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Package Thickness Capability Improvement of Secure Microcontroller Flex-PCB-based Product through DMAIC Approach

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***Abstract*— *Secure microcontroller flex-PCB-based product is used for printer ink cartridges. One of the most critical characteristic of this product is the package thickness. Too low or too high package thickness will result to an assembly issue at customer's side. During the initial production line stressing stage, it was noted that the process performance or Ppk of package thickness is 45% way below the set plant Ppk target. This extremely low Ppk value attained strongly suggests that the package thickness response is highly inconsistent and would result to a projected high defect rate based from the Yield-PPM-sigma level chart. This will impact overall assembly yield performance. Package thickness Ppk improvement is therefore necessary to improve also the overall assembly yield.*

DMAIC tools and methodology will be used during the discussions in this technical paper in helping improve the package thickness Ppk and consequently improve overall assembly yield.

***Keywords*— *DMAIC; Package Thickness capability; Potting; Resin dispensing.*

I. INTRODUCTION

Secure microcontroller product uses flex-PCB (35-mm width tape with sprocket holes), reel-to-reel, and resin encapsulation (potting) technology. This product is used as a main component in one of the most leading printer brand's ink cartridge product. It provides ink cartridges a unique identity so that the printer can verify that it is genuine. It consists of a programmable crystal interconnected to a flex-PCB substrate through epoxy diebonding and gold wirebonding. Package outline is 4.94 mm x 9.5 mm x 0.625 mm. To be able to achieve the 0.625 mm package thickness, the potting resin height has to be limited from 0.400 to 0.550 mm dispensed over a 0.150 mm-thick CuNiAu plating flex-PCB substrate thus resulting to a package thickness specification of 0.550 to 0.700 mm.

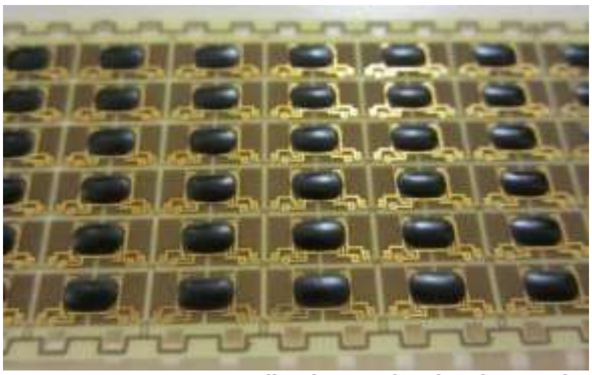

Figure 1. Secure Microcontroller Flex-PCB-based product sample

1.1 Define Phase

1.1.1 Low package thickness Ppk during Line stressing stage

During the initial line stressing stage of this product, large variation in package thickness is experienced per lot resulting to package thickness Ppk not meeting the desired plant target.

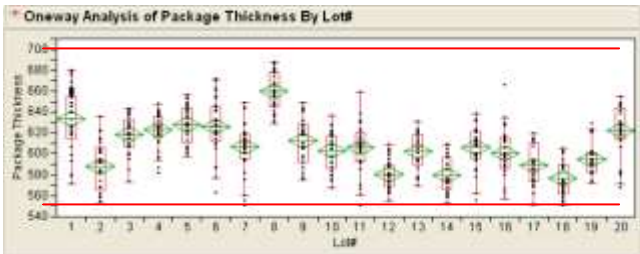

Figure 2. Initial line stressing data

1.1.2 Assembly defect pareto

Incorrect package thickness ranks 2nd based on the initial line stressing run defect pareto. The average incorrect package thickness PPM-defect rate experienced at the early weeks of production contributes to around 15% of the total assembly yield detractors.

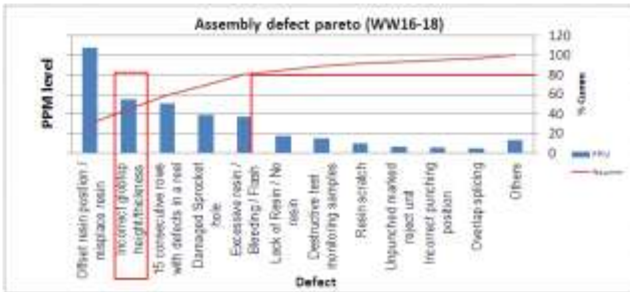

Figure 3. Assembly defect pareto

1.1.3 Potting process description

The potting process uses a 2-head dispense system; each head utilizes a 12-fold nozzle for faster resin encapsulation process. In-line curing is linked to the potting machine to instantly cure the dispensed resin. The 1st dispense head encapsulates the even rows while the 2nd head encapsulates the odd rows. Using a hand-held micrometer, the package thickness is manually measured then recorded to compute for the Ppk afterwards.

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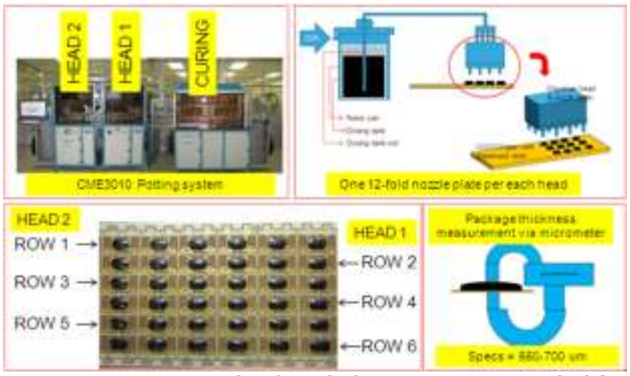

Figure 4. Potting process and package thickness measurement methodology

1.2 Map and Measure Phase

1.2.1 Macro Map

Potting process directly affects the package thickness response since the resin dispensed forms the top portion of the module. Furthermore, package thickness measurement is performed right after potting process, thus focus of the project is at this particular station.

