THE EFFECTIVE USE OF TRIZ METHODOLOGY IN THE OPTIMIZATION OF THE TERMINAL SOLDERING PROCESS OF BALANCED ARMATURES

Dennie Rey Ceasar F. Hiballes

Engineering Department, MedTech, and Specialty Audio
Knowles Electronics (Philippines) Corporation, Cebu Light Industrial Park, Basak, Lapu-Lapu City, Cebu
Dennie.Hiballes@knowles.com

ABSTRACT

The unit handling in the Terminal Soldering process of the balanced armature (BA) assembly line at Knowles Electronics Philippines was identified as an area for improvement to address the observed long cycle time affecting productivity. In response, a new fixture was designed using the TRIZ (Theory of Inventive Problem Solving) methodology which utilized inventive principles such as segmentation, nested doll, preliminary action, and mechanics substitution.

The newly designed fixture streamlined the handling of the balanced armature during the Terminal Soldering process and facilitated a faster transition. A qualification run compared the new fixture with the existing fixture which demonstrated enhanced productivity, improved handling precision, and increased operator satisfaction due to the ease of operation.

The TRIZ-based solution effectively optimized the process, offering a path forward for addressing similar manufacturing challenges.

1.0 INTRODUCTION

1.1 Background of the Study

Knowles Electronics manufactures balanced armature (BA) drivers. This involves manual processes in the assembly manufacturing which utilize fixtures in the handling. A comparison of the cycle time is shown in Figure 1.

One of the major manual processes in the balanced armature production is the Terminal Soldering process. This poses an opportunity to improve the fixture handling. The study focuses on the Terminal Soldering process; other processes are also being worked on separately and are not covered in this study.

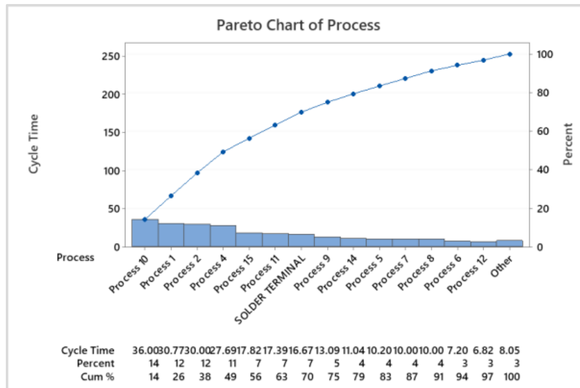


Fig. 1 Process Cycle Time Comparison

The Terminal Soldering process consists of two distinct phases: the main process and the handling process as illustrated in Figure 2. The main process involves connecting the coil to terminal pads using soldering techniques. The handling process, on the other hand, includes the arrangement or preparation of the BA before and after the main process. In this phase, operators place 25 individual units one by one into the 25 cavities of the fixture. After soldering, the units are then removed and placed on a magnet bar.

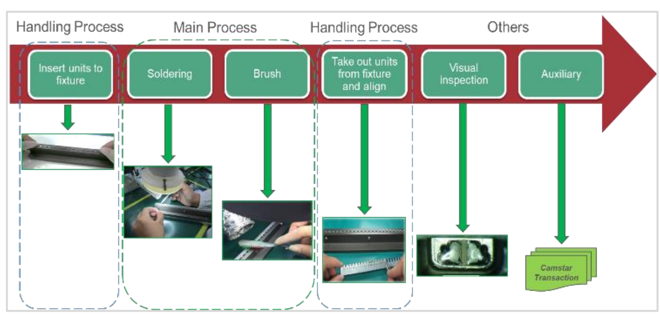


Fig. 2 Elemental Steps of Terminal Soldering

1.2 Statement of the Problem

The repetitive handling of the units before and after Terminal Soldering using the 25 – Cavity Fixture, involved excessive and non-value-adding movements, resulting in longer cycle time as shown in Figure 3.

