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Squeegee Blades vs. Pump Technology: A Comparison of Solder Paste Print Performance

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Abstract
Enclosed print heads have recently been available to circuit board manufacturers as an alternate technology to conventional squeegee printing. By design, enclosed print heads offer several advantages one of which is isolating the solder paste from the ambient environment thereby stabilizing the rheology of the paste for longer periods. In addition, enclosed print heads decouple print speed from the pressure within the paste allowing for better control during the print operation.

Very little has been done to demonstrate the advantages of enclosed print heads with regards to print process capability. This will be the topic of the paper presented here. The study compares the performance of two designs of enclosed print head to that of a squeegee system on the basis of deposit consistency.

Introduction

As with all manufacturing processes solder paste printing is subject to variations from both special and common causes. The paste deposition process is the leading contributor of defects in the SMT assembly process because it is subject to the highest number of defect generating opportunities in the circuit board assembly process. Any operation aimed at improving printing performance typically results in higher first pass yields. This study compares squeegee blade printing versus enclosed head printing of solder paste. Data is collected from 1206, 0805, 50 mil pitch and 20 mil pitch devices for a 50 board run. In all, 19,200 data points are tracked for the purpose of statistical analysis.

The following are schematics describing the three types of print system under consideration in this paper.

Trailing Edge Metal Blade Printing

With trailing edge metal blade printing only two print parameters can typically be controlled: squeegee speed and downward squeegee pressure. The speed cannot be set so high that the paste does not roll as it moves across the stencil or too low so the print cycle time does not keep up with the manufacturing line. The blade pressure is usually set so that no paste remains on the stencil behind the squeegee. Too high a pressure will damage the stencil by either coining the edges of the image or breaking the fine webs between small pitch apertures. (Figure 1)

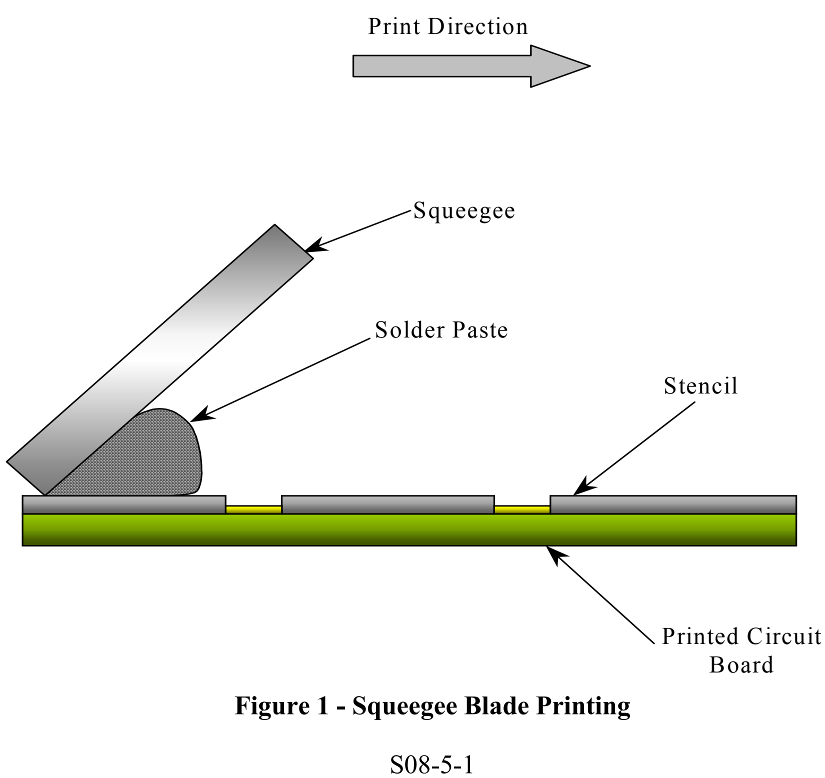

Figure 1 - Squeegee Blade Printing

Higher pressures will also shear thin the paste to such an extent that the flux will separate from the metal and problems such as lack of tack at placement or solderability will occur further down the assembly line. The contact angle of the blade is controlled by pressure and blade flexibility. Contrary to popular belief the paste does not fill the aperture until the paste bead has traveled at least 75% beyond the start of the aperture and fills from the front backwards.[1] Typical advantages of trailing edge printing are: easy set up and relatively low cost. Disadvantages are shorter life of solder paste due to evaporation of flux components, absorption of humidity and paste waste during clean up.

