils. The paste handling and storage history indicated that paste may have been improperly stored. The odd results at 10 mil aperture sites raises concern that the paste may not perform as expected in production. A decision can be made to avoid using the paste for product designs that include the small 10 mil aperture features.

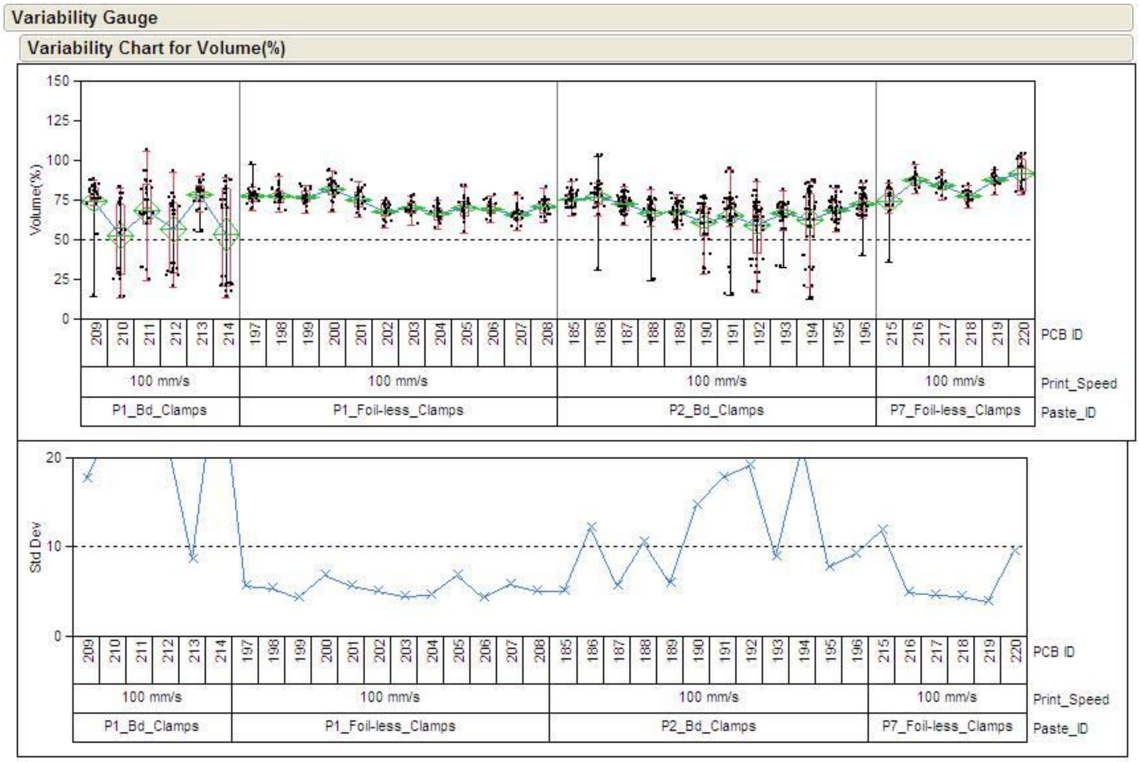

Figure 7 C10_NSMD Foil-less Clamps and Regular Board Clamps

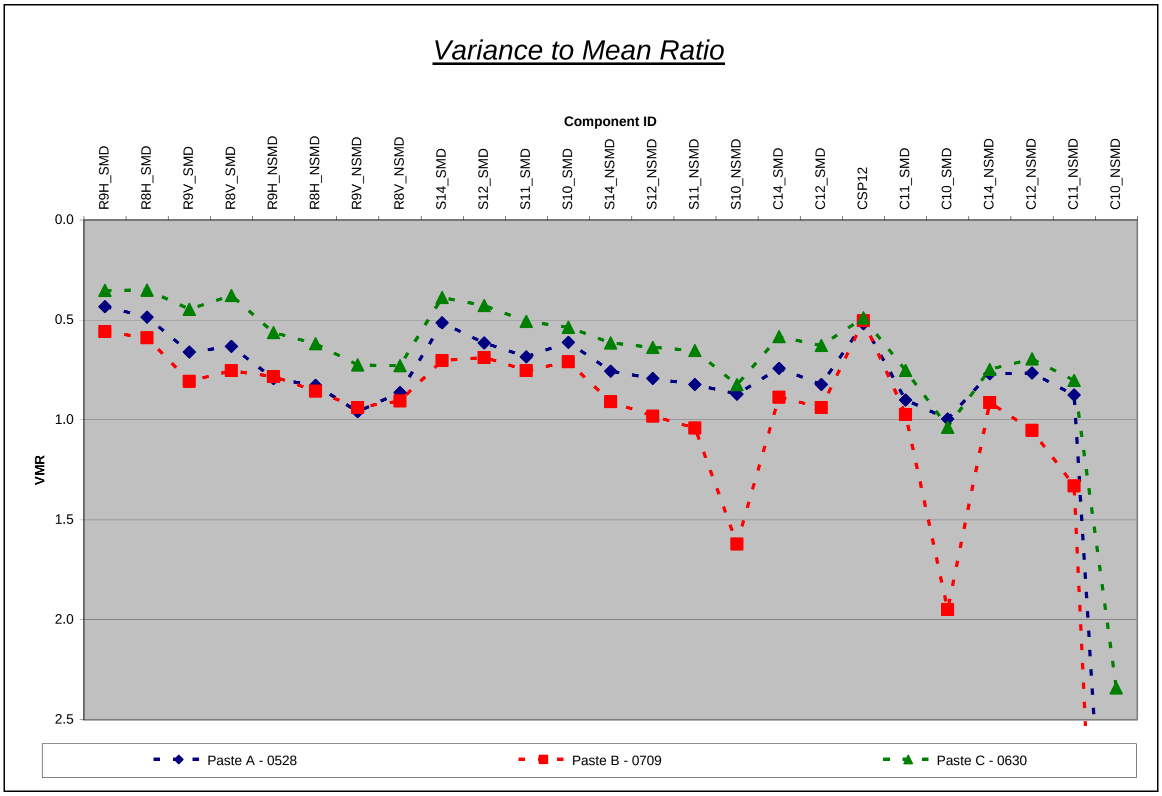

Figure 8 Three Pastes - 3 Months - 25 Aperture Patterns

Figures 9 and 10 are images of two 0.3 mm pitch pad sites on a customer test vehicle that offers many different pad sizes and pad spaces. Print product test trials of the customer paste product include three different stencils. The