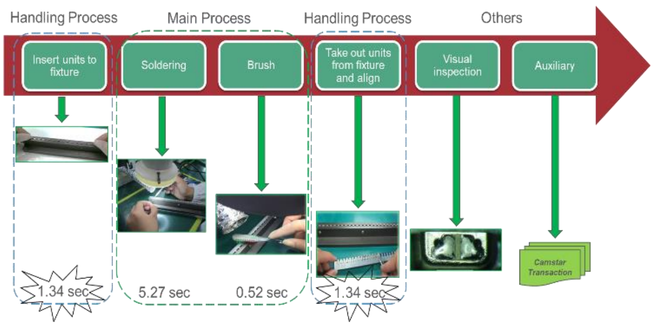


Fig 3. Elemental Step Cycle Time

1.3 Objective of the Study

This study aims to resolve the contradiction between improving productivity and maintaining ease of operation in the handling process of the Terminal Soldering phase using the TRIZ methodology to improve the cycle time.

2.0 REVIEW OF RELATED WORK

Not Applicable

3.0 METHODOLOGY

The TRIZ (Theory of Inventive Problem Solving) methodology[1] was chosen as the methodology to be used in the study over conventional approaches such as DMAIC and PDCA. The rationale behind this is that, unlike DMAIC and PDCA which focus on process improvement, TRIZ emphasizes innovation. It provides a range of inventive principles and techniques that can help users overcome technical contradictions and find breakthrough solutions. TRIZ encourages users to think outside the box and explore unconventional approaches to problem-solving. The corresponding steps of the TRIZ Methodology are outlined in Figure 4.

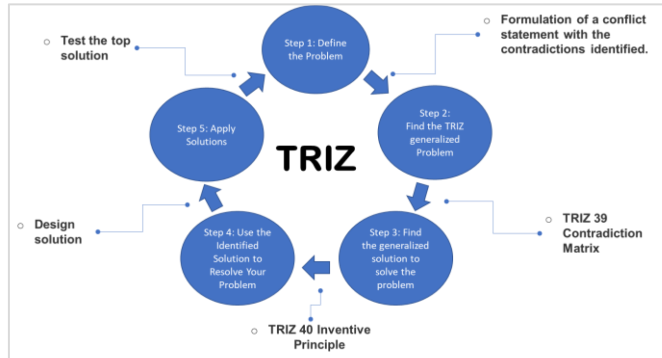


Fig 4 Steps in Problem-Solving using TRIZ Methodology

4.0 RESULTS AND DISCUSSION

4.1 **Step 1**: Define the Problem

The primary problem identified in the Terminal Soldering Process of the BA assembly line is the handling process. It requires improvement due to longer cycle times that affect productivity.

4.1.1. Long Cycle Time

Due to the manual handling process involved, the cycle time for operators is longer, affecting the productivity of the operations.

4.1.2 Low Productivity

The longer cycle time caused by the handling process directly affects the overall productivity of the operations.

4.2 **Step 2:** Generalized Problem by Finding Contradiction

The second step is to formulate the contradiction, which occurs when improving one aspect of a system leads to the worsening of another aspect. TRIZ uses a matrix shown in Figure 5, consisting of 39 engineering parameters and 40 inventive principles to help find the best way to solve contradiction.

The 39 Engineering Parameters (EP) (see Figure 6) and 40 Inventive Principles (IP) (see Figure 7) are the fundamental components of TRIZ[1]. It was derived through the analysis of thousands of patents across various industries. These parameters represent the key characteristics of technical systems that can be manipulated to achieve desired outcomes, while the inventive principles capture recurring patterns of innovative solutions to technical problems.