The Rheometric Pump

The Rheometric pump (RP) is an enclosed printing system in which the solder paste is fully contained and consequently not exposed to environmental conditions that typically shorten the life of the paste. One of the major consumables in the SMT industry has been solder paste due to the large amount being wasted in standard blade printing. Enclosed print heads significantly reduce the amount of solder paste waste by preventing it from deteriorating when exposed to environmental elements. In the RP, solder paste rolls inside a sealed chamber rather than in open air as in a squeegee system. The only paste that is in contact with stencil is at the point of application. Standard solder paste cartridges that provide the pressure required to fill the apertures continually replenish the paste. A fundamental difference between squeegee and enclosed printing resides in the fact that in squeegee printing the pressure driving the paste in the aperture is a function of squeegee speed and downward pressure applied to the squeegee. In enclosed print head, the same pressure is decoupled from the print speed. For intrusive solder paste printing enclosed head printing provides the supplemental pressure required to fill via holes consistently.

When the RP is properly adjusted the amount of paste left on the stencil after a full days production is typically of the order of a few grams rather than hundreds of grams for standard blade printing. This method of printing is not compatible with all paste formulations due to the higher pressures generated during the print process. (Figure 2)

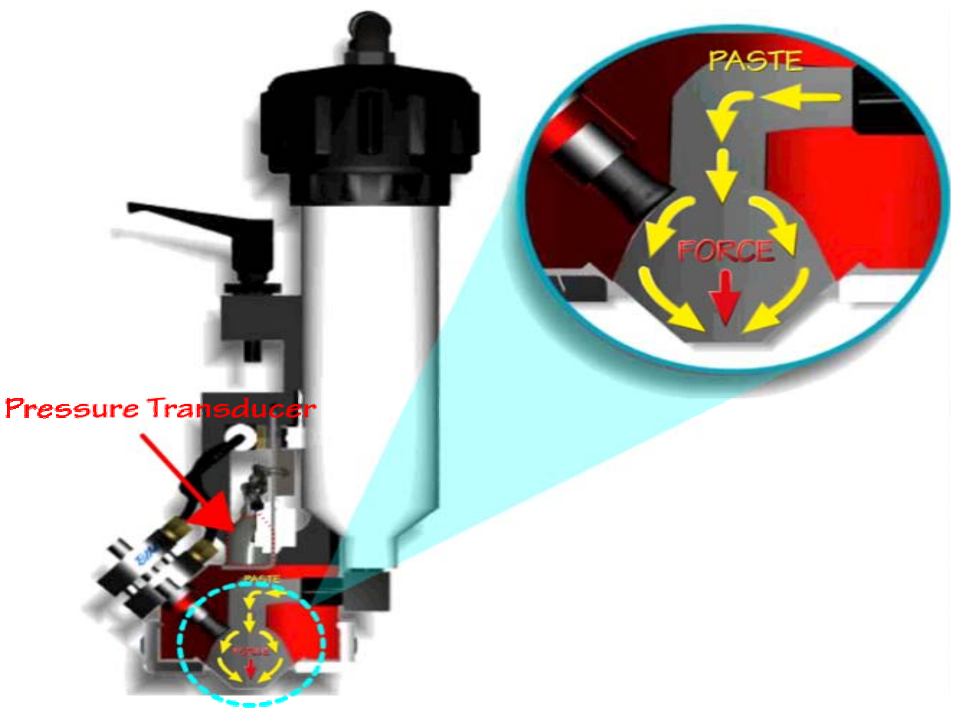

Figure 2 - Cross-section of MPM's Rheopump

Next Generation Pump Technology

The Next Generation Pump Technology (NGP) is based an enclosed print head, similar in principle to the RPPbut with radical design improvements. The "inward" facing blades of the RP have been replaced by two blades that remain parallel to each other during the print stroke while pressure is applied pneumatically to the paste through a flexible membrane. The blades are embedded in a replaceable insert that also incorporates the flexible membrane. The blades flex with the print direction in a manner that is similar to trailing edge blade printing. Paste is supplied by standard paste cartridges, which are directly connected to the insert as shown in Figure 3.