apertures at these sites are square shaped. The square aperture size for the 0.20 mm pad size is 0.20 mm (< 8 mils). The square aperture size for the 0.15 mm pad size is 0.15 mm (< 6 mils). Each stencil has a different stencil thickness, 4.0, 3.5, and 3.0 mils. Figure 11 shows the preliminary results of ongoing print trials. It is noted that these trials include the customer's current paste product. New experimental paste products will be used for additional print trials to observe performance differences among the stencils and between various paste products.

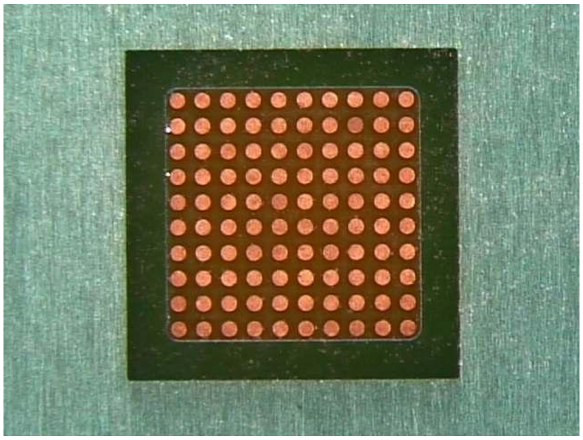

Figure 9 Pad Size (0.20 mm) x Pad Space (0.10 mm)

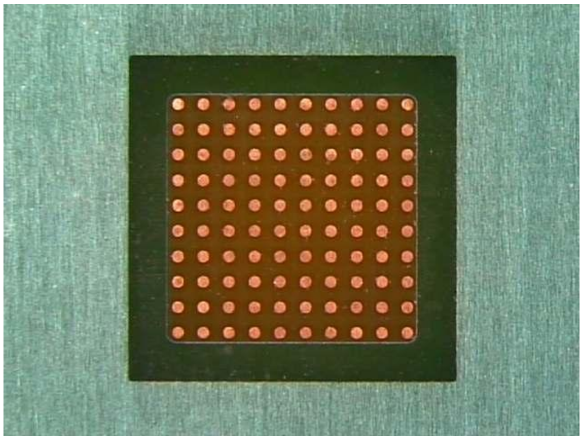

Figure 10 Pad Size (0.15 mm) x Pad Space (0.15 mm)