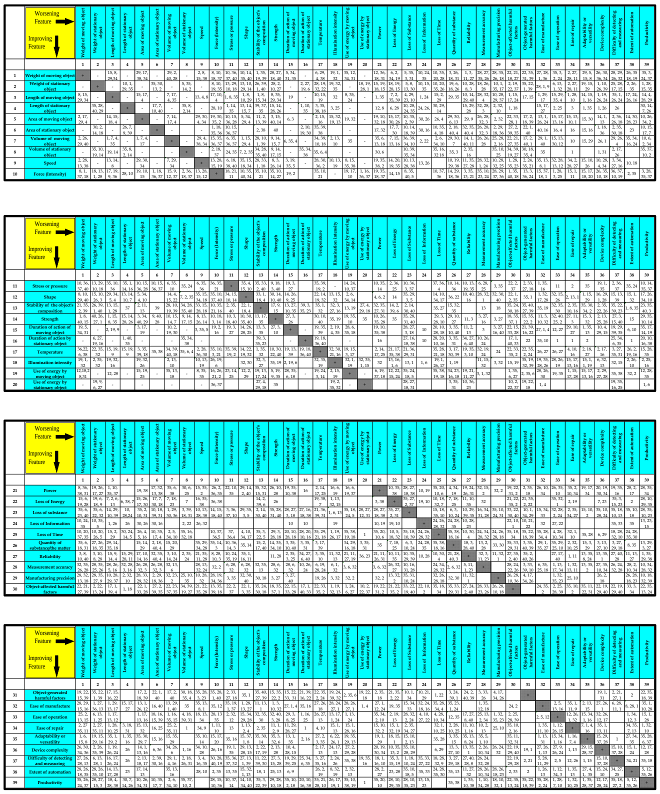


Fig. 5 Contradiction Matrix

39 Engineering Parameters	
1: Weight of moving object	21: Power
2: Weight of stationary	22: Loss of Energy
3: Length of moving object	23: Loss of substance
4: Length of stationary	24: Loss of Information
5: Area of moving object	25: Loss of Time
6: Area of stationary	26: Quantity of substance/the Matter
7: Volume of moving object	27: Reliability
8: Volume of stationary	28: Measurement accuracy
9: Speed	29: Manufacturing precision
10: Force (Intensity)	30: Object-affected harmful
11: Stress or pressure	31: Object-generated harmful
12: Shape	32: Ease of manufacture
13: Stability of the object	33: Ease of operation
14: Strength	34: Ease of repair
15: Durability of moving obj.	35: Adaptability or versatility
16: Durability of non moving obj.	36: Device complexity
17: Temperature	37: Difficulty of detecting
18: Illumination intensity	38: Extent of automation
19: Use of energy by moving	39: Productivity
20: Use of energy by stationary	

Fig. 6 39 Engineering Principles (EP)

40 Inventive Principles	
1. Segmentation	21. Skipping
2. Taking out	22. Blessing in disguise or Turn Lemons into Lemonade
3. Local quality	23. Feedback
4. Asymmetry	24. Intermediary
5. Merging	25. Self-service
6. Universality	26. Copying
7. â€œNested dollâ€	27. Cheap short-living objects
8. Anti-weight	28. Mechanics substitution
9. Preliminary anti-action	29. Pneumatics and hydraulics
10. Preliminary action	30. Flexible shells and thin films
11. Beforehand cushioning	31. Porous materials
12. Equipotentiality	32. Color changes
13. The other way round	33. Homogeneity
14. Spheroidality â€" Curvature	34. Discarding and recovering
15. Dynamics	35. Parameter changes
16. Partial or excessive actions	36. Phase transitions
17. Another dimension	37. Thermal expansion
18. Mechanical vibration	38. Strong oxidants
19. Periodic action	39. Inert atmosphere
20. Continuity of useful action	40. Composite materials

Fig. 7 40 Inventive Principles (IP)

4.2.1 Contradiction Statement

Based on the identified general problem, the contradiction statement was formulated as follows:

> ***"IF the*** operator efficiently places and removes BA in a fixture to speed up the handling process, ***THEN*** productivity will increase due to shorter cycle time, ***BUT*** this can lead to increased complexity in the operations and potential operator fatigue, impacting the ease of operation for operators.**"**

4.2.2 Improving Aspect

The improving aspect from the statement, "***THEN*** productivity will increase due to shorter cycle times" corresponds to the Productivity (EP #39) parameter of the TRIZ engineering parameters list.

This parameter represents the need to increase efficiency and throughput in the handling process by reducing cycle times. The goal is to improve productivity by speeding up the placement and removal of the BA.

4.2.3 Worsening Aspect

The worsening aspect of the statement, "***BUT*** this can lead to increased complexity in the operations and potential operator fatigue, impacting the ease of operation for operators." relates to the Ease of Operation (EP #33) parameter of the TRIZ engineering parameters list.