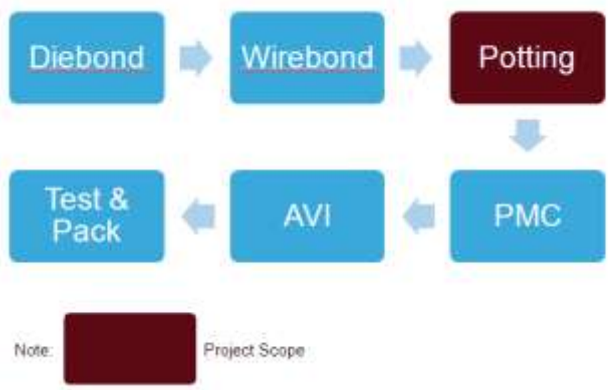

Figure 5. Macro process flow

1.2.2 Detailed potting process flow

To be able to identify the different potential factors or X's that may affect the output response or Y, potting process was broken down to per step level.

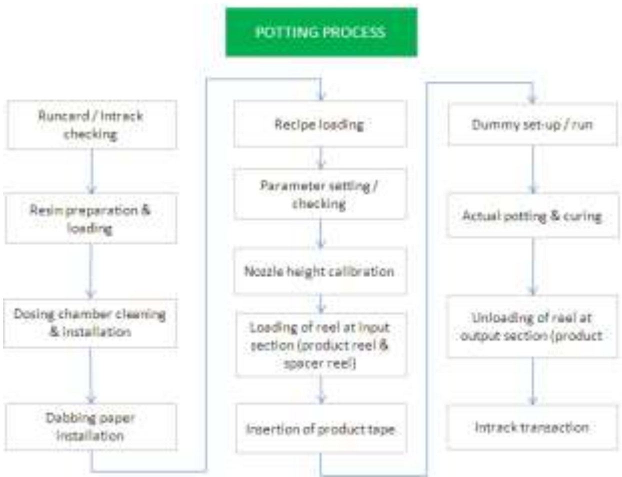

Figure 6. Potting process detailed flow

1.2.3 Input variable identification

Using an input-output worksheet or simply called an I-O worksheet, each particular step within the process was carefully examined to identify potential X's out of the Key Process Input Variables or KPIVs. In an I-O worksheet, each input variable is categorized based on the input type, characteristic and specification if applicable. In summary, there were 45 KPIVs identified as potential X's.

Table 1. Input-Output worksheet

			Process Inputs (KPIVs)						
Process Step	VA/NVA	SOP	Type of Input	Input	Characteristic of Input (KPIV / X)	C/N	Specification	MSA	Capability
Runcard / Intrack checking	NVA	8372295	Raw Material / Information	Actual lot in reel	Correctness of information (lot status)	Control lable	System vs actual must be tallied	n/a	n/a
Resin preparation & loading	VA	8372295	Raw Material / Information	Resin in can	Shelf life / temp	Control lable	7 months @ cold storage (0 to 5 °C) / 12 months @ freezer (-40 °C min) after date of manufacture	n/a	n/a

1.2.4 Cause & Effect prioritization

Using a cause and effect matrix or a CE matrix, the identified KPIVs from the I-O worksheet is tabulated and scored based on its impact to the Y which is package thickness consistency. A score of 0 for no impact to as high as 9 for strong impact on Y. The KPIVs getting a score of 3 or up is automatically selected and is prioritized for further analysis. In summary, there were 34 out of 45 KPIV's selected as potential X's.

Table 2. Cause and Effect Matrix

0 = No impact on Y
1 = Weak impact on Y
3 = Moderate impact on Y
9 =Strong impact on Y

Note: 1. If doubtful about the impact of X on Y, give at least 3 or 9
2. Ratings should be based on impact of X on Y irrespective of occurrence of cause (X)

Cause and Effect Matrix

				1						
				Package thickness consistency (ppK)						
			Is Y Continuous / Discrete?	Continuous						
			Customer Priority	8						
S.No	Process Step	Input	Characteristic of Input (KPIV / X)		Total	Is X Continuous / Discrete?	Operating Range (for X)	Count 3's	Count 9's	X Selected / Discarded?
1	Runcard / Intrack checking	Actual lot in reel	Correctness of information (lot status)	0	0	Discrete	System vs actual must be tallied	0	0	Discard the X

1.2.5 Failure mode & effects analysis

To further trim down the selected 34 KPIVs, Failure mode and Effects Analysis or FMEA is carried out. Each remaining KPIV is assessed based on the standard FMEA scoring for severity, occurrence, and detection. From these scores, the

Risk Priority Number or RPN is calculated. The RPN is simply the product of severity, occurrence, and detection scores. High RPN values indicate a more critical KPIV.

Table 3. Failure mode & effects analysis

Item / Function	Failure Mode	Failure Effect	SEV	Class	Failure Cause	Control Prevention	OCC	Control Detection	DET	RPN
Liquid Encapsulation	Low package thickness cpK	Scrapped parts (Yield impact)	7	F	Incorrect shelf life & temperature	Resin handling & storage procedure (S) / Product label showing manufacturing date (S)	2	Resin can label checking (EP3) / Cold storage & freezer	4	56
Liquid Encapsulation	Low package thickness cpK	Scrapped parts (Yield impact)	7	F	Incorrect thawing time & temperature	Resin thawing procedure (S / Use of Resin Exposure TAG (S) / Controlled thawing area (EP2)	2	Resin Exposure TAG checking (EP3) / Thawing room	4	56

1.2.6 *X-funnel reduction*

The KPIVs assessed using FMEA were transferred to an X-funnel worksheet. Using the FMEA RPN scores, only 13 KPIV's were finally selected from the X-funnel worksheet.