Arbitrary specification limits of transfer efficiency for paste printing during production are 150% for the UCL and 50% LCL. It is commonly difficult to standardize these values because the variation in transfer efficiency is the major cause for line defects from stencil printing, not necessarily the average amount deposited. However, using the results of data analysis from a print study is useful to characterize a stencil printing process. Figures 12-15 are tabulated data results from the initial phase of a case study aimed for development of a 0.3 mm pitch precision print process. As further print trials are introduced into the case study, process attributes will be evaluated for improvement opportunities of the process.

It can be noted that results for the 230 micron square aperture pattern (S9_NSMD) show an average transfer efficiency of 65%. The DPMO for the customer's specification limits ranges from 768-2376 for the four different print speeds in these print trials. This aperture size could show great promise for the customer's new product designs. In the existing process, the data analysis shows that process capability (Cpk) indices of this aperture pattern range from 0.94-1.06 for the four different print speeds. However, the process potential (Cp) indices range from 1.59-1.70. This observation raises considerably the expectations that the aperture pattern performance has the potential for improvement. Among the attributes to be evaluated, it is new stencil manufacturing technology that could show the most significant improvement.

Conclusion

The evaluation of solder paste print products using the current standard printing process offers a quality assessment of these pastes and suggests improvement techniques for the tooling and process setup. Using statistically based analysis to characterize the stencil printing process demonstrates an approach for quantitatively benchmarking the current process.

This approach provides a measure with which to contrast precision stencil printing processes and materials. This approach will be required for further miniaturization of electronic assembly products.

This paper summarizes techniques for establishing a precision print process by analyzing the variation in transfer efficiency. Some attribute examples shown included squeegee blade wear, rectangular aperture orientation, print speed, solder mask design, board clamping approach, pad size and pad space. The list of major attributes that pose significant opportunity for variation in transfer efficiency should be further considered. Figure 16 suggests theoretical test design proposal alternatives for 0.3 mm pitch. Note that the combined size and space measure 0.3 mm. The opportunity for test vehicle attributes that contribute to variation in the stencil printing process would start with considerations about the pad design limitations. Clearly mask design tolerance may not be the same at both ends of the size range. The uniform size, shape and locations of board pads may also be a consideration.

The distribution of stencil aperture characteristics is not generally known, but is assumed to be within a tolerance level. For 0.3 mm pitch arrays on a typical stencil design, uniform stencil aperture dimensions could conceivably become the most significant source for variation in transfer efficiency for miniaturized electronics assembly. There could be new challenges from stencil aperture tolerance considerations, especially with respect to a variety of array locations within real product design layouts. New alternative innovative manufacturing technologies are being tried for precision printing processes at new levels of miniaturization. The method shown in this paper for reporting the variation in transfer efficiency could become vitally important, staggering product design considerations if interaction is shown to occur between the distribution of aperture dimensions for a 0.3 mm pitch component array and nearby 01005 locations, QFNs, or open copper pads for shield attachment.

Perfecting the stencil printing process also requires perfecting use of visual software tools. A conventional reporting approach that only presents data in a traditional set of metric units may need change. The axis settings of the figures should be well labeled with clearly marked units, but preferred units of measure may alternatively be selected to better convey visual presentation of transfer efficiency. For example, slight variation of cubic micron units could be a recognizable concern. But, variation expressed in cubic mils or nanoliters may allow for a more clear understanding. Consider 38-40 aperture patterns are in the precision stencil printing process; conceivably, just 1 or 2 aperture patterns get consideration for an alternative solder deposition during the miniaturized assembly. Among 40 aperture patterns, it could be determined certain aperture patterns can be eliminated from the stencil (in the actual manufacturing process strategy) and these solder joints will be approached by use of performs, paste dispense, or innovative jet printing processes. These 1 or 2 aperture patterns normally fit into a stencil printing process but although they are not the 0.3 mm pitch components, they just can't fit properly in the new product design. Frequently, alternate solder deposition processes may prefer alternate units of measure. Consequently, alternate units and alternate axis settings on box plots could be useful. Venn diagrams[9] (for all solder deposition processes) can be devised including the results from transfer efficiency, and a comparison made from the data between the variation in transfer efficiency in the stencil printing process and other alternative soldering methods. The point to be made is that the preferred units of measure for axis settings should best convey the message of the transfer efficiency variation, and then used to determine the comprehensive solution for all soldering on the new product design for the actual manufacturing strategy.