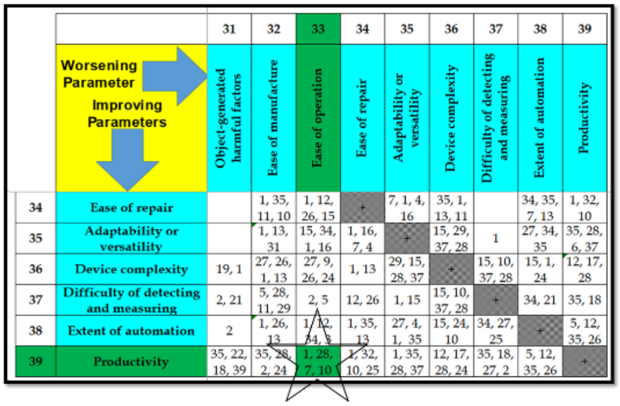
It refers to the simplicity of the process. The parameter relates to making the handling process simple, user-friendly, and comfortable for operators.

*4.3 **Step 3:** Generalized Solution Contradiction Matrix*

Step 3 of the TRIZ methodology is finding solutions by plotting the improving and worsening parameters from the contradiction matrix as shown in Figure 8.

According to the contradiction matrix, the inventive principles that can resolve the contradiction between the engineering parameters Productivity (EP #39) and Ease of Operation (EP #33) are the following:

- Segmentation (IP #1)
- Nested doll (IP #7)
- Preliminary Action (IP #10)
- Mechanics Substitution (IP #28)



		31	32	33	34	35	36	37	38	39
	Worsening Parameter / Improving Parameters	Object-generated harmful factors	Ease of manufacture	Ease of operation	Ease of repair	Adaptability or versatility	Device complexity	Difficulty of detecting and measuring	Extent of automation	Productivity
34	Ease of repair		1, 35, 11, 10	1, 12, 26, 15	+	7, 1, 4, 16	35, 1, 13, 11		34, 35, 7, 13	1, 32, 10
35	Adaptability or versatility		1, 13, 31	15, 34, 1, 16	1, 16, 7, 4	+	15, 29, 37, 28	1	27, 34, 35	35, 28, 6, 37
36	Device complexity	19, 1	27, 26, 1, 13	27, 9, 26, 24	1, 13	29, 15, 28, 37	+	15, 10, 37, 28	15, 1, 24	12, 17, 28
37	Difficulty of detecting and measuring	2, 21	5, 28, 11, 29	2, 5	12, 26	1, 15	15, 10, 37, 28	+	34, 21	35, 18
38	Extent of automation	2	1, 26, 13	1, 12, 34, 3	1, 35, 13	27, 4, 1, 35	15, 24, 10	34, 27, 25	+	5, 12, 35, 26
39	Productivity	35, 22, 18, 39	35, 28, 2, 24	1, 28, 7, 10	1, 32, 10, 25	1, 35, 28, 37	12, 17, 28, 24	35, 18, 27, 2	5, 12, 35, 26	+

Fig. 8 Contradiction Matrix

*4.4 **Step 4:** Identified Solution from 40 Inventive Principles*

In Step 4, the new fixture design will be developed by incorporating the identified four inventive principles to solve the conflict between improving productivity and maintaining ease of operation in the Terminal Soldering process.

4.4.1 Segmentation (IP #1)

This principle involves splitting the fixture into different key components. The key components are the Main Holder, Magnet Bar, and the BA Support.

4.4.1.1. Main Holder

The Main Holder Fixture shown in Figure 9, is responsible for securely holding the various major parts in place during the process. It is equipped with a spring mechanism for easy access and handling by the operator.

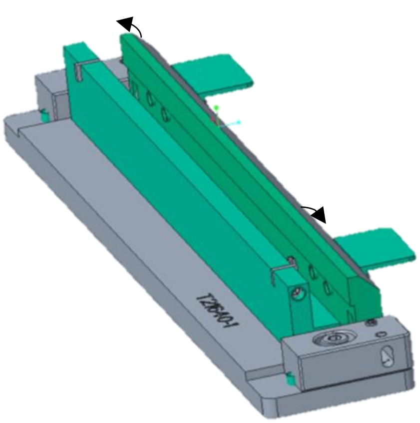


Fig. 9 Main Holder Fixture

4.4.1.2 Magnet Bar

The Magnet Bar shown in Figure 8, is responsible for holding the BA.

