ULTRASONIC CLEANING INTEGRATION IN VALUE-ADDED MANUFACTURING (VAM): A NOVEL APPROACH TO YIELD IMPROVEMENT

Jaypee Dumaguit
Ronald Aaron Diaz

Research and Development – NPI Department, MedTech and Specialty Audio
Knowles Electronics (Philippines) Corporation, Cebu Light Industrial Park, Basak, Lapu-Lapu City, Cebu
Jaypee.Dumaguit@knowles.com
Ronald.Diaz@knowles.com

ABSTRACT

This paper presents a significant yield improvement initiative in the Value Added Manufacturing (VAM) processes of Knowles Electronics Philippines, where the baseline yield of 90% was significantly increased to 99% through the use of the Lean Six Sigma Methodology.

A comprehensive root cause analysis was performed, which identified contamination-related defects as the primary yield limiter. In response, a novel cleaning process utilizing ultrasonic technology was conceptualized and implemented, replacing conventional cleaning techniques that were insufficient at removing the contamination.

The introduction of ultrasonic cleaning addressed the contamination issue and process variability, leading to more consistent output quality. The creative redesign of the cleaning stage demonstrated both technical innovation and strategic agility, achieving rapid deployment without disrupting production flow. This study highlights the effectiveness of combining structured DMAIC problem-solving framework with innovative process engineering to drive substantial yield improvements in the electronics manufacturing environment.

1.0 INTRODUCTION

1.1 Background of the Study

Value-Added Manufacturing (VAM) is a highly complex process where even minor process inefficiencies can significantly impact overall yield and profitability. Yield losses often stem from microscopic defects or contamination introduced during the connector assembly. In high-volume production environments, improving yield is not just a matter of efficiency—it is a critical competitive advantage. At the center of this challenge lies the need for innovative, cost-effective solutions that enhance process reliability without requiring extensive equipment changes or capital investment. This study emerged from a recurring issue within the VAM cleaning stage, where standard methods of swabs dipped into IPA were unable to effectively remove certain flux contaminants, leading to reduced product quality and rework. A deeper investigation, guided by the DMAIC methodology, led to the development and implementation of a novel ultrasonic cleaning process aimed at restoring and enhancing yield performance.

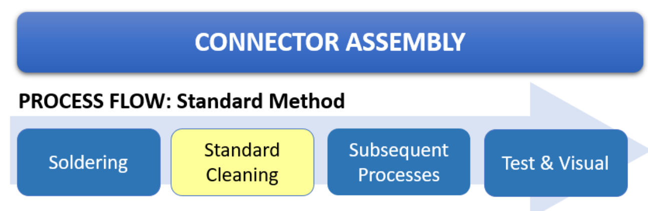


Fig. 1. Process Flow of Standard Cleaning of Connector Assembly

1.2 Statement of the Problem

The primary issue addressed in this study is the suboptimal connector yield in the assembly line, which was at 90%. Despite adherence to established process controls, yield losses persisted, primarily due to insufficient cleaning performance that allowed microscopic flux contaminants to remain on connector surfaces. These residual particles were identified as the leading contributors to downstream defects, ultimately affecting functional performance and reliability. Previous attempts to optimize the existing cleaning methods yielded only marginal improvements. A more effective, innovative approach was necessary to significantly improve yield while maintaining throughput and quality standards.

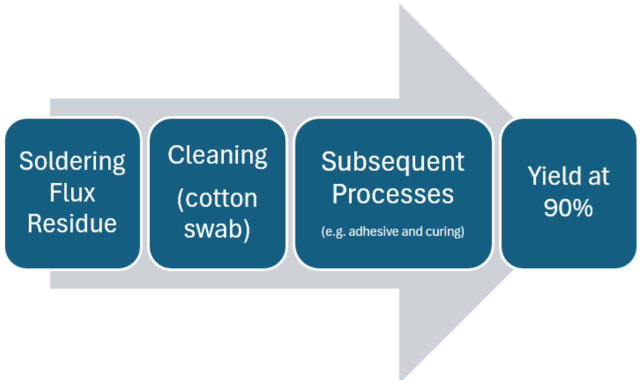


Fig. 2. Elemental processing steps leading to suboptimal yield at 90%

1.3 Objectives of the Study

The main objective of this study is to improve connector yield in the manufacturing process of Knowles Electronics Philippines from 90% to a targeted 99% through the implementation of a reengineered cleaning solution.

