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CONTROLLING THE ASSEMBLY PROCESS WITH THE USE OF SPC

William Beair, Alton Moore, and Eric Gilley
Raytheon Company
McKinney, TX, USA

ABSTRACT

With increasing deployment of both micro BGA's, 0201discreet and other small components on contemporary CCA designs, the ongoing maintenance of controlled repeatable manufacturing process is more important than ever. As component sizes and pitch decrease, the demand for greater accuracy and repeatability of the assembly equipment increases. Beginning with process characterization, and followed by development of a process control plan to assess, track and control assembly, this paper will discuss a successful methodology for SPC in a CCA process area.

INTRODUCTION

Surface Mount Technology continues to experience design trends emphasizing increased miniaturization of package components and board footprints. With these trends are needs for controls to ensure low defect production. Standard preventive maintenance and equipment calibration may not be sufficient to meet these needs.

A statistical strategy has been developed to identify performance trends, to allow equipment maintenance to be proactively scheduled to correct deteriorating trends in equipment and to reduce rework and scrap.

Core assembly processes, including screen print, component placement, reflow and wave soldering will be evaluated to identify potential defect driving parameters and methods for implementing Statistical Process Control (SPC). Metrics for these control charts have been determined by machine specifications and capability studies.

Screen Print Process Characterization

It has been widely documented that 80% of all defects in SMT manufacturing originate at the solder paste screen print operation. Further scrutiny as to cause and prevention of defects revealed the following via Failure Mode Effect Analysis (FMEA). Figure 1 details each major defect category, its current control method, and the effectiveness of that method. These factors were combined to assign prioritization for SPC implementation, as highlighted (yellow) in the last column of Figure 1. This exercise determined that printer alignment is a key parameter that should be monitored on a periodic basis via an enhanced method.

Screen Print	Defects	Quality Characteristics	Standard Control method	Potential for Defect (1 - 5)	Effectiveness of measurement	Potential of escape (1 - 5)	Risk Priority Number
	Solder Bridge	Print Alignment	Visual Inspection	4	1 mil	3	**12**
			Periodic calibration				
		Coverage	2d machine inspection	2	+/- 5%	3	**6**
		Height	Controlled by stencil height / machine settings	2	Developed settings by use of DOE to achieve minimal variability	2	**4**
	Solder Open	Alignment	Visual Inspection	4	1 mil	3	**12**
			Periodic calibration				
		Coverage	2d machine inspection	2	+/- 5%	3	**6**
		Height	Controlled by stencil height / machine settings	2	Developed settings by use of DOE to achieve minimal variability	2	**4**
	Tombstone	Alignment	Visual Inspection	4	1 mil	3	**12**
			Periodic calibration				
		Coverage	2d machine inspection	2	+/- 5%	3	**6**
		Height	Controlled by stencil height / machine settings	2	Developed settings by use of DOE to achieve minimal variability	2	**4**
	Solder Insufficient	Alignment	Visual Inspection	4	1 mil	3	**12**
			Periodic calibration				
		Coverage	2d machine inspection	2	+/- 5%	3	**6**
		Height	Controlled by stencil height / machine settings	2	Developed settings by use of DOE to achieve minimal variability	2	**4**

Figure 1 (Screen Print FMEA)

Placement Process Characterization

During the placement process, components are placed onto board pad sites and held in place by wet solder paste. With the reduced size of components (e. g. the aforementioned 0201 discreets and micro BGAs) and increased board density, inspection for placement accuracy has become very demanding. Automatic Optical Inspection technology, deployed after placement, helps detect missing and reversed components, but more subtle accuracy issues such as component misalignment still result in assembly defects. The modified FMEA is shown in (Figure 2) provides details. Prioritization exercise indicated that component placement accuracy should be incorporated into SPC controls.

SMT Reflow Process Characterization

The reflow process is a computer controlled heating process that converts solder paste to finished solder joints. Its control parameters include specifically defined temperature zones and conveyance (belt) speeds to achieve a desired reflow profile. These profiles are tailored for each board design to achieve specific temperature ramp rates, flux activation (soak times), time above reflow (183C) and maximum peak temperatures. All are computer controlled via built in thermocouples and the computer software. Per the FMEA analysis (Figure 3), all four characteristics (ramp rate, soak time, time above reflow and maximum temperature) are incorporated in the SPC program, as each parameter presents certain risks to product quality.

