LEADTIME IMPROVEMENT – BALANCED ARMATURE AGING REDUCTION

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ABSTRACT

Knowles Electronics Philippines (KEP) Product A balanced armature transducer assembly requires an Aging Process with a minimum of 12 Hours oven time to fully cure the applied cement adhesives that contributes 34.70% of the total processing lead time.

This paper will explain on how the Aging time was reduced from 12 Hours to 3 Hours minimum through PDCA approach. Series of evaluations were conducted, considering Quality and Yield. Full Qualification Plan was generated, which includes Reliability Tests, DSC Test (Differential Scanning Calorimetry) and Engineering Tests for Product Performance Drift.

Based on the Product Qualification Results, eliminating the Aging Process (12 Hours to 0 Hour) has no significant impact to Product and Process performance in terms of Quality and Yield. However, based on the specific cement adhesive curing requirement per DSC testing, to ensure full cement adhesive curing, an additional of 3 Hours is required. Thus, instead of totally eliminating the Aging process, it is only reduced from 12 Hours to 3 Hours.

With Aging Time reduction, the over-all processing lead time for Product A was reduced by 30.8%.

This initiative is now fully implemented across all major Product families.

1. 0 INTRODUCTION

Knowles Electronics standard manufacturing process for any balanced armature transducer products requires the use of cement adhesives on certain processes to adhere raw material parts together, and to seal the gaps between each part. This requires 40 minutes to 1-hour oven curing at 65±5ºC or 110 ±5ºC depending on the process, every after cement adhesive application. In addition to the current curing process, products are then loaded in a final curing oven, at 65±5ºC for 12Hours minimum to ensure complete curing of cement adhesives – Aging process.

Cement adhesives used in Knowles products are unique and are mixed in-house. However, the set curing parameters in mainline were not fully optimized since there is a final curing process at the end of the assembly, which is the Aging process.

Product A balanced armature transducer family is the top volume runner for Knowles with an over-all process lead time of 4.33 days (see Figure 1). Plotting the Product A per process time, Aging process is the top contributor to the longer balanced armature transducer lead time.

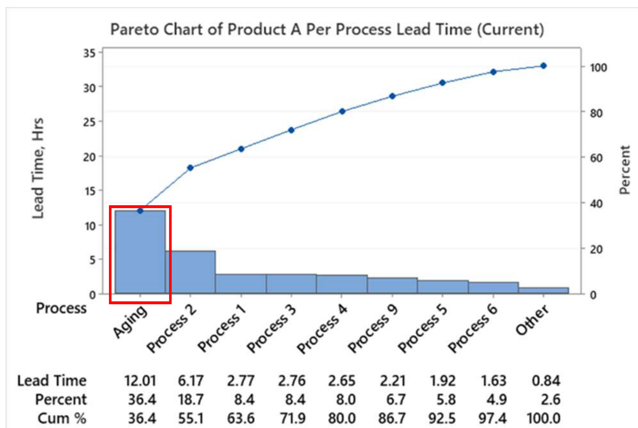


Figure 1. Product A Per Process Lead Time

To address the prevailing demand, Engineering formed a Team to focus on bringing significant improvements on the assembly line.

2. 0 REVIEW OF RELATED WORK

N/A

3.0 METHODOLOGY

To achieve this process lead time improvement goal, the following activities has been conducted:

- PDCA Methodology
- Product Functional Performance Comparison
- Differential Scanning Calorimetry Test (DSC)
- Product Performance Drifting Test
- Reliability Tests

This project utilized the PDCA (Plan-Do-Check-Act) cycle as its framework for continues improvement and problem-solving (see Figure 2).

Figure 2. PDCA Cycle

3.1 Plan

Processes with oven curing were identified through process-mapping. There are 6 processes with cement adhesive application which requires oven for curing (see Figure 3).

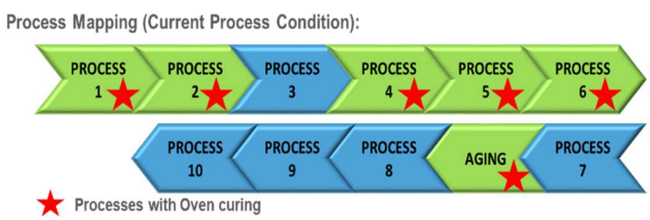


Figure 3. Product A Process Flow

How-How analysis was used to generate ideas on how to reduce the 12Hours Aging time (see Figure 4).