Table 4. X-funnel worksheet

Xs Funnel Reduction Sheet

S.No	Xs from I-O Worksheet / Fishbone Diagram	C&E Score: Score	C&E Score: Decision	FMEA Score: S	FMEA Score: O	FMEA Score: D	FMEA Score: RPN Score	FMEA Score: Decision
1	Correctness of information (lot status)	0	Reject					
2	Shelf life / temp	3	Select	7	2	4	56	Reject
3	Thawing time / temp	3	Select	7	2	4	56	Reject
4	Floor life	3	Select	7	2	4	56	Reject
5	Dosing tank condition	3	Select	7	2	4	56	Reject
6	Dosing chamber condition	3	Select	7	2	4	56	Reject
7	Resin hose condition	3	Select	7	2	4	56	Reject
8	Vacuum hose condition	3	Select	7	2	4	56	Reject
9	Compressed air Supply pressure	3	Select	7	2	4	56	Reject
10	Vacuum Supply pressure	3	Select	7	2	4	56	Reject
11	Dosing piston (golden nut & bolt) condition	3	Select	7	2	4	56	Reject
12	Dosing cylinder condition	3	Select	7	2	4	56	Reject
13	Nozzle plate condition	3	Select	7	2	4	56	Reject

1.2.7 *Measurement system analysis*

Measurement System Analysis or MSA was conducted prior starting the Analyze phase to ensure that the measurement system is fit for data gathering. This is very important to ensure that any variation determined during the data gathering stage is not coming from the measurement system itself.

1.2.7.1 *Stability test*

Stability test was performed using a calibrated 0.5 mm-thick reference block. Based on the X-bar & R charts, there is no out-of-control or special causes observed over time indicating that the measurement system is stable. This signifies that the measurement system can be used anytime without compromising the integrity of the data.

1.2.7.2 *Bias test*

Bias test passed in all three reference values. The low, mid, and high reference values used are calibrated reference blocks measuring 0.4 mm, 0.6 mm, and 0.8 mm-thick respectively. Bias test performed on all reference blocks show p-values greater than 0.05. This indicates that the measurement system will give the correct measurement in reference to actual or true value.