Specifically, the study aims to: (1) map out the source of contact pin contamination using the DMAIC framework; (2) design and integrate a novel ultrasonic cleaning technique to address those causes; and (3) validate the effectiveness of the new process through yield tracking and defect analysis. The study also seeks to demonstrate how creative problem-solving and disciplined process improvement methodologies can deliver rapid, high-impact results in a highly controlled production environment.

2.0 REVIEW OF RELATED WORK

Ultrasonic cleaning is a highly effective method widely employed in electronics manufacturing to ensure the cleanliness and reliability of sensitive components such as printed circuit boards (PCBs) and electronic modules. The process utilizes high-frequency sound waves, typically ranging from 20 kHz to 200 kHz, which are transmitted through a liquid cleaning medium—usually water or specialized cleaning solutions.

When these ultrasonic waves propagate through the liquid, they induce rapid pressure fluctuations that create microscopic cavitation bubbles. These bubbles grow and collapse violently in a process known as cavitation, generating localized high-energy jets and shock waves. This mechanical action dislodges and removes contaminants such as flux residues, oils, dust, solder particles, and other pollutants from the surfaces of electronic components. Importantly, ultrasonic cleaning is capable of reaching intricate, recessed, and hard-to-access areas without the need for disassembly, making it especially valuable for complex assemblies.

By effectively eliminating contaminants, ultrasonic cleaning plays a critical role in preventing corrosion, electrical shorts, and other failures that can compromise product performance and longevity. This contributes to enhanced product reliability and reduces the risk of costly rework or warranty claims. [1].

3.0 METHODOLOGY

This study employs the DMAIC (Define, Measure, Analyze, Improve, Control) methodology (refer to Fig.3) to have a structured & phased approach, data-driven decision making, and emphasis on sustainability (control phase). Moreover, it promotes a culture of continuous improvement leading to higher quality and increased efficiency.

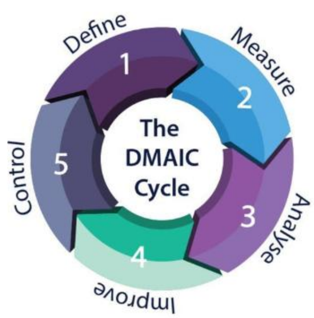


Fig. 3. Root Cause Framework using DMAIC Methodology

3.1. Define Phase

In the Define Phase, the project scope was precisely delineated to concentrate specifically on the connector cleaning process, which was identified as the primary bottleneck impacting overall yield performance. This focused approach ensured that efforts were targeted toward the most critical area affecting product quality and throughput. To effectively address the issue, a cross-functional team was assembled, comprising experts from various relevant disciplines: process engineers who understand the manufacturing workflow, quality engineers responsible for defect analysis and control, and equipment engineers with expertise in the cleaning machinery and technology. This diverse team structure facilitated a comprehensive understanding of the problem from multiple perspectives, enabling a well-rounded approach to problem-solving.

3.2 Measure Phase

During the Measure Phase, the team systematically collected baseline data related to the connector yield and defect rates prior to any process improvements. This involved gathering quantitative metrics on the number of connectors produced, the percentage meeting quality standards, and the types and frequencies of defects encountered (see Fig. 4 & Fig. 5). The Pareto chart of failures indicates that contamination on the contact pin (Cement NG) is the top yield detractor for the connector assembly.

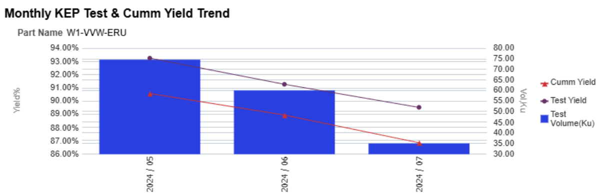


Fig. 4 Yield running from 87% to 93%. Average yield is 90%.