Figure 4. How-How Analysis Brainstorming

With the 12Hours Aging, the average total curing time of per cement adhesive PN in the whole balanced armature transducer assembly is 15.2Hours (see Table 1).

Table 1. Cement adhesive per Process with Curing Time

PROCESS	CEMENT ADHESIVE	OVEN TEMP	CURING TIME, Hr								TOTAL OVEN TIME, Hr
			1	2	3	4	5	6	7	8	
PROCESS 1	PN 3	65ºC	1.0			0.67	0.67	1.0	1.0	12.0	16.3
PROCESS 2	PN 2	110ºC		1.0	0.5	0.67	0.67	1.0	1.0	12.0	16.8
PROCESS 3	PN 1	65ºC			0.5	0.67	0.67	1.0	1.0	12.0	15.8
	PN 1	-			0.5	0.67	0.67	1.0	1.0	12.0	15.8
PROCESS 4	PN 1	65ºC				0.67	0.67	1.0	1.0	12.0	15.3
PROCESS 5	PN 1	65ºC				0.67	0.67	1.0	1.0	12.0	15.3
	PN 4	65ºC					0.67	1.0	1.0	12.0	14.7
PROCESS 6	PN 1	65ºC						1.0	1.0	12.0	14.0
PROCESS 7	PN 1	65ºC							1.0	12.0	13.0
	PN 1										
AGING	N/A	65ºC								12.0	-
AVERAGE CURING TIME PER CEMENT ADHESIVE PN											15.2

Evaluation plan has been developed to conduct Control and Trial runs, enabling a comparison of results at the functional level up to Reliability. This plan also includes the Storage Confirmation Test for Product Drift and Differential Scanning Calorimetry (DSC) for the cement adhesive PNs used.

3.2 Do

Both Control and Trial jobs underwent a controlled build process to ensure consistency and accuracy of execution. This approach involves carefully managing variables, parameters, and settings to minimize any external influences that could impact the results. By running both jobs under controlled conditions, any differences or variations in outcomes can be attributed to the specific changes introduced in the Trial jobs, rather than external factors (see Table 2).

Table 2. Summary of Experimental Combinations

Part Number	CONTROL	TRIAL
Product A	12 hours Aging	Skip Aging Process

During the evaluation phase, both Control and Trial run jobs were subjected to Reliability tests, ensuring product performance consistency and robustness.

Conducting a Storage Confirmation Test to check for product performance drifting is a critical quality measure. This test is typically carried out under controlled storage conditions over a specific duration to assess how well the product retains its intended functionality and performance characteristics over time. 1:1 functional tests and X-rays were conducted to the products stored under controlled condition. Test were performed before storage and every after 1 day, 14 days and 30 days of storage.

The cement adhesives used were subjected to Differential Scanning Calorimetry (DSC) testing process to precisely measure the heat flow within the cement adhesive as a function of temperature, providing a deep understanding of its thermal behavior, phase transition and characteristics.

Oven temperature profiling was performed with the specific objective of evaluating the stabilization time of 65ºC and 110ºC ovens. By reviewing the temperature changes overtime, the team aimed to determine the duration required for the ovens to reach a stable and reliable operating state, ensuring optimal conditions for Production process.

3.3 Check

The qualification results for both Control and Trial run jobs were evaluated using multiple criteria. The assessment involved analyzing the Products' performance concerning the functional test response curves, Cpk values for each test parameter, and THD (Total Harmonic Distortion) performance after storage confirmation tests.

All the test parameter requirements yielded results with Cpk values above 1.33 and demonstrates process stability (see Table 3).