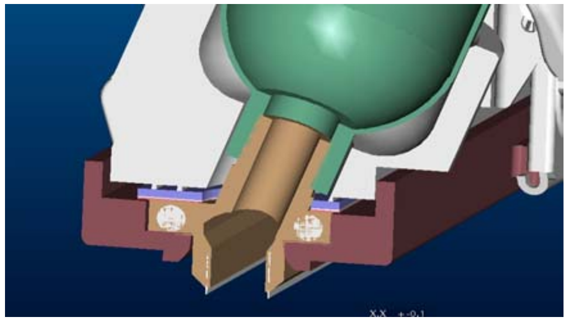

Figure 3 - Cross-section of MPM's Next Generation Pump

Experimentation

Objective

- To determine the print capability of the NGP by printing and measuring solder paste height and volume and also determine the print capability depending on the pad orientation.
- To benchmark against an equivalent squeegee blade print system
- To benchmark against an equivalent RP system

Equipment and Test Material

- Stencil Printer: MPM AP Excel
- Inspection Machine: SVS 8100 3D Laser System
- Solder Paste Material: Type III, 63 Sn- 37Pb, No clean solder paste
- 12" Squeegee Blades
- 12" Rheopump
- 16" Next Generation Pump with 12" insert

Test

The board used for this test is shown in Figure 4. The sample size for this test is 50 boards. The stencil wipe cycle is set to run after every 5 boards printed. Table 1 shows the common process parameters used for the printing with blades, RP and NGP. These parameters are optimized based on the test specifications.

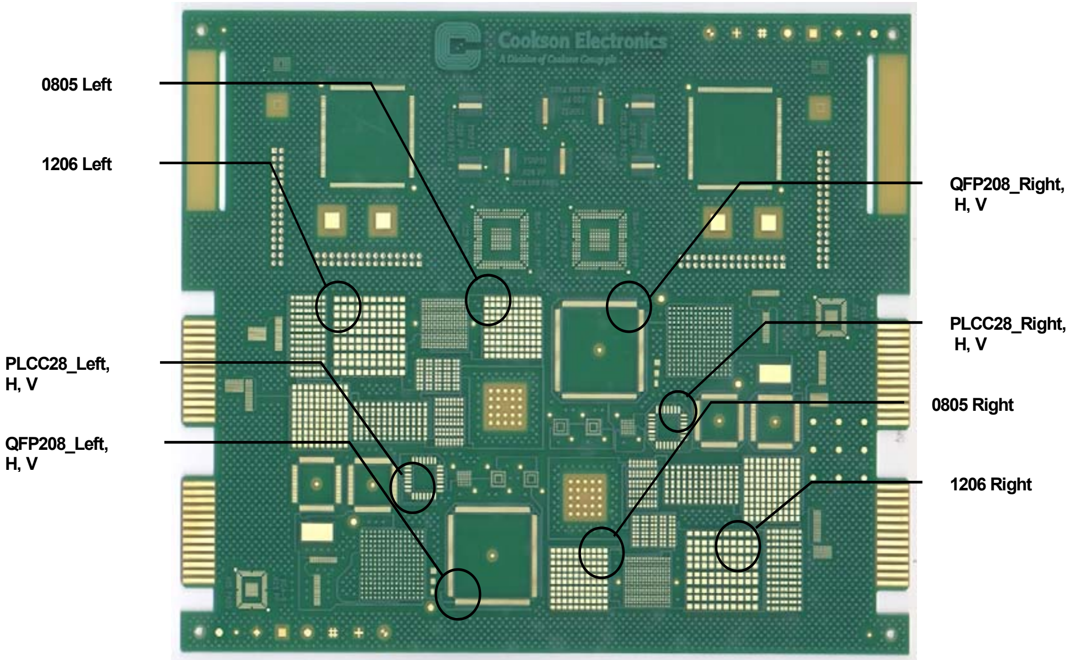

Figure 4 - Test Board

Table 1 - Print Parameters

Parameters	Squeegee Blades	Rheopump	Next Gen Pump
Print Speed	2 inch/sec	2 inch/sec	2 inch/sec
Down force	18 lbs	20 lbs	35 lbs
Downstop	75 mils	30 mils	75 mils
Lift Height	-150 mils	-30 mils	-75 mils

The pump specific parameters for the RP are:

- Print Pressure: 1.5 psi
- PID: 3

The pump specific parameters for the NGP are:

- Cartridge Refill Pressure: 9 psi
- Membrane Refill Pressure: 0.5 psi
- Membrane Print Pressure: 1.5 psi.