Placement	Defects	Quality Characteristics	Standard Control method	Potential for Defect (1 - 5)	Effectiveness of measurement	Potential of escape (1 - 5)	Risk Priority Number
	Solder Bridge	Placement	Visual Inspection	4	+/- 2 mils	4	**16**
			Periodic calibration				
		Placement pressure	Part definition & board height	3	Eng defined	1	**3**
	Solder Open	Placement	Visual Inspection	4	+/- 2 mils	4	**16**
			Periodic calibration				
	Tombstone	Placement	Visual Inspection	4	+/- 2 mils	4	**16**
			Periodic calibration				
	Missing	Placement		4	AOI inspection	1	**4**
		Placement program	Eng controlled programs				
	Reversed	Placement program	Eng controlled programs	1	AOI inspection	1	**1**
		Reel loaded incorrectly	Operator function	4	AOI inspection	1	**4**
	Wrong	Placement program	Eng controlled programs	1	AOI inspection	1	**1**

Figure 2 (Placement FMEA)

Solder Reflow	Defects	Quality Characteristics	Standard Control method	Potential for Defect (1 - 5)	Effectiveness of measurement	Potential of escape (1 - 5)	Risk Priority Number
	Solder Bridge	Ramp rate	Solder Profile	2	Eng controlled	1	**2**
			Machine control limits	2	Software controlled	2	**4**
	Solder Open	Soak time	Profile controlled	2	Eng controlled	1	**2**
			Machine control limits	2	Software controlled	2	**4**
		Peak temperature	Profile controlled	2	Eng controlled	1	**2**
			Machine control limits	2	Software controlled	2	**4**
		Time above reflow	Profile controlled	2	Eng controlled	1	**2**
			Machine control limits	2	Software controlled	2	**4**
	Tombstone	Ramp rate	Profile controlled	2	Eng controlled	1	**2**
			Machine control limits	2	Software controlled	2	**4**
		Soak time	Profile controlled	2	Eng controlled	1	**2**
			Machine control limits	2	Software controlled	2	**4**
	Solder void	Ramp rate	Profile controlled	2	Eng controlled	1	**2**
			Machine control limits	2	Software controlled	2	**4**
		Soak time	Profile controlled	2	Eng controlled	1	**2**
			Machine control limits	2	Software controlled	2	**4**
		Peak temperature	Profile controlled	2	Eng controlled	1	**2**
			Machine control limits	2	Software controlled	2	**4**
		Time above reflow	Profile controlled	2	Eng controlled	1	**2**
			Machine control limits	2	Software controlled	2	**4**

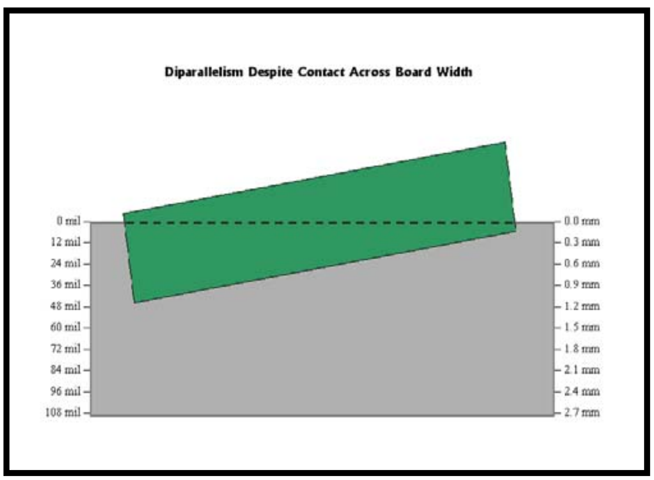
Figure 3 (Reflow FMEA)

Wave Solder Process Characterization

Wave solder process is a dynamic process where pre-heat, dwell time, parallelism, wave depth and wave contact length are critical process parameters. Interactions among parallelism, dwell time, immersion depth and contact length are also critical.

A good example of an interaction is shown in Figure 4 [1]. This illustration shows that exclusively monitoring the wave depth can result in a diparallelism condition. Figure 5 shows the results FMEA that was conducted on the wave solder process.