3.3.1 Electro-Acoustic Cpk Results

Table 3. Per Test Parameter Result Comparison

Item	Parameter	Condition	Average	Stdev	Cpk
1	RELSENS @200 Hz	Control	1.72	0.20	2.07
		Trial	1.78	0.16	2.64
2	RELSENS @500 Hz	Control	1.12	0.11	4.80
		Trial	1.16	0.10	5.64
3	SENSITIVITY @1000 Hz	Control	94.71	0.28	2.00
		Trial	94.64	0.26	2.13
4	PKREL1 Amp	Control	6.52	0.34	2.45
		Trial	6.59	0.28	3.03
5	PKREL1 Freq	Control	2891.84	51.38	2.54
		Trial	2915.83	49.19	2.82
6	VLREL1 Amp	Control	-8.48	0.50	1.68
		Trial	-8.22	0.55	1.68
7	VLREL1 Freq	Control	5279.88	71.14	1.73
		Trial	5257.39	68.86	1.90
8	PKREL2 Amp	Control	-5.75	0.64	2.22
		Trial	-5.40	0.77	1.99
9	PKREL2 Freq	Control	6349.91	83.21	1.40
		Trial	6325.40	85.91	1.45
10	THD-1	Control	0.73	0.20	6.36
		Trial	0.70	0.14	9.25
11	THD-2	Control	0.79	0.36	3.39
		Trial	0.84	0.35	3.47
12	THD-3	Control	1.82	0.98	2.44
		Trial	1.72	0.79	3.08
13	THD-4	Control	0.60	0.35	3.74
		Trial	0.57	0.28	4.63
14	THD-5	Control	0.80	0.35	3.55
		Trial	0.77	0.26	4.86
15	THD-6	Control	0.68	0.33	3.87
		Trial	0.74	0.33	3.82
16	IMPEDANCE-1	Control	234.68	3.60	3.18
		Trial	236.03	3.47	3.18
17	IMPEDANCE-2	Control	300.22	6.33	1.80
		Trial	303.29	6.05	2.05

3.3.2 Electro-Acoustic Response Results

Functional test response curves showed no significant difference between both Control and Trial run jobs with respect to its acoustic requirements (see Figure 5).

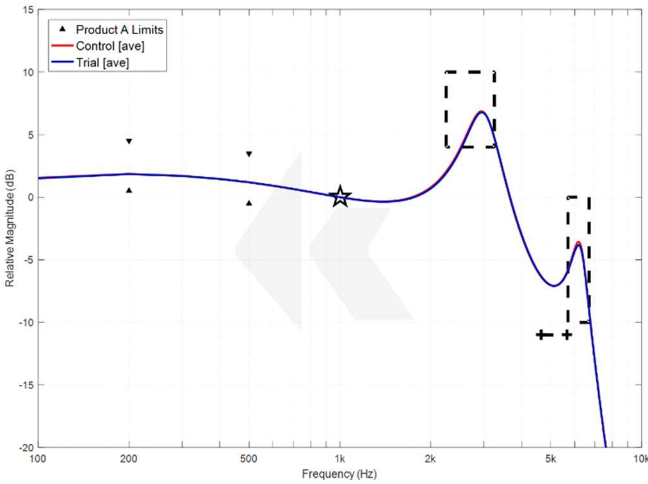
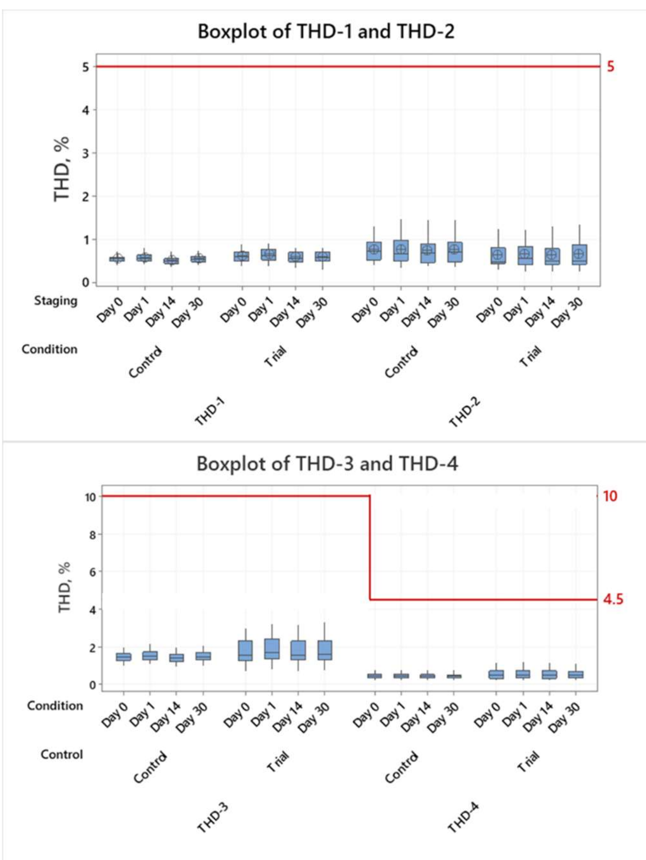


Figure 5. Product A Test Response Curve Comparison

3.3.3 Total Harmonic Distortion Performance

THD-1 to THD-6 (Total Harmonic Distortion) boxplots comparison showed comparable results both for Control and Trial run jobs with no significant difference after days of storage (see Figure 6).