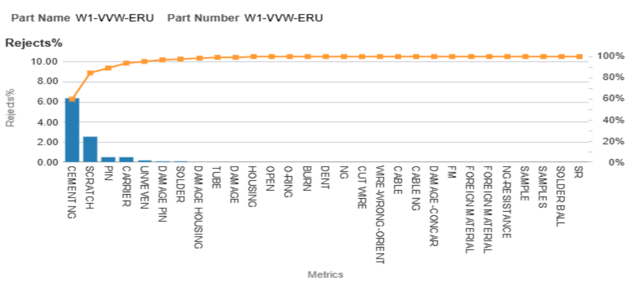


Fig. 5 Pareto of Rejects

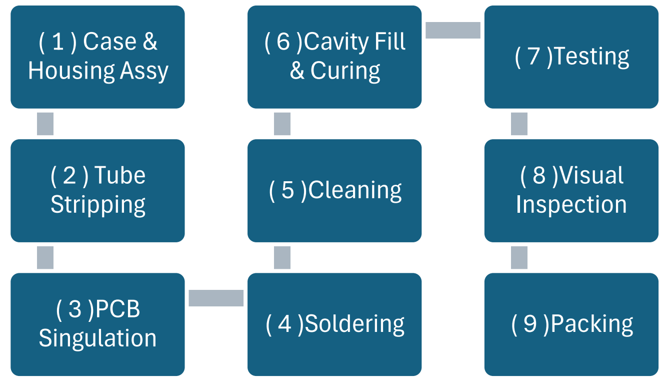


Fig.6 Connector Assembly Process Flow

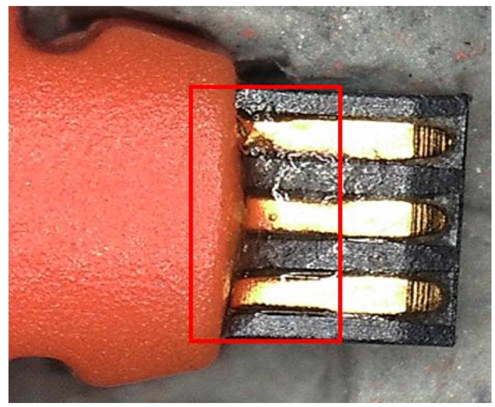


Fig. 7 Defect Signature found either in Curing, Testing & Visual

3.3 Analyze Phase

3.3.1 Process Mapping & Component Contaminant Analysis

During the Analyze Phase, the project team undertook a comprehensive process mapping exercise to gain a detailed understanding of the entire connector assembly workflow and to identify potential sources contributing to yield loss. The process map, illustrated in Figure 6, visually represents each step in the assembly sequence, providing a clear overview of the flow from initial component preparation through to final inspection.

From this detailed process mapping, critical insights were gained regarding the stages at which contamination-related defects predominantly occurred. Specifically, defect signatures associated with contaminants were detected during three key process steps: Cavity Fill & Curing (Step 6), Testing (Step 7), and Visual Inspection (Step 8), as highlighted in Figure 7. This observation suggested that contamination issues were not isolated to a single stage but rather spanned multiple phases of the assembly process, indicating the need for targeted investigation at these points.

To further characterize the nature of the contamination, representative samples exhibiting defects were subjected to elemental analysis using Energy Dispersive X-ray Spectroscopy (EDX). This analytical technique enabled the team to determine the precise elemental composition of the contaminants present on the printed circuit board (PCB) surfaces. The results, presented in Figure 8, revealed that the elemental profile of the contaminants closely matched that of the flux and adhesive materials used during assembly. This finding confirmed that residues from these substances were contributing to the observed defects, thereby pinpointing a critical source of contamination impacting connector quality.