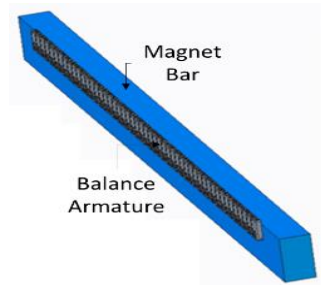


Fig.8 Magnet Bar

4.4.1.3 BA Support

The BA Support shown in Figure 10, is designed to guide the BA and prevent it from tilting.

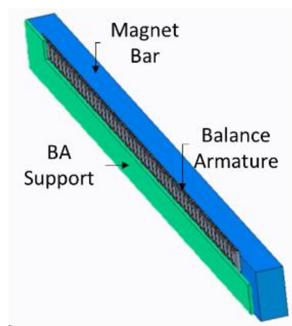


Fig.10 BA Support

4.4.2 Nested Doll (IP #7):

The nested doll principle enables the new fixture design to nest each part inside the other. In this design, the BA Support is placed on a Magnet Bar, which guides and aligns the BA. Subsequently, the Magnet Bar containing the BA is inserted into the main holder fixture, enabling operators to perform the terminal soldering process with ease. This innovative approach optimizes space and efficiency, improving the handling process. The illustration in Figure 11 demonstrates how the fixture components are nested with each other.

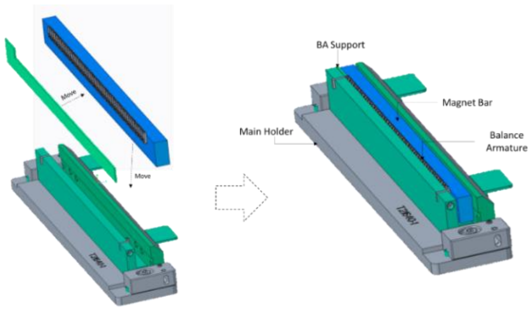


Fig.11 New Fixture

4.4.3 Preliminary Action (IP #10):

Preparing the BA in advance can help speed up the handling process. This preparation can also simplify operations for the operator.

The BA will be prepared in the Magnet Bar prior Terminal Soldering process as shown in Figure 12.

Fig.12 Preparation of BA in Magnet Bar before Terminal Soldering

4.4.4 Mechanics Substitution (IP #28):

This principle involves using different forms of energy or mechanical methods to perform the handling process. In this approach, the fixture incorporates a magnetic object to securely hold the BA without the need for additional mechanical support. The magnetic force provided by the magnet bar prevents any movement or misalignment of the BA, enhancing the accuracy and consistency in soldering. The illustration in Figure 13 shows the BA before and after the improvements of the fixture.

Fig.13 BA Prior Terminal Soldering Process

*4.5 **Step 5:** Apply Solutions:*

In Step 5, an evaluation plan has been developed to carry out control and trial runs, allowing for a comparison of results at the functional level. This plan included an analysis of the elemental cycle time for the Terminal Soldering process, which will help assess the effectiveness of the new fixture design.

Control and trial runs were executed to assess the impact on yield, electroacoustic performance, and cycle time.

4.5.1 Evaluation Run

Both control and trial runs followed the same process. the outcomes were evaluated based on yield, functional test response, and cycle time.

4.5.1.1 Yield

The yield results, reflected in Figure 14, revealed that based on the visual inspection and test result criteria, were comparable in both control and trial runs jobs. Statistical analysis, indicated by a P-value of 0.085, which is greater than the significance level of 0.05, suggests that there is no significant difference in yield between the two lots (see Figure 15) thereby rejecting the null hypothesis (H_0).

Fig. 14 Yield Comparison

Test

Null hypothesis H_0: $\eta_1 - \eta_2 = 0$
Alternative hypothesis H_1: $\eta_1 - \eta_2 \neq 0$

Method	W-Value	P-Value
Not adjusted for ties	43132.00	0.102
Adjusted for ties	43132.00	0.085

Fig. 15 Test for Significance Comparing Yields

4.5.1.2 Electroacoustic Response

Functional test response curves showed no significant difference between both Control and Trial run jobs concerning electroacoustic requirements (refer to Figure 16).