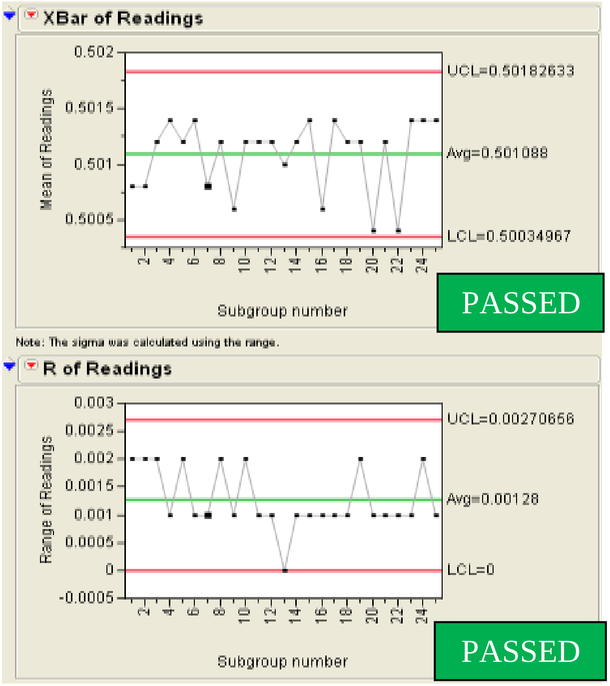

Figure 7. Stability testing using a 0.5 mm-calibrated reference block

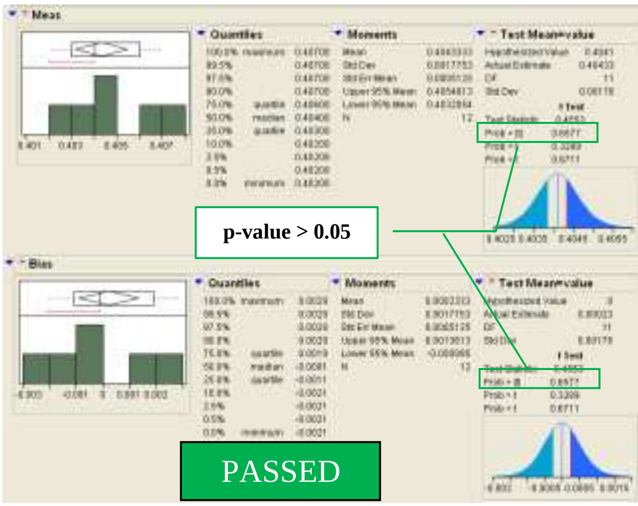

Figure 8. Bias testing using a 0.4 mm-calibrated reference block

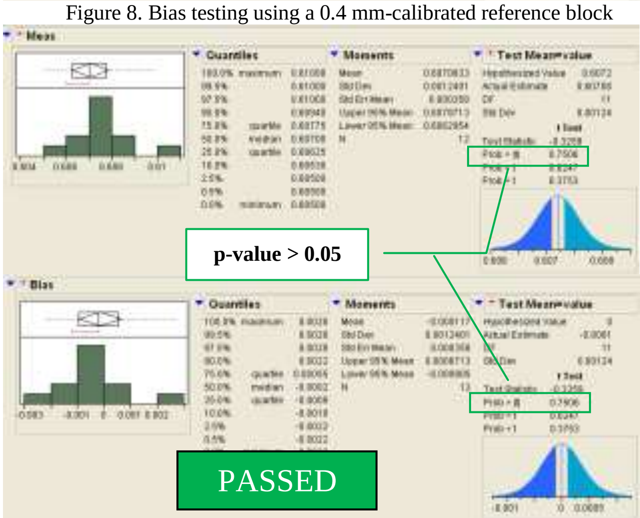

Figure 9. Bias testing using a 0.6 mm-calibrated reference block

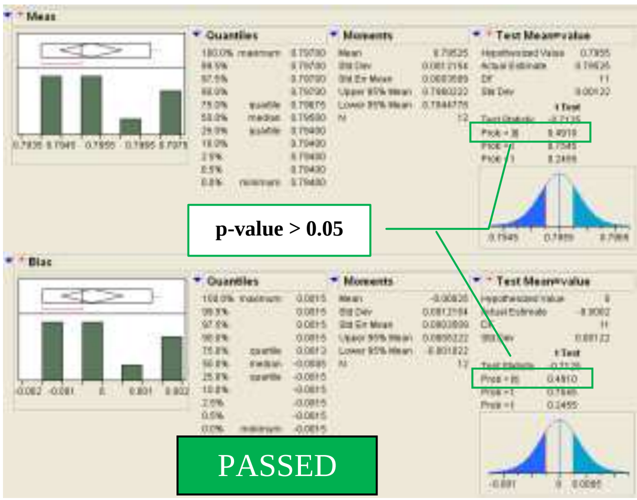

Figure 10. Bias testing using a 0.8 mm-calibrated reference block

1.2.7.3 Linearity test

Measurement system is passing the linearity test. Intercept and reference p-values are greater than 0.05 thus measurement tool is acceptable in terms of linearity. This indicates that the measurement system will give the correct value over the expected operating range of the gauge.

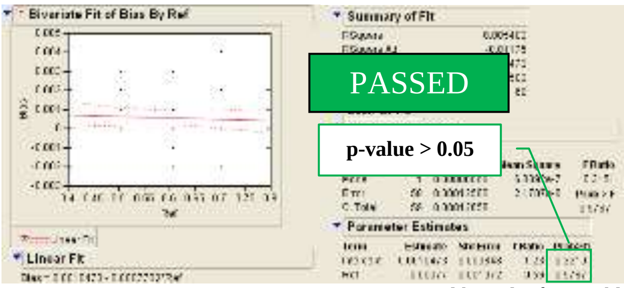

Figure 11. Linearity testing using 0.4 to 0.8 mm-calibrated reference blocks

1.2.7.4 Gauge repeatability & reproducibility

Measurement system passed the Gauge Repeatability & Reproducibility test or GR&R test based on percent repeatability & reproducibility or %R&R, number of distinct categories or NDC, and precision-to-tolerance or P/T ratio values. This signifies that the measurement system will give the correct data regardless of user and will give the same value regardless of number of measurement done.

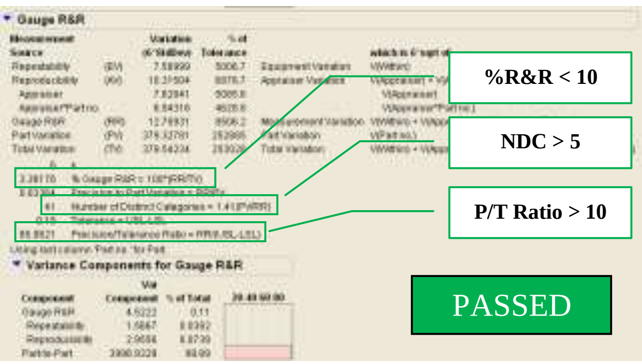

Figure 12. Gauge repeatability & reproducibility testing

1.2.8 Current process performance

Package thickness capability is not meeting the set plant target based on the weekly SPC monitoring from production data. The average package thickness Ppk from WW1214 to WW1225 is significantly comparable with the computed Ppk from the line stressing lots.

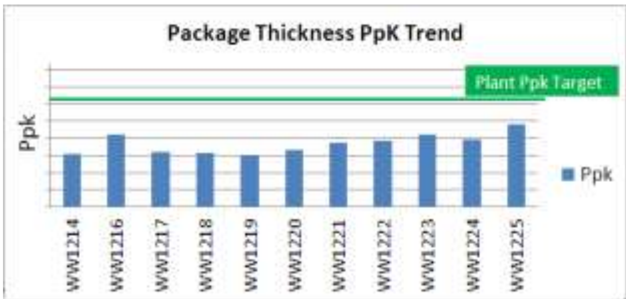

Figure 13. Package thickness Ppk trend

1.2.9 Quick wins

Based on the FMEA & X-funnel reduction performed, immediate actions were established to be able to address low-hanging fruit issues discovered from 7 out of the final 13 KPIVs. These actions are summarized as below:

1. Establish PM frequency (cleaning & checking of de-aeration line)
2. Installation of resin fumes exhaust line near the dispense bed area to prevent resin fumes crystallization on dosing pistons or push pin
3. Establish minimum tape Z-height parameter setting.
4. Installation of resin purge valve to improve resin purging effectiveness during resin change
5. Re-design dispense bed by relocating vacuum holes to correct position. Fabricate & install on potting machine.
6. Establish PM frequency (cleaning & checking of dispense bed vacuum line)
7. Installation of resin weighing system for all dosing tanks to ensure effective resin volume monitoring
8. Establish weight limit for resin left-over to ensure sufficient volume of resin in tank during dispensing
9. Modify design of resin tank rod to maximize resin left-over in tank. Install on dosing tanks.
10. Establish standard measurement methodology of package thickness using micrometer.

II. EXPERIMENTAL SECTION

2.1 Analyze Phase

2.1.1 Validation plan

A statistical test plan was prepared to help analyze statistically the contribution of the remaining 6 out of the final 13 KPIVs to the package thickness Ppk.

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Table 5. Statistical test plan matrix

Statistical Test Plan and Results

Y (or mini Y)	Unit of Meas	Y treated as	X	True nature of X	Range of X, if continu	Levels of X, if discrete or converted	Hypothesis Statement: Null Hypothesis	Hypothesis Statement: Alternative	Graphical Analysis	Statistical Test	Beta	Alpha	Sample Size
package height	um	Continuous	Product tape condition / flatness	Discrete	N/A	With clamp Without clamp	[illegible]	[illegible]	One way analysis	F-test	0.1	0.1	156 (26 per row)
package height	um	Continuous	Delay discharge after intake valve	Continuous	~50 ms	50 ms 150 ms	[illegible]	[illegible]	na	DOE	0.1	0.1	24 (4 per row)
package height	um	Continuous	Delay move back dosing piston	Continuous	~0 ms	0 ms 100 ms	[illegible]	[illegible]	na	DOE	0.1	0.1	24 (4 per row)
package height	um	Continuous	Delay intake valve	Continuous	~20 ms	20 ms 120 ms	[illegible]	[illegible]	na	DOE	0.1	0.1	24 (4 per row)
package height	um	Continuous	Delay discharge valve	Continuous	~20 ms	20 ms 120 ms	[illegible]	[illegible]	na	DOE	0.1	0.1	24 (4 per row)
package height	um	Continuous	Delay till intake stop	Continuous	~0 sec	0 sec 9.9 sec	[illegible]	[illegible]	na	DOE	0.1	0.1	24 (4 per row)

2.1.2 Validation on product tape condition

2.1.2.1 Normality testing

Based on the normality test performed, package thickness distribution is non-normal. The p-value < 0.05 indicates that package thickness distribution is non-normal.