Figure 4 (Wave Depth / Parallelism)



Wave Solder	Defects	Quality Characteristics	Standard Control method	Potential for Defect (1 - 5)	Effectiveness of measurement	Potential of escape (1 - 5)	Severity of condition
	Solder Bridge	Wave parallelism	Glass plate	4	visual measurement of plate	3	12
		Wave depth	Glass plate	4		4	16
		Insufficient pre heat	Computer controlled	3		3	9
	Solder missing	Wave parallelism	Glass plate	4	visual measurement of plate	3	12
		Wave depth	Glass plate	4		4	16
		Insufficient pre heat	Computer controlled	3		3	9
	Insufficient Barrel fill	Wave parallelism	Glass plate	4	visual measurement of plate	3	12
		Wave depth	Glass plate	4		4	16
		Insufficient pre heat	Computer controlled	3		3	9

Figure 5 – Wave Solder FMEA

Identify Key SPC Process Parameters

After prioritization via the FMEA's, key parameters (Figure 6) were identified to be monitored/ measured for each process. It was determined that each parameter would be measured weekly, except placement equipment was scheduled for monthly measurements. This was due to placement's history of maintaining stability following calibration/adjustment.

Screen Print Process					
Print Alignment	Visual Inspection	4	1 mil	3	**12**
	Periodic calibration				
Placement Process					
Placement Acuracy	Visual Inspection	4	+/- 2 mils	4	**16**
	Periodic calibration				
Reflow Process					
Ramp rate	Solder Profile	2	Eng controlled	1	**2**
	Machine control limits	2	Software controlled	2	**4**
Soak time	Profile controlled	2	Eng controlled	1	**2**
	Machine control limits	2	Software controlled	2	**4**
Peak temperature	Profile controlled	2	Eng controlled	1	**2**
	Machine control limits	2	Software controlled	2	**4**
Time above reflow	Profile controlled	2	Eng controlled	1	**2**
	Machine control limits	2	Software controlled	2	**4**
Wave Solder Process					
Wave parallelism	Glass plate	4	visual measurement of plate	3	**12**
Wave depth	Glass plate	4		4	**16**
Insufficient pre heat	Computer controlled	3		3	**9**

Figure 6 (Identified SPC Process Parameters)

Screen Print SPC Measurement Data

A specific test vehicle is printed and measured multiple times weekly to determine the accuracy and repeatability of the print in both x and y directions. The material that is screen printed is an adhesive, rather than solder paste. This is because the adhesive is more firm and stable, so it provides for a more accurate measurement. Specification limits were determined by capability studies and the machine specifications. Figures 7 thru 10 shows typical examples of Xbar and R charts that measure x and y axis accuracy and repeatability. Control limits are calculated automatically using Shewart methods, which are based on variation of the data being analyzed.

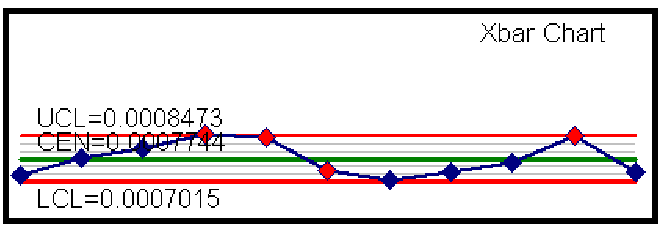


Figure 7 (Screen Print X Axis Xbar Chart)

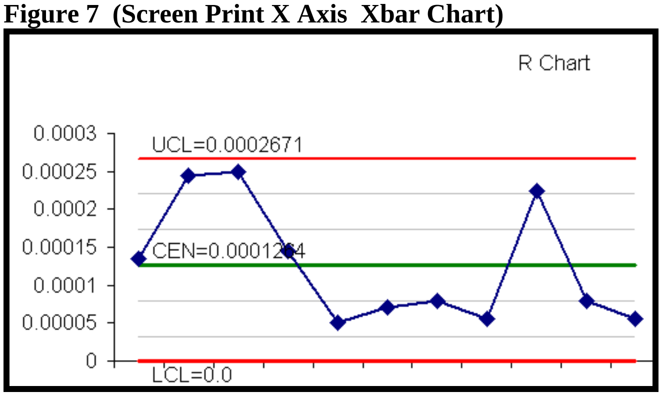


Figure 8 (Screen Print X-Axis R Chart)

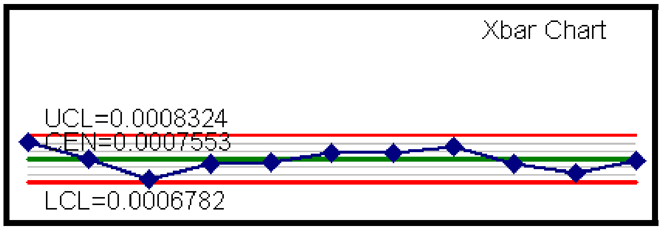


Figure 9 (Screen Print Y Axis Xbar Chart)