The method for reporting variation in transfer efficiency can be impressively detailed and complex, but can conveniently omit necessary attributes merely to encourage limited discussion of results shown. This is a potential concern if the unrecognized attributes possess characteristic features that contribute to variation. For example, if a new product introduction design is to include a 0.3 mm pitch array closely surrounded by 01005 components, nearby QFNs with ground pads, and enormous open copper pad for shields, then a test vehicle with a similar design has the opportunity to indicate variation in transfer efficiency from print test trials. Print test trials using various innovative stencil manufacturing technologies could indicate their viability in the precision print process as measured by the variation in transfer efficiency. However, this would only be conclusive if there no characteristic difference exists in the manufacturing tolerance among test stencil apertures when compared to manufacturing tolerance for actual manufacturing introduction of new stencil design technology. Omission of the comprehensive mix of stencil features could cause the test trial printing process (established using a test stencil with limited features) to be bogus. Similarly, if there is a process difference among test stencil apertures because of location of the aperture arrangement, a newly established precision print process from a non-representative aperture arrangement (in the test stencil) could also show bogus results. It's not merely the pad size, pad space, mask design, and aperture manufacturing technology, but also the comprehensive arrangement of the aperture layout could alter the print results.

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[9] Yeh, Y.-C., "Concepts of Probability," Handbook of Industrial Engineering, 1992, John Wiley & Sons, Inc., pp. 2401-2406