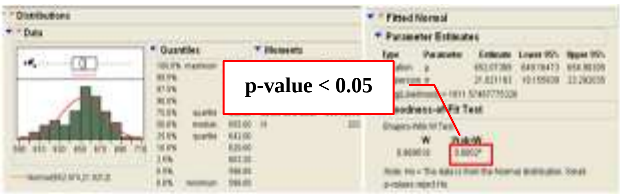

Figure 14. Normality testing on package thickness data distribution

2.1.2.2 One-way analysis per row

Package thickness per row was analyzed. Result shows that row edges (1st & 6th row) have the largest variation on potting thickness. The p-value likewise shows that there is significant difference between row to row in terms of package thickness. Average readings on inside rows are comparable with each other, while outside rows have lower average readings. These factors contribute to the overall low Ppk.

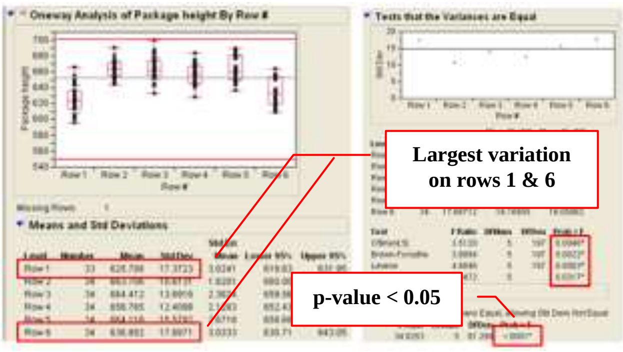

Figure 15. One-way analysis of package thickness data per row

2.1.2.3 Defect mechanism

Existing dosing table on potting machine uses vacuum only as its holding mechanism for the tape during dispensing. Tape planarity during dispensing is not completely achieved with this existing design resulting to uneven potting height. The modules on the 1st & 6th row of the tape are not properly settled on the dosing table during dispensing resulting to large variation on potting thickness.

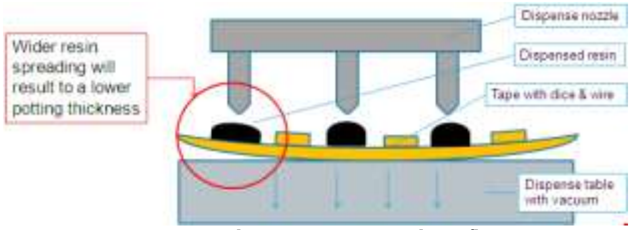

Figure 16. Resin dispensing on a non-planar flex-PCB

Potting process utilizes volumetric resin dispensing to achieve consistent resin volume & potting thickness per module. However, the non-planar tape during dispensing will result to uneven potting thickness due to inconsistent resin spreading.

2.1.2.4 Statistical testing of proposed action

A 2-variance test or F-test was performed to test the hypothesis statement that the package thickness standard deviation with clamp is lesser than without clamp. Dosing bed was installed with a pizza-roller type clamp + spring clamp type on railing to check if it will improve planarity of tape during resin dispensing.

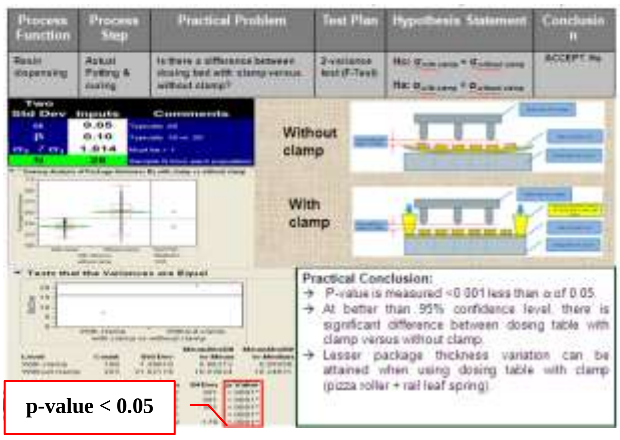

Figure 17. Statistical testing (F-test) with clamp versus without clamp

P-value is measured < 0.001 which is less than α of 0.05. At better than 95% confidence level, there is significant difference between dosing table with clamp versus without clamp. Lesser package thickness variation can be attained when using dosing table with clamp (pizza roller + rail leaf spring).

The graphs below show the comparison of before and after clamping installation. Notice the significant improvement in the package thickness variation per row after clamp installation.

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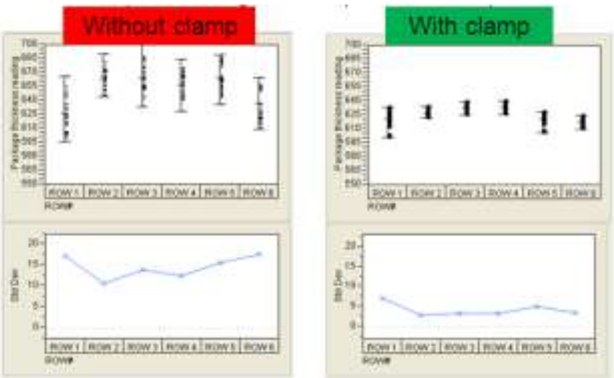

Figure 18. Package thickness per row data with clamp versus without clamp

Both conditions (clamp versus without clamp) manifest a non-normal distribution (p-level < 0.05), thus transformation was performed prior computing for the non-normal process capability or Cpnk.