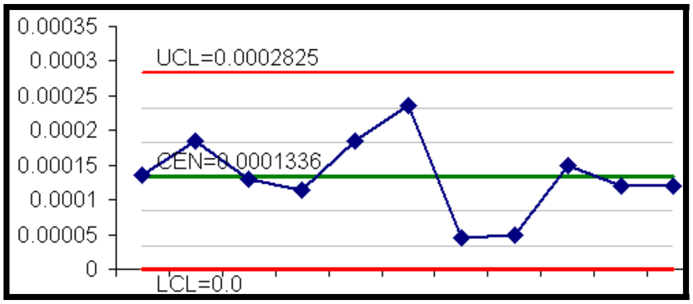


Figure 10 (Screen Print Y Axis R Chart)

Placement SPC Measurement Data

The SPC Placement SPC program is also concerned with accuracy and repeatability. With this, the machines place precisely machined and calibrated components at 0°, 90°, 180°, and 270° rotations on target pad sites, and then replicate these placements 8 times each for a total of 512 placements. The control limits (USL/LSL) are specified in the measurement software at ± 0.066 mm. The measurement software assesses whether Delta X max and Delta Y max are within ± 0.015 mm from nominal, 3 sigma X and Y is within 0.049 mm and the CpK is 1.333 or higher for in both x and y.

As shown in figure 11, on the 5th month of testing, the CpK for the x axis was under the limit of 1.33. Responding accordingly, down time was scheduled and the problem was identified and corrected. In the absence of these protocols, it is likely that quality of product would have been adversely affected.

Month 1		Month 2		Month 3		Month 4		Month 5	
cpkx	cpky	cpkx	cpky	cpkx	cpky	cpkx	cpky	cpkx	cpky
1.42	1.9	1.37	1.46	1.43	1.88	1.35	1.5	1.3	1.79

Figure 11 (Placement Monthly SPC CpK measurements)

Reflow SPC Measurement Data

A standard test board is set up with thermocouples and is run weekly to generate a history of profile repeatability. Data including ramp rate, soak time, time above 183 and maximum reflow temperature are plotted on x bar and r control charts. Special attention is taken to ensure thermocouple integrity to prevent false readings. This data was also used to allow us to standardize multiple ovens to allow one set of oven profiles. Figure 12 – 15 are example SPC charts for the reflow process. Control limits are calculated automatically using Shewart methods, which are based on variation of the data being analyzed.

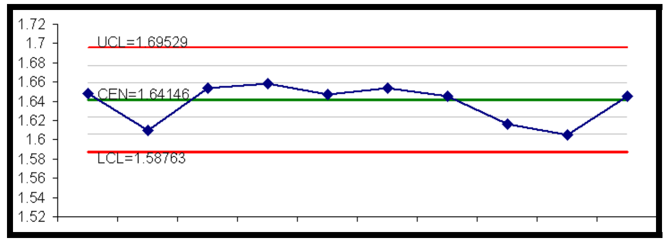


Figure 12 (Reflow Ramp Rate)

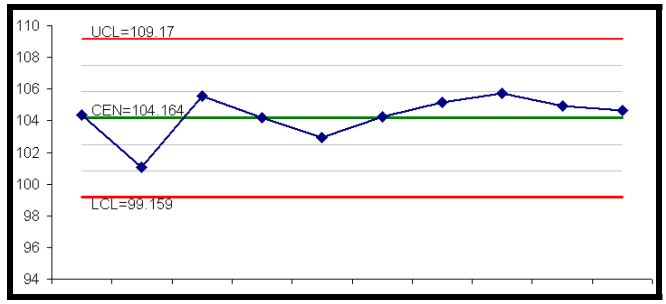


Figure 13 (Reflow Soak Time)

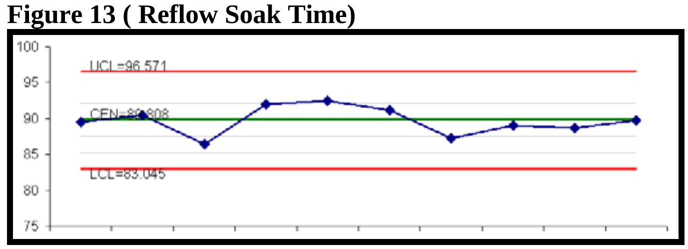


Figure 14 (Reflow Time Above 183)