Response Variables

The response variables collected from these test and the specification limits for them are:

- Solder paste deposit Volume: +/- 50% of nominal value.
- Solder paste deposit Height: +/- 2 mils of nominal value.
- Solder paste deposit X and Y offsets: +/- 4 mils from target position.

Devices Inspected

The data is collected for selected features on the Test Board A shown in Figure 4. The board is inspected in a GSI Lumonics model 8100 inspection machine. The data is reported for each selected feature on the boards instead of averaging the values for a complete device. Following are the device features for which the data is collected.

- 0805
- 1206
- PLCC28 – 50 mils
- QFP 208 – 20 mils

Analysis

The data analysis conducted in the present study involves a pair wise comparison of the three print systems. Using a normal F test or a paired-t test wherein only two levels can be compared at a time, would increase the probability of making type I errors. [3] For this reason, the decision was make to perform a Tukey's test which performs a multiple comparison and reduces the probability of making type I error. The Tukey's test requires that the data sets to be compared have a normal distribution and similar variances. Thus, the data was validated for normality using the Anderson Darling test and for equal variances using the Bartlett test.

Tukey's Test

Results for a Tukey's test are presented in the form of confidence intervals for difference between the means of the pairs of the factor levels that are being compared. The results of this test can be interpreted as follows: [4]

- If the confidence interval for the means of the pair being compared contains zero, the corresponding means have no significant statistical difference.
- If the confidence interval does not contain zero, there is a significant statistical difference between the means being compared.

From the results shown in Figure 5, it is seen that there is no significant variation between the RP and the NGP based on the confidence intervals (since the interval for RP vs. NGP contains zero). Since neither of the intervals for NGP vs. blades and RP vs. blades contains zeros, there is a significant statistical difference between these data. These results suggest that pump printing produces significant statistical differences compared to squeegee blade printing.

Tukey's pairwise comparisons

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Family error rate = 0.0100
Individual error rate = 0.00356

Critical value = 4.19

Intervals for (column level mean) - (row level mean)

                   Blades      NGP

NGP                 12.6
                   162.3

Rheopump            29.5       -58.0
                   179.2        91.8
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Figure 5 - Tukey's Test Results

Box Whisker Plots

Box-Whisker plots are used to graphically compare the performance of the three print systems. Figure 6 shows the box whisker plots for squeegee blades, NGP and the RP. It can be noted from the figure that the mean value for the squeegee blades is highest and the NGP data shows the least amount of variability. The range of the data for the NGP is the smallest when compared to the other two print systems. Also, the plot shows that the data for NGP is more symmetric compared to the data for the squeegee blades and RP, which are slightly skewed from the nominal. Thus, it can be concluded from the box plots that the NGP produces least amount of print variability when compared to the squeegee and RP systems.