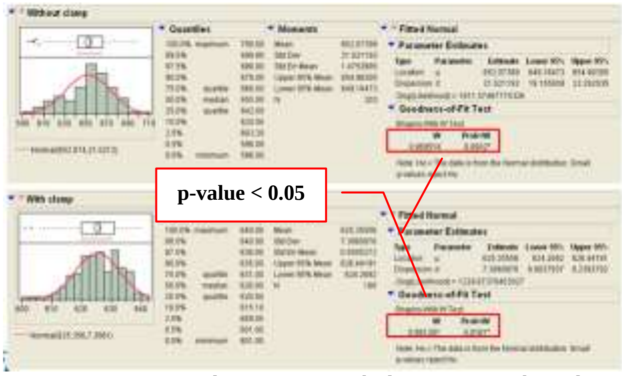

Figure 19. Normality testing on with clamp versus without clamp

Overall package thickness Cpnk significantly improved by three-fold after clamp installation. This improvement is attributed to the decrease in package thickness variation per row due to new clamp installed.

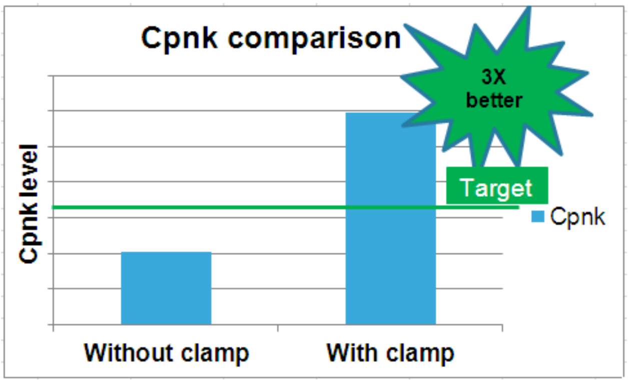

Figure 20. Cpnk comparison of with clamp versus without clamp

2.1.3 Validation result

1 of 1 potential critical X's that undergo validation was found to be valid. Other factors will be validated through DOE.

Table 6. Validation results matrix

Statistical Test Plan and Results

Y (or mini Y)	Unit of Meas	Y treated as	X	True nature of X	Range of X, if continuous	Levels of X, if discrete or converted into	Hypothesis Statement: Null Hypothesis	Hypothesis Statement: Alternative Hypothesis	Graphical Analysis	Statistical Test	Beta	Alpha	Sample Size	p-value	Decision
package height	um	Continuous	Product base condition / flatness	Discrete	N/A	With clamp Without clamp	$\sigma_{with\ clamp} = \sigma_{without\ clamp}$	$\sigma_{with\ clamp} < \sigma_{without\ clamp}$	One-way analysis	F-test	0.1	0.05	[illegible]	0.001	X is significant Hence, move forward
package height	um	Continuous	Delay discharge after intake	Continuous	> 50 ms	50 ms 150 ms	$\mu_{50\ ms} = \mu_{150\ ms}$	$\mu_{50\ ms} \neq \mu_{150\ ms}$	na	DOE	0.1	0.05	[illegible]		
package height	um	Continuous	Delay move back dosing piston	Continuous	> 0 ms	0 ms 100 ms	$\mu_{0\ ms} = \mu_{100\ ms}$	$\mu_{0\ ms} \neq \mu_{100\ ms}$	na	DOE	0.1	0.05	[illegible]		
package height	um	Continuous	Delay intake valve	Continuous	> 20 ms	20 ms 120 ms	$\mu_{20\ ms} = \mu_{120\ ms}$	$\mu_{20\ ms} \neq \mu_{120\ ms}$	na	DOE	0.1	0.05	[illegible]		
package height	um	Continuous	Delay discharge valve	Continuous	> 20 ms	20 ms 120 ms	$\mu_{20\ ms} = \mu_{120\ ms}$	$\mu_{20\ ms} \neq \mu_{120\ ms}$	na	DOE	0.1	0.05	[illegible]		
package height	um	Continuous	Delay till intake stop	Continuous	> 0 sec	0 sec 9.9 sec	$\mu_{0\ sec} = \mu_{9.9\ sec}$	$\mu_{0\ sec} \neq \mu_{9.9\ sec}$	na	DOE	0.1	0.05	[illegible]		

III. Results and Discussion

3.1 Implementation phase

3.1.1 DOE planning sheet

2K factorial was designed with package thickness average and standard deviation as response. The experiment includes 2 replicates and a blocking variable (dosing head). A total of 128 runs in all.

Table 7. Design of Experiment matrix

Response #	Type	Unit of Measure	Specification
Response 1	Package thickness (stdev)	µm	Minimize
Response 2	Package thickness (average)	µm	550-700

S.No	Input Variables	Levels	Specifications
1.	Delay discharge after intake valve	50 ms, 150 ms	
2.	Delay move back dosing piston	0 ms, 100 ms	
3.	Delay intake valve	20 ms, 120 ms	
4.	Delay discharge valve	20 ms, 120 ms	
5.	Delay till intake stop	0 sec, 9.9 sec	

S.No	Noise Variables	Measurable?
1.	Dosing Head	No

Type of Experiment Design	2K Factorial
Sample Size (Number of	2
Sample Size (Number of Repeats)	4

3.1.2 DOE Results

The low Rsquare Adj for both standard deviation and package thickness indicates that only a small amount of the total variation is adequately explained.

For the package thickness (average) response, at better than 95% confidence level, Delay Intake valve & Delay till intake stop are found to be insignificant (p-value = 0.8932 & 0.5394 respectively, do not reject Ho), while Delay discharge valve is very significant (p-value < 0.001, reject Ho). Delay discharge after intake valve & Delay move back dosing piston were not removed since it interacts with Delay discharge valve.