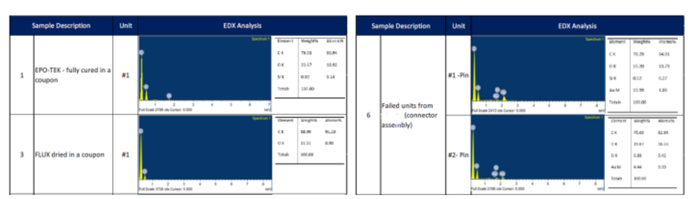


Fig. 8 EDX Analysis of Components used (Adhesive (1), Flux (3) & Reject sample (4)

The process mapping and elemental analysis provided a foundation for understanding the contamination problem, enabling the team to focus subsequent improvement efforts on mitigating flux and adhesive residues during the identified process steps.

3.3.2 Design Limitation

Further in-depth analysis and physical teardown of the connector assemblies revealed a critical insight regarding the source and pathway of contamination escape. It was observed that the contaminants were creeping out exclusively from one side of the assembly. This asymmetrical leakage was traced back to a specific design characteristic of the connector's sealing structure.

Upon closer examination, it was determined that the side exhibiting contamination escape corresponded to the region where the sealing wall was notably thinner compared to other areas. This thinner wall section represented the weakest point in the seal integrity, effectively serving as the path of least resistance for contaminants to migrate outward. Figure 9 illustrates this design feature and highlights the localized area where the seal's structural vulnerability exists.

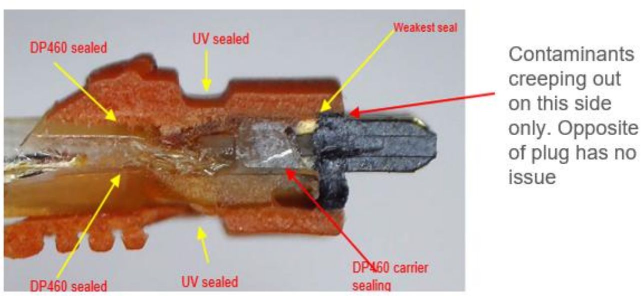


Fig. 9 Product Structure and the Adhesives

3.3.3 Why-Why Analysis

Figure 10 illustrates the detailed cause-and-effect revealed by the Why-Why Analysis.

The findings emphasize that the Standard Cleaning process did not adequately address the nature of the contaminants, nor did it reach all critical surfaces of the pins.

Identifying this fundamental process weakness provided a clear direction for improvement efforts to adopt a more robust and thorough cleaning technology such as ultrasonic cleaning to effectively eliminate contaminants and enhance connector quality.

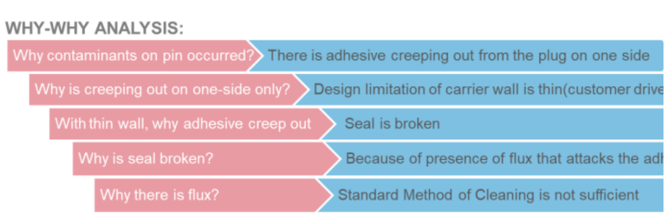


Fig. 10. Why-Why Analysis

3.4 Improve Phase

In the Improve Phase, the project team focused on developing a novel ultrasonic cleaning process specifically designed to address the root cause of contamination caused by flux residues on connector pins. Recognizing that traditional cleaning methods were insufficient, the team leveraged ultrasonic technology to enhance contaminant removal efficacy (refer to Fig. 11).

Fig. 11. Ultrasonic Process in Effectively Cleaning the Flux Contaminants

A series of controlled experiments were systematically conducted to optimize critical cleaning parameters, These experiments were carefully designed to ensure that the ultrasonic cleaning process was fully compatible with the delicate materials and components used in the connectors, avoiding any risk of damage or degradation. Additionally, the process was tailored to integrate seamlessly with the existing manufacturing flow, minimizing disruption and maintaining throughput.