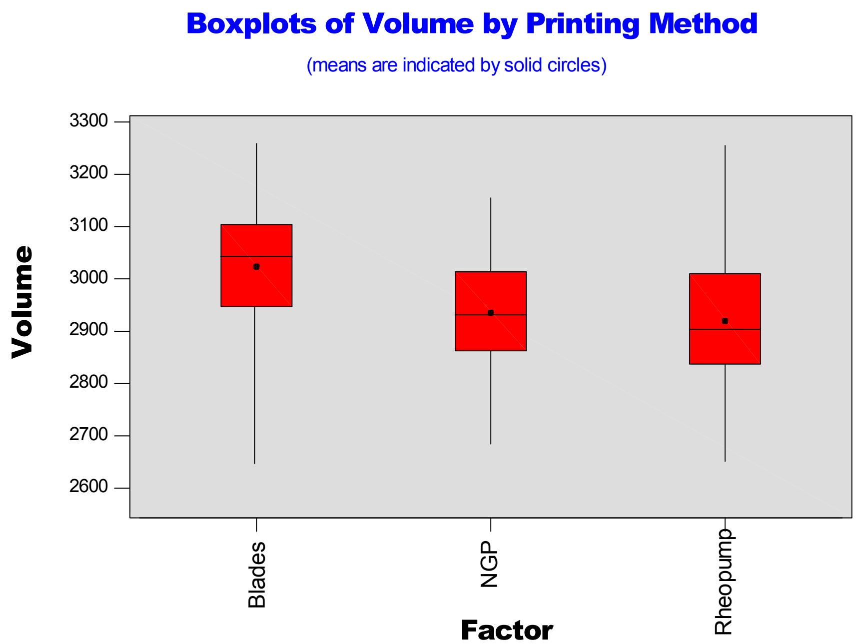


Figure 6 - Box–Whisker Plots, Comparison by Volume of Print Systems

Comparison of Horizontal and Vertical Pads

Variations in the amount of solder paste deposited on pads depending on their orientation with respect to the print stroke when using squeegee blades is a typical phenomenon. This test is aimed at comparing the performances of squeegee blades, RP and NGP on the basis of printing horizontal and vertical pads consistently. This part of the study is based on the same data collected for the print quality comparison above. The orientation of the vertical and horizontal pads in relation to print stroke direction is illustrated in Figure 7.

The vertical and the horizontal pads are compared based on the height and volume of the solder paste deposits for a QFP208 (20 mil pitch) device.

The comparison is done using a paired-t test.[4] Figure 8 shows the Box-whisker plots for the differences in means of horizontal and vertical pad deposit volumes. The consolidated results are as given in Table 2.

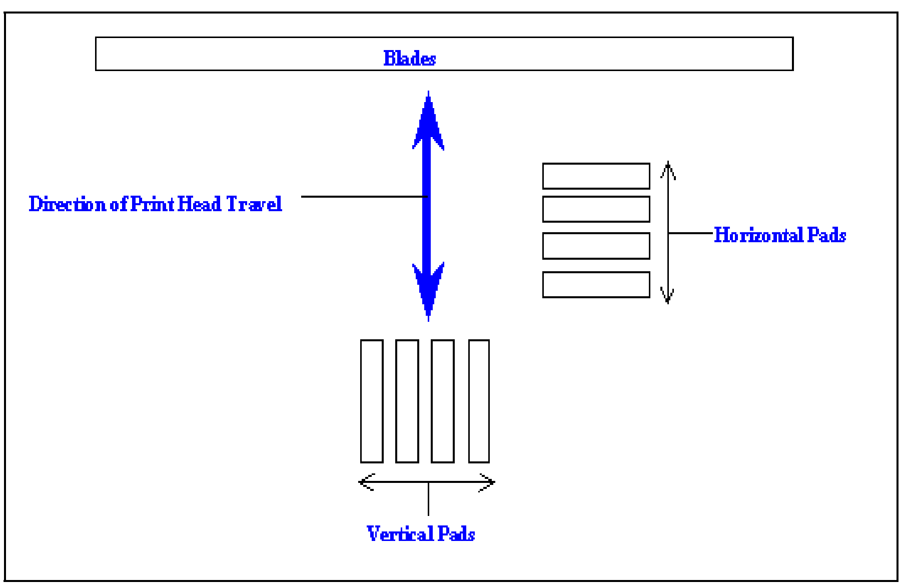
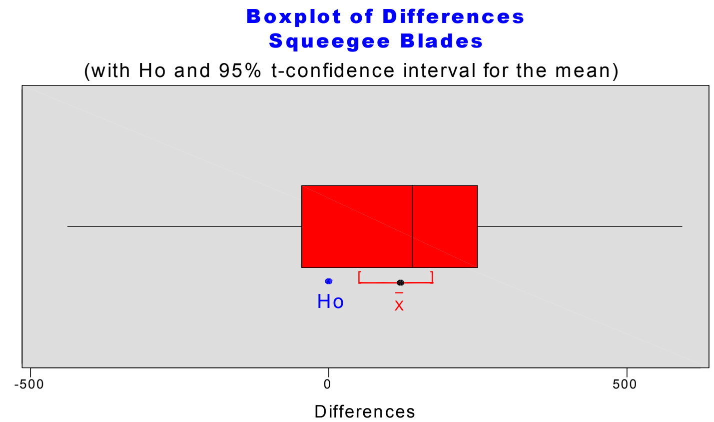
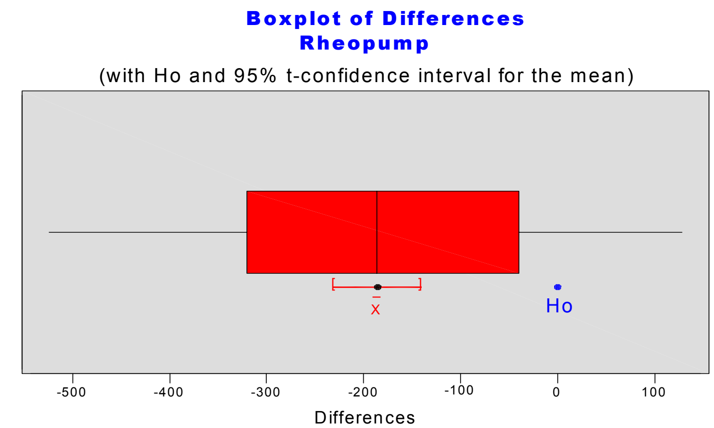