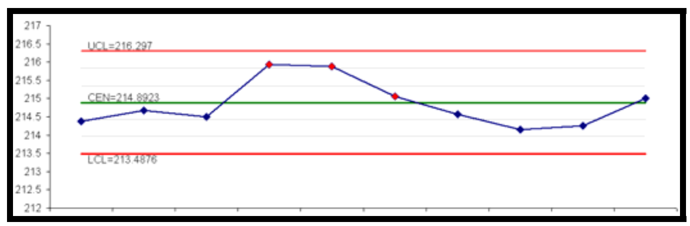


Figure 15 (Peak Solder Refow Temperature)

Wave Solder SPC Data

With the use of a wave optimizer weekly pre heat, right dwell time, left dwell time and immersion depth is measured**.** The right and left dwell time measurements we very useful in our initial set up of the wave solder SPC process. Figure 16 – 19 are the control charts for the wave solder process. Control limits are calculated automatically using Shewart methods, which are based on variation of the data being analyzed.

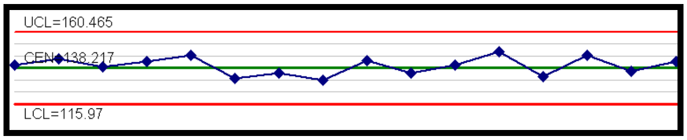


Figure 16 (Wave Solder Pre Heat)

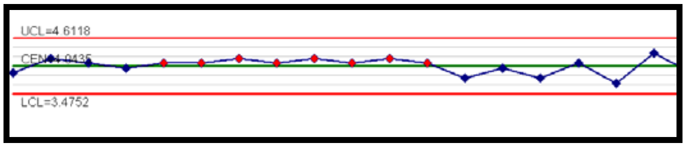


Figure 17 (Right Dwell Time)

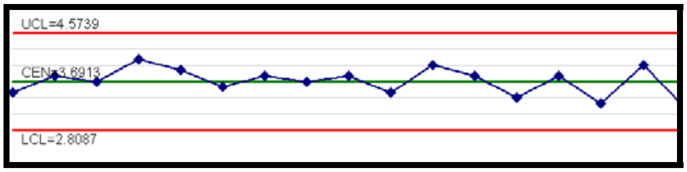


Figure 18 (Left Dwell Time)

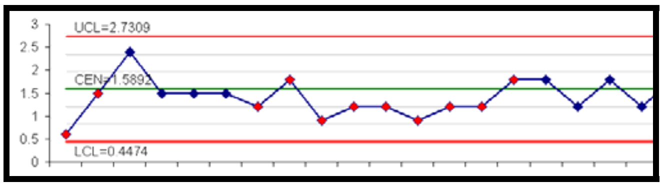


Figure 19 (Wave Solder Immersion Depth)

Quality Improvement Results

Since the inception of this SPC program, overall quality as measured by SMT defect rates has consistently improved. Figure 20 shows a 20 month trend of consistent improvement, with defect rates being cut by 50% over the period.

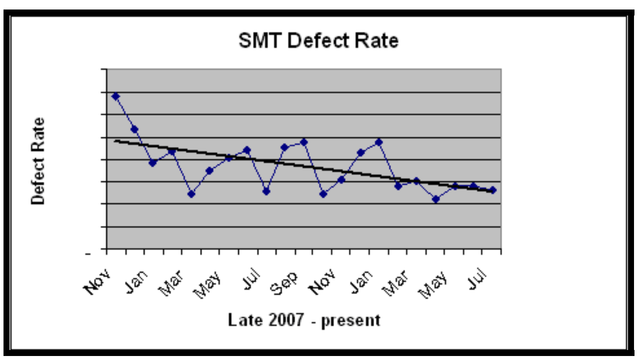


Figure 20 (Dpmo trends since inception of SPC)

CONCLUSIONS

The implementation of a proactive, data driven, statistical program for quality improvement has resulted in tangible results in this CCA shop. By performing routine checks and corrections as needed on parameters that most effect process performance, a steady history of improved quality has been achieved.

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REFERENCE

[1] Martin Ingall and Nissim Sasson, Parallelism as a High Impact New Frontier in Wave Solder Optimization