To systematically optimize the ultrasonic cleaning process, a full factorial Design of Experiment (DOE) was conducted. This approach allowed the team to evaluate the effects and interactions of two critical input variables—Tab1 (representing the duration of Isopropyl Alcohol (IPA) ultrasonic cleaning) and Tab2 (representing the duration of Deionized (DI) water ultrasonic cleaning)—on the cleanliness of the connector pins, which was identified as the key output response metric. The ultrasonic cleaning frequency was fixed at 40 Hz and could not be adjusted based on the existing machine setup.

Figure 12 illustrates the optimum ultrasonic cleaning parameters derived from this experimental study. To further refine and finalize the cleaning settings, the Response Optimizer tool within the Minitab statistical analysis software was utilized.

StdOrder	RunOrder	CenterPt	Blocks	Tab1	Tab 2	Cement on Pin
2	1	1	1	10	5	1.00
4	2	1	1	10	10	0.95
3	3	1	1	5	10	0.85
1	4	1	1	5	5	0.75

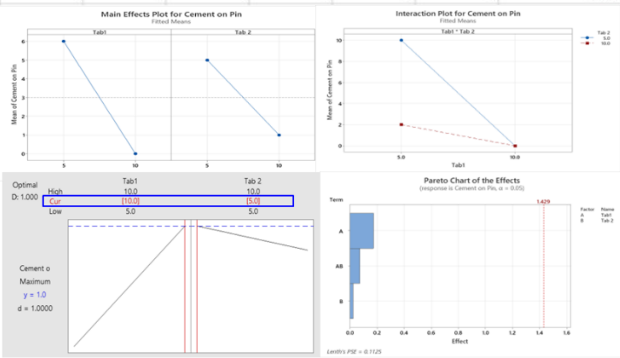


Fig. 12. Optimum Parameter for Ultrasonic Washing.

The optimization process concluded that the best cleaning performance was achieved with Tab1 set to 10 minutes of IPA ultrasonic cleaning, followed by Tab2 set to 5 minutes of DI water ultrasonic cleaning. These settings provided the most effective balance between thorough contaminant removal and process efficiency, ensuring high-quality cleaning without unnecessary extension of cycle times.

Following parameter optimization, the ultrasonic cleaning method was piloted on a limited production scale. This pilot phase provided valuable real-world data, demonstrating a significant improvement in connector yield rates. The results validated the effectiveness of the ultrasonic cleaning process in substantially reducing flux-induced contamination, thereby directly addressing the root cause identified earlier in the project.

A confirmatory run (Fig 13) was then performed to validate the conclusions based on the optimized parameter.

With Cleaning Improvement	Confirmatory Run at 200pcs			
Curing Processes	80°C, 30min	80°C, 40min	80°C, 30min	155°C, 3min
Good	200	200	200	200
NG	0	0	0	0

Fig. 13. Confirmatory run at 100% yield.

The success of the pilot, along with the confirmatory run, established a strong foundation for full-scale implementation, providing confidence that this innovative cleaning approach would reliably enhance product quality and manufacturing efficiency across the entire production line.

4.0 RESULT AND DISCUSSION

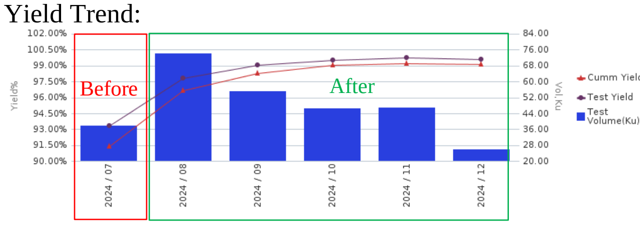
4.1 DMAIC – Control Phase

4.1.1 Effectiveness Monitoring

The mass production performance was monitored to validate the large-scale effectiveness of the ultrasonic cleaning process.

The results from the mass production monitoring confirmed the elimination of contamination on the connector pins, effectively addressing the root cause of defects that previously compromised product quality. This significant improvement in cleanliness directly contributed to enhanced product reliability and a marked increase in yield rates (Fig 14).