Figure 7 - Horizontal and Vertical Pad Orientation with Respect to Print Stroke Direction





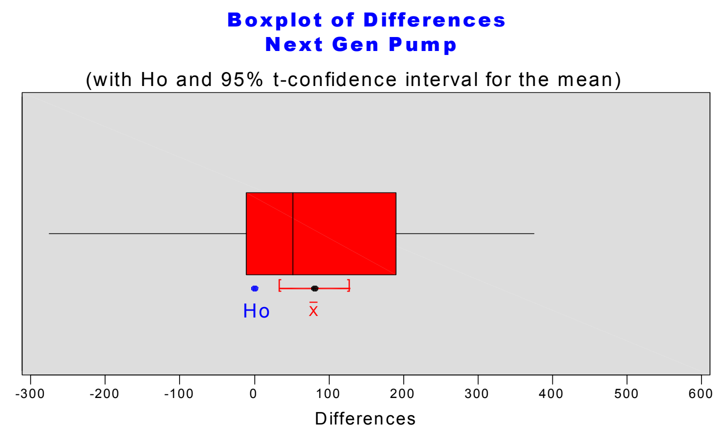


Figure 8 - Box Plots of Horizon/Vertical Pad Volume Differences

Table 2 - Paired T test results

Vertical – Horizontal Pad Volume			
Factor	Mean of Differences	Confidence Interval	P Value
NGP	80.9	(52.0, 176.1)	0.001
RP	-185.8	(-231.9, -139.7)	0.000
Squeegee Blades	114.0	(33.5, 128.4)	0.001

Comparing all the three box plots and the paired-t test results, the following observations can be made:

1. The P-values for all the three factor levels are less than 0.05 (95% confidence level) suggesting that for all the three print systems the amount of volume deposited on the vertical and horizontal pads are statistically different.
2. The absolute value of the mean and standard deviation of differences for the NGP are the smallest compared to both the RP and the squeegee blade systems. Thus, the NGP printing appears more consistent when compared to the RP and squeegee blades.
3. The mean and confidence intervals of differences for the squeegee blades and the Next Generation Pump are positive, while those for the RP are negative. Thus in the case of squeegee blades and the NGP the volumes deposited on the vertical pads are larger compared to those on the horizontal pads. By contrast, the RP produces smaller volumes on vertical pads than on the horizontal pads.

Based on the two previous tests, the data shows that statistically, the NGP produces more consistent deposits both in terms of overall volumes deposited and pad orientation.

Process Capability Analysis

A Process capability analysis was performed on the height and volume of the deposits for the three printing systems. Two Process Capability Indexes were used for this particular test. They are Cp and Cpk defined as follows: [2]

The desired Cp value for the present study is 2.00 and that for Cpk is 1.67. The Cpk values can be converted to defect levels i.e. parts per million. Thus two processes may be compared on the basis of their Cp and Cpk scores.