Although the whole model ANOVA is significant (<0.0001), the predictive capability of the model is unsatisfactory with an Rsquare Adj of only below 50%

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indicating that only 50% of the total variation is adequately explained. Below is the drawn-out equation:

Package thickness (average) = 621.9127 – 1.4986 (Delay discharge after intake valve) – 1.0636 (Delay move back dosing piston) – 5.7461 (Delay discharge valve) – 1.8292 (Delay discharge after intake valve*Delay discharge valve) – 1.8111 (Delay move back dosing piston*Delay discharge valve)

RSquare	0.517808
RSquare Adj	0.476023
Root Mean Square Error	6.651413
Mean of Response	621.9127
Observations (or Sum Wgts)	64

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	2753.3254	550.665	12.4469
Error	58	2565.9954	44.241	Prob > F
C. Total	63	5319.3208		<.0001*

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
				1.0204
Lack Of Fit	2	90.2214	45.1107	Prob > F
Pure Error	56	2475.7740	44.2103	0.3671
Total Error	58	2565.9954		Max RSq
				0.5346

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	621.91266	0.831427	748.01	<.0001*
Delay discharge after intake valve(50,150)	-1.498594	0.831427	-1.80	0.0767
Delay move back dosing piston(0,100)	-1.063594	0.831427	-1.28	0.2059
Delay discharge valve(20,120)	-5.746094	0.831427	-6.91	<.0001*
Delay discharge after intake valve*Delay discharge valve	-1.829219	0.831427	-2.20	0.0318*
Delay move back dosing piston*Delay discharge valve	-1.811094	0.831427	-2.18	0.0335*

Figure 21. Package thickness average response ANOVA

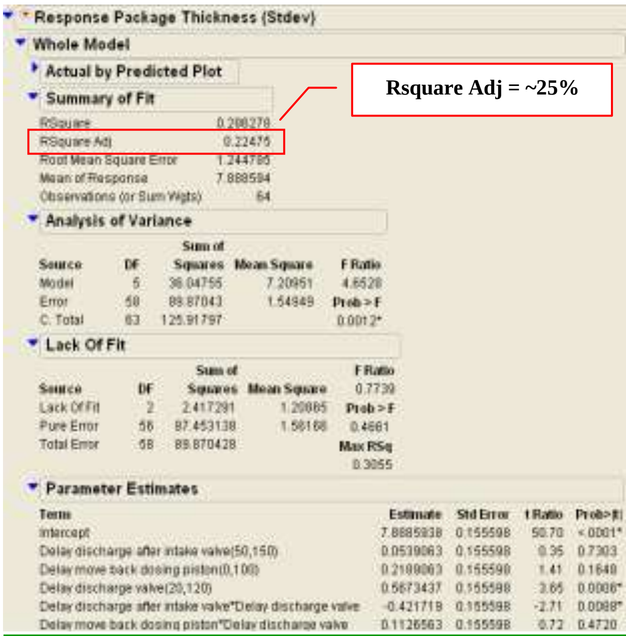
For the package thickness (stdev) response, at better than 95% confidence level, Delay Intake valve & Delay till intake stop are found to be insignificant (p-value = 0.9073 & 0.6123 respectively, do not reject Ho), while Delay discharge valve is very significant (p-value = 0.0014, reject Ho). Delay discharge after intake valve & Delay move back dosing piston were not removed since it interacts with Delay discharge valve.

Although the whole model ANOVA is significant (=0.0012), the predictive capability of the model is unsatisfactory with an Rsquare Adj of only below 25% indicating that only 25% of the total variation is adequately explained. Below is the drawn-out equation:

Package thickness (stdev) = 7.8886 + 0.0539 (Delay discharge after intake valve) + 0.2189 (Delay move back dosing piston) + 0.5673 (Delay discharge valve) – 0.4217 (Delay discharge after intake valve*Delay discharge valve) + 0.1126 (Delay move back dosing piston*Delay discharge valve)

3.1.3 DOE Optimization

From the prediction profiler, the optimum response in package thickness average and stdev responses can be achieved by setting delay discharge after intake valve, delay move back dosing piston, & delay discharge valve at low level (50 ms, 0 ms, & 20 ms respectively). Although delay move back dosing piston & delay discharge after intake valve as independent factors are insignificant, it cannot be set arbitrarily at any level because it is significantly interacting with delay discharge valve.



RSquare	0.286278
RSquare Adj	0.22475
Root Mean Square Error	1.244786
Mean of Response	7.888594
Observations (or Sum Wgts)	64

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	36.04755	7.20951	4.6528
Error	58	89.87043	1.54949	Prob > F
C. Total	63	125.91797		0.0012*

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
				0.7739
Lack Of Fit	2	2.417291	1.20865	Prob > F
Pure Error	56	87.453138	1.56166	0.4661
Total Error	58	89.870428		Max RSq
				0.3055

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	7.8885938	0.155598	50.70	<.0001*
Delay discharge after intake valve(50,150)	0.0539063	0.155598	0.35	0.7303
Delay move back dosing piston(0,100)	0.2189063	0.155598	1.41	0.1648
Delay discharge valve(20,120)	0.5673437	0.155598	3.65	0.0006*
Delay discharge after intake valve*Delay discharge valve	-0.421719	0.155598	-2.71	0.0088*
Delay move back dosing piston*Delay discharge valve	0.1126563	0.155598	0.72	0.4720

Figure 22. Package thickness stdev response ANOVA

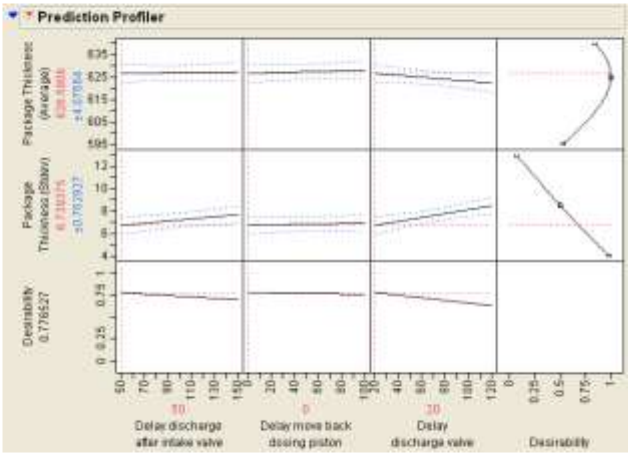


Figure 23. Prediction profiler

3.1.3 Validation of optimum condition

Package thickness capability is highly acceptable using the optimum condition learned from the DOE study. Both dispense heads show good process capability or cpk based from actual production validation lot.