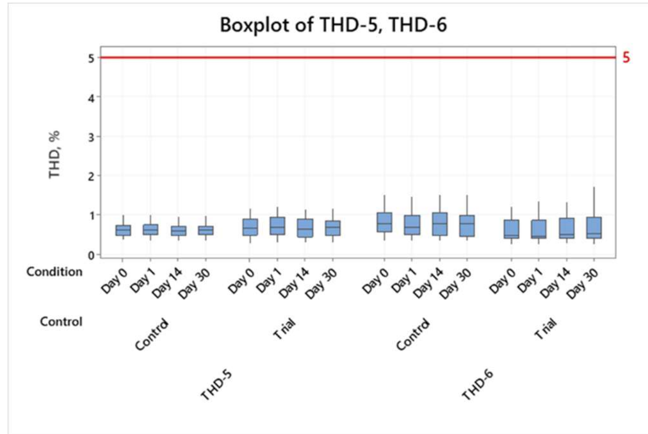


Figure 6. THD-1 to THD-6 (Total Harmonic Distortion) Performance Comparison using Minitab

3.3.4 Differential Scanning Calorimetry Results

DSC test results showed the optimum curing time of the cement adhesives that results in the best properties, ensuring the cement adhesive attains its maximum strength and durability (see Figure 7).

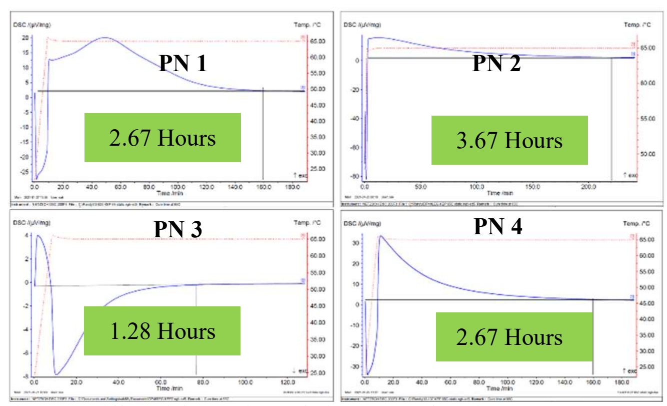


Figure 7. Differential Scanning Calorimetry Results using NETZSCH DSC 200F3

3.3.5 Reliability Tests Results

The Reliability tests showed positive and consistent results, confirming the dependability and stability of the tested Products (see Table 4).

Table 4. Reliability Test Results Comparison

Reliability Tests Results	Control	Trial
Damp Heat	PASS	PASS
Thermal Shock	PASS	PASS
HALT Test	PASS	PASS
IEC	PASS	PASS
Mechanical Shock	PASS	PASS

Temperature stabilization time were already identified both for 65±5ºC and 110±5ºC ovens. Maximum stabilization time during loading and unloading of parts in a 65±5ºC oven is 6 minutes and 13 minutes for a 110±5ºC oven.

3.4 Act

With the conforming evaluation results, the team decided to implement the recommended changes to the Production line to address the identified inefficiencies and reduce waiting time. Implemented actions were well-documented and reflected in the Work Instructions, PFMEA (Process Failure Modes and Effects Analysis) and CP (Control Plan). Minimum Time Window in CAMSTAR was also set-up to ensure that jobs loaded in the oven will comply with the set curing times prior unloading.

4.0 RESULTS AND DISCUSSION

The comprehensive evaluation process helps ensure that the products meet the required standards and performance expectations before proceeding with the implementation.

Functional test performances of Trial run jobs showed comparable results with the Control. The results suggest that any changes made did not significantly affect the products' performance compared to the Control jobs.

Storage confirmation test results through ANOVA analysis showed that there are no statistically significant differences in THD performance between the Control and Trial run jobs, with P values > 0.05 (see Figure 8).

Figure 8. THD Drift Performance Comparison using ANOVA

Through DSC testing, optimal curing