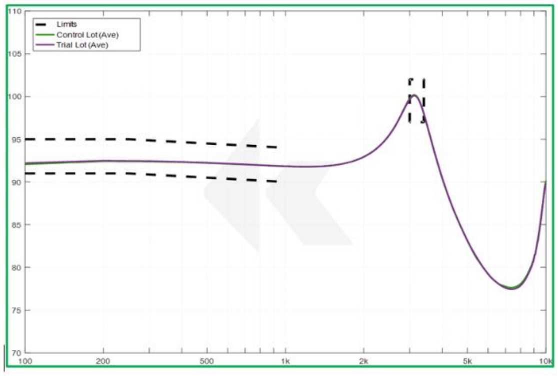


Fig. 16 Functional Test Response Comparison

4.5.1.3 Cycle Time of the Handling Process

As shown in Figure 17, the cycle time of the handling process before and after the Terminal Soldering process was faster in the trial run jobs compared to control jobs.

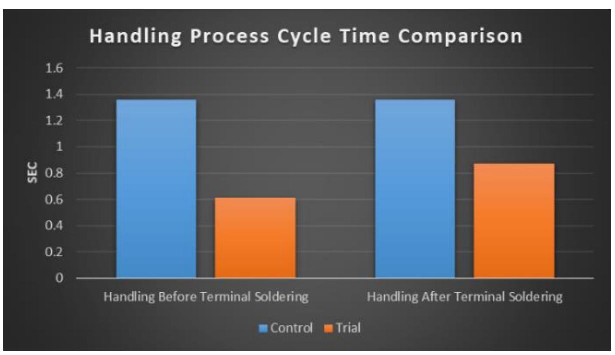


Fig. 17 Cycle Time Comparison

4.6. Implementation

The evaluation results led the team to decide to implement the new fixture. All documentation was updated accordingly and reflected in the Work Instructions.

The qualification run comparing the new fixture designed using TRIZ methodology with the existing fixture provided significant improvements in the Terminal Soldering process.

The new fixture reduced cycle time and handling time, leading to increased productivity. The segmented design and pre-arranged layout allowed for smoother transitions and faster throughput. Operators found the new fixture easier to use due to its ergonomic and user-friendly features. Magnetic elements and quick-release mechanisms streamlined handling, and placement, contributing to ease of operation. The fixture also improved handling precision and consistency, resulting in better quality control and consistent soldering quality. It minimized the risk of damage to balance armatures during handling.

Overall, the new fixture outperformed the existing fixture in terms of efficiency and operator preference due to its simplicity and effectiveness.

The deployment of the new fixture resulted in an annual savings of $10k and considerable proliferation to other balanced armature families for additional savings opportunities.

The successful implementation of the TRIZ methodology demonstrates its potential for optimizing manufacturing challenges and creating innovative solutions for future applications.

5.0 CONCLUSION

It is concluded that the application of the TRIZ methodology in optimizing the Terminal Soldering process effectively resolved the contradiction between productivity and ease of operation in the Terminal Soldering process.

The new fixture design significantly improved handling efficiency, productivity, and operator comfort. TRIZ provided a systematic approach to identify inventive principles and developed a practical solution.

6.0 RECOMMENDATIONS

It is recommended that the designed TRIZ-based fixture for the Terminal Soldering process be adopted across the different balanced armature families of Knowles Electronics Philippines. It is also recommended to explore the use of TRIZ methodology in other similar processes.

7.0 ACKNOWLEDGMENT

The proponent would like to express his gratitude to the Knowles Electronics Management, for the support and guidance throughout this project. We also extend our thanks to the cross-functional team whose efforts made this project a success.

8.0 REFERENCES

1. Malaysia TRIZ Innovation Association (MyTRIZ) "TRIZ (Theory of Inventive Problem Solving) Level 1 Practitioner Training"

9.0 ABOUT THE AUTHORS

Dennie Rey Ceasar F. Hiballes, received his B.S. in Electronics and Communications Engineering from the University of St. La Salle – Bacolod in 2004, and is also a graduate of Technological University of the Philippines – Visayas with a degree in B.S. in Electronics Engineering Technology in 2001. He is currently connected to Knowles Electronics (Philippines) Corporation as a Sr. Equipment Design Engineer.

10.0 APPENDIX

Not Applicable