Figure 9 shows a sample plot for comparison of Cpk values for the solder paste volumes in the case of the three print techniques considered in this paper. It can be noted that the Cpk values for all the components are higher that the desired value of 1.67. (The tolerance limits for the Cp and Cpk analysis are based on customer specifications). Similar results are observed throughout the remaining of the data set for both height and volume. As a conclusion, it can be noted that the overall print quality produced by the NGP is better than by printing with squeegee blades or the RP.

$$C_p = \frac{USL - LSL}{6\sigma}$$

$$C_{pk} = \min\left(\frac{\mu - LSL}{3\sigma}, \frac{USL - \mu}{3\sigma}\right)$$

LSL: Lower Specification Limit
μ: Mean
USL: Upper Specification Limit
σ: Standard Deviation of the process

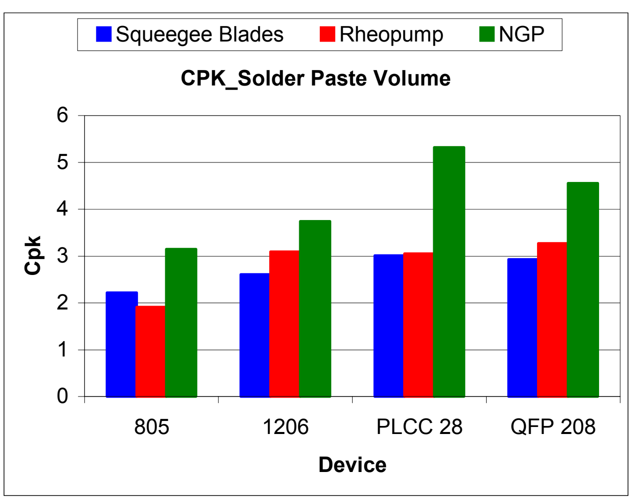


Figure 9 - Cpk – Solder Paste Volume for Various Devices

Solder Paste Compaction

Compaction is defined as a phenomenon in which the flux and the solder paste particles separate. When this happens within an enclosed print head, solder paste can become excessively viscous to the point where paste flow becomes impossible. Paste compaction is a common problem encountered by enclosed print head users. Tendency to compact is primarily a function of the paste; however, judicious design of the pump cavity can delay the onset of compaction. The main reason for the flux/solid separation can be attributed to pressure variations inside the chamber of the print head. A paste that does not allow flux to migrate through its solder particles will be less prone to compaction. While most of the pastes used in the SMT industry today have very good compaction resistance characteristics, it is not uncommon to come across solder pastes that compact within a few hundred prints.

In order to better understand the compaction phenomenon, the flow of flux through solder balls has been approximated with laws that describe the flow of viscous fluid through porous media. Darcy's Law of fluid flow through porous media is defined as:

$$Q = K_f \Delta P \frac{A}{L}$$

Where

ΔP = P1-P2

P1: Input Pressure (Print pressure)

P2: Output Pressure (at stencil level)

K_f: Permeability Co-efficient

L: Height of the Paste Chamber

A: Cross Sectional Area of the Pump Chamber

The equation quantifies the flow rate of flux through the solder paste under print pressure, as a function of the viscosity of the flux, solder particle size and the dimensions of the paste chamber. As can be seen from Darcy's law, the flow rate of flux is directly proportional to the cross-section and inversely proportional to the length or height of the paste chamber. For this reason, the NGP cross section was designed with a significantly smaller chamber than the Rheopump.

A series of Paste Compaction tests were performed to verify this hypothesis. These tests involved printing 2000 boards with every 40^{th} board being inspected. A process capability analysis was performed on solder paste height and volume data collected. Results indicated that the Next Generation Pump delays and sometimes even eliminates compaction.

Conclusions

- Based on the results of Tukey's Multiple Comparison test, Pump Printing shows statistically significant differences when compared to squeegee printing.
- NGP printing produces volumes that are better centered about the mean and yields smaller standard deviation when compared to the other two print techniques.
- Although squeegee blades produce the largest solder paste deposits, they yield the highest standard deviation.
- Paired T-tests performed on the vertical and horizontal solder paste volume show that the NGP produces more consistent prints and minimizes the difference between the horizontal and vertical pad deposits.
- The NGP and squeegee blades show similar behavior in terms of vertical and horizontal pad volumes.
- Cp and Cpk analyses based on deposit volumes and heights show that the print quality for the NGP is more consistent and accurate than for squeegee or Rheopump printing.
- The design of the NGP paste chamber delays or eliminates compaction.

References

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2. Besterfield, H., Quality Control, Fifth Edition, Prentice Hall, New Jersey, 1998.Schmidt, S., Understanding Industrial Designed Experiments, Air Academy Press & Associates, Colorado Springs, CO 80920, 1997.MINITAB, User's Guide 2: Minitab Inc., Release 13, 2000.