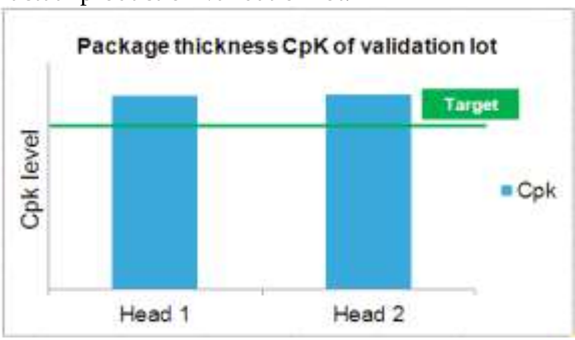


Figure 24. Validation of optimum condition

Saldo Rex Salivio, Wency Ubana Jr., and Herbert Fernandez, "Package Thickness Capability Improvement of Secure Microcontroller Flex-PCB-based Product through DMAIC Approach," *International Research Journal of Advanced Engineering and Science*, Volume 4, Issue 4, pp. 28-35, 2019.

3.1.4 Corrective / Preventive Actions

Actions were generated and implemented based on the validation and DOE results.

Table 8. Corrective / Preventive Action Matrix

Item	Problem	Validated KPIV/Cause	Containment Action	Permanent Action	Responsible / Completion Date	Status
1	Low package thickness ppk	Substrate tape not flat on dosing table during dispensing	-	Installation of tape pizza rollers on dispensing beds	S. Salivio / WW1226	Done
			-	Installation of leaf spring clamp on dispensing bed's transport rail	S. Salivio / WW1226	Done
2	Low package thickness ppk	Valve timing (delay parameters) no optimized	-	Set delay parameters to optimum settings based on DOE conducted	S. Salivio / WW1327	Done

3.1.5 Implementation Results

Both Ppk and PPM targets were simultaneously met starting July 2013. Highest impact contribution on Ppk improvement is attributed to the installation of clamp mechanism on dosing bed. Measurement methodology standardization is a complementary action to the clamp mechanism installation as can be seen in the graph at points A and B. The full implementation of quick win actions and the DOE results actions further stabilized the PPM level as shown in points C and D of the graph.

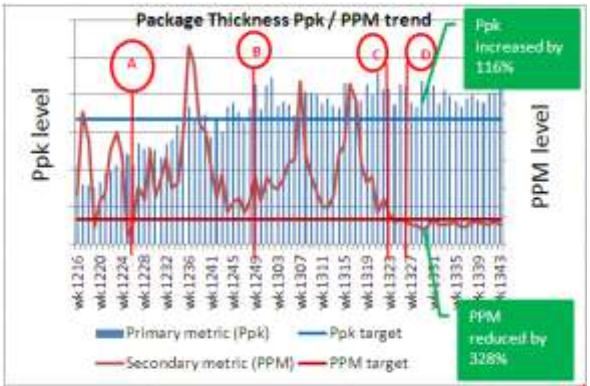


Figure 25. Package Thickness Ppk / PPM trend

In summary, Ppk increased by 116% while PPM defect-rate was significantly reduced by 328% as compared to their corresponding initial line stressing values.

Table 9. Document update matrix

Item	Action Item	Due Date	Responsible	Doc # / Rev	Remarks
1	Potting monitoring procedure - Update procedure on potting thickness measurement methodology	WW12 49	R. Yu	8384553 / B	Done
2	FMEA for Potting - update process FMEA to include additional potential failure causes & corresponding controls established	WW13 50	S. Salivio	F00005258	Done

3.2 Control Phase

3.2.1 Documentation

As part of standardization practice, pertinent documents were revised and updated to reflect the changes and improvements made through this project.

IV. CONCLUSION

We therefore conclude that package thickness Ppk can be improved significantly by installing clamping mechanism for flex-PCB-based substrates at potting dispense bed. This ensures that resin is dispensed evenly across all modules thus lessening the package height variation row-to-row and eventually improving the Ppk performance.

The improvement in package thickness Ppk translates also to a reduction in the reject PPM level thus improving yield and significantly reducing the risk of customer returns.

V. RECOMMENDATIONS

It is recommended to fan-out all the machine improvements to future potting machine acquisitions and similar dispensing technology and platform.

VI. ACKNOWLEDGMENT

First and foremost, we give thanks and glory to our Lord for providing us strength and wisdom to successfully complete this project.

We give our deepest gratitude to our family who empowered us to continue and persevere in our work.

We would like to recognize also the support and commitment accorded to us by our former Assembly Director Jun Bernabe, OPS1 Assembly & TnF Director Ernesto Arcebal and Quality Director Dr. Tony Villaflor.

Lastly, this project wouldn't have been accomplished without the proper guidance of our advisers Leojay Manuel, Joseph Tuazon, Vincent Sanil, Dr. Bernie Redona, and our six-sigma black belt champion Ms. Mairel Diocera.

REFERENCES

- Equipment manuals
- SAS-JMP Manuals

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Saldo Rex Salivio, Wency Ubana Jr., and Herbert Fernandez, "Package Thickness Capability Improvement of Secure Microcontroller Flex-PCB-based Product through DMAIC Approach," *International Research Journal of Advanced Engineering and Science*, Volume 4, Issue 4, pp. 28-35, 2019.