Yield Trend:



Reject Trend:

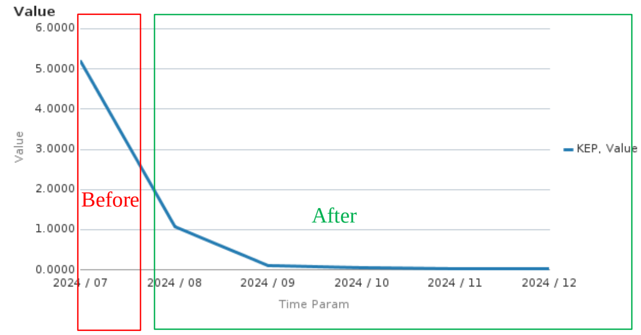


Fig. 14. Mass-Production Yield Performance

4.1.2 Calendar Savings

Item	Saving
Model A	$ 117,633
Model B	$ 24,437
Total Savings	**$ 142,070**

4.1.3 Documentation

To ensure the sustainability and consistency of the improvements achieved through the ultrasonic cleaning implementation, the corresponding quality documentation was comprehensively updated. This included revisions to the Process Flow, Process Failure Mode and Effects Analysis (PFMEA), Control Plan, and Work Instructions (Fig. 15).

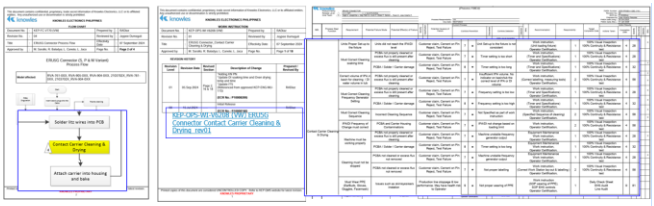


Fig.15. Documentation Updates

5.0 CONCLUSION

This study demonstrates that the implementation of ultrasonic cleaning significantly improves connector yield performance, increasing it from 90% to 99%. The enhanced yield is attributed to the effective removal of contaminants from the connector pins, which are critical to ensuring optimal electrical and mechanical functionality. Ultrasonic cleaning's ability to reduce contamination levels minimizes defects and enhances product quality and reliability. Consequently, this process not only improves manufacturing efficiency but also reduces rework and associated costs. Overall, the adoption of ultrasonic cleaning represents a successful and impactful advancement in connector production quality.

6.0 RECOMMENDATIONS

Based on the positive outcomes observed from the implementation of ultrasonic cleaning, the following recommendations are proposed for future practice:

- Wider Adoption in Manufacturing: It is recommended that ultrasonic cleaning be integrated as a standard cleaning process in connector manufacturing lines to consistently achieve higher yield rates and improved product reliability.
- Extension to Other Components: Given the success with connector pins, ultrasonic cleaning should be evaluated for other sensitive electronic components where contamination affects performance, potentially broadening its application scope.

Implementing these recommendations can further enhance manufacturing quality, reduce defects, and contribute to the development of more reliable electronic assemblies.

7.0 ACKNOWLEDGEMENT

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8.0 REFERENCES

1. Ultrasonic Cleaning of Electronics. https://www.kemet.co.uk/blog/cleaning/ultrasonic-cleaning-of-electronics

9.0 ABOUT THE AUTHOR

Jaypee D. Dumaguit is a licensed Electronics Engineer from the University of San Jose Recoletos, Cebu. With a combined 19 years of experience in high-volume manufacturing as an engineer from previous and current companies, he has developed a strong expertise in process development and in data-driven decision-making, ensuring precision and efficiency in complex processes. He is currently serving as a Sr. Advanced Manufacturing Engineer at Knowles Electronics (Philippines) Corporation for eight years, focusing on process development and yield optimization.

Ronald Aaron Diaz is a licensed Electronics Engineer from the Eastern Visayas State University with 14 years of experience in Process Engineering and NPI (New Product Introduction) development for hearing health technology & electronic parts manufacturing.

At Knowles Electronics (Philippines) Corporation, he is an Advanced Manufacturing Engineer with more than 7 years of experience in NPI (New Product Introduction) for hearing health technology under R&D Department with focus on process design, development, and line release.

10.0 APENDIX

Not Applicable