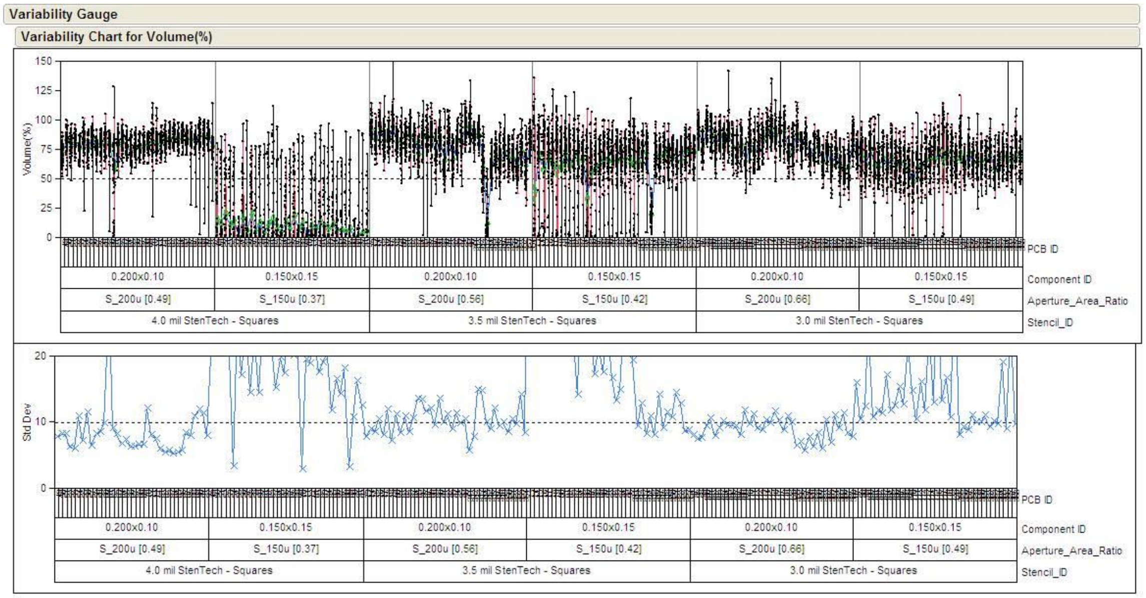

Figure 11 0.3 mm Pitch Variability Chart - 3 stencils

Vol%	50 mm/s	100 mm/s	125 mm/s	150 mm/s
CSP12	84	82	86	85
0201_ST	80	79	79	80
R8V	81	81	82	83
R8H	93	94	96	96
LGA_153	107	107	109	111
C12_NSMD	82	80	83	83
S12_NSMD	79	78	80	81
C11_NSMD	79	78	80	80
S11_NSMD	74	73	75	75
C10_NSMD	75	73	75	75
S10_NSMD	74	72	74	75
C9_NSMD	59	56	55	58
S9_NSMD	65	65	67	67
C8_NSMD	23	21	21	25
S8_NSMD	48	47	47	49

Figure 12 Average Volume for 15 Aperture Patterns at 4 Print Speeds

Cp	50 mm/s	100 mm/s	125 mm/s	150 mm/s
CSP12	2.69	2.78	2.79	2.67
0201_ST	3.30	3.21	3.14	3.40
R8V	2.40	2.43	2.32	2.08
R8H	2.38	2.30	2.16	2.21
LGA_153	2.55	2.90	2.63	2.58
C12_NSMD	2.64	2.45	2.38	2.51
S12_NSMD	2.64	2.71	2.62	2.65
C11_NSMD	2.18	2.16	2.06	2.18
S11_NSMD	2.54	2.51	2.35	2.52
C10_NSMD	1.90	1.58	1.49	1.67
S10_NSMD	2.38	2.30	2.12	2.24
C9_NSMD	0.81	0.80	0.71	0.79
S9_NSMD	1.59	1.62	1.61	1.70
C8_NSMD	0.71	0.78	0.72	0.69
S8_NSMD	0.80	0.81	0.75	0.76

Figure 13 Process Potential for 15 Aperture Patterns at 4 Print Speeds

Cpk	50 mm/s	100 mm/s	125 mm/s	150 mm/s
CSP12	2.42	2.42	2.62	2.46
0201_ST	2.74	2.61	2.59	2.84
R8V	2.03	2.05	2.03	1.84
R8H	2.27	2.13	1.93	1.98
LGA_153	1.84	2.07	1.80	1.70
C12_NSMD	2.28	2.04	2.08	2.20
S12_NSMD	2.16	2.19	2.20	2.24
C11_NSMD	1.78	1.71	1.71	1.82
S11_NSMD	1.88	1.80	1.76	1.89
C10_NSMD	1.41	1.13	1.11	1.27
S10_NSMD	1.74	1.62	1.56	1.67
C9_NSMD	0.39	0.35	0.30	0.37
S9_NSMD	0.94	0.96	0.99	1.06
C8_NSMD	-0.08	-0.11	-0.11	-0.06
S8_NSMD	0.24	0.24	0.21	0.24

Figure 14 Process Capability for 15 Aperture Patterns at 4 Print Speeds

PPM	50 mm/s	100 mm/s	125 mm/s	150 mm/s
CSP12	0.0	0.0	0.0	0.0
0201_ST	0.0	0.0	0.0	0.0
R8V	0.0	0.0	0.0	0.0
R8H	0.0	0.0	0.0	0.0
LGA_153	0.0	0.0	0.0	0.2
C12_NSMD	0.0	0.0	0.0	0.0
S12_NSMD	0.0	0.0	0.0	0.0
C11_NSMD	0.1	0.1	0.1	0.0
S11_NSMD	0.0	0.0	0.1	0.0
C10_NSMD	11.0	355	418	73
S10_NSMD	0.1	0.6	1.5	0.3
C9_NSMD	120,370	148,446	187,158	131,481
S9_NSMD	2376	2023	1528	768
C8_NSMD	597,370	632,936	626,709	569,219
S8_NSMD	236,059	240,043	260,872	233,649

Figure 15 DPMO for 15 Aperture Patterns at 4 Print Speeds

265u aperture-35u space
255u aperture-45u space
245u aperture-55u space
235u aperture-65u space
225u aperture-75u space
215u aperture-85u space
205u aperture-95u space
195u aperture-105u space
185u aperture-115u space
175u aperture-125u space
165u aperture-135uspace
155u aperture-145u space

Figure 16 Design Proposal Alternatives for 0.3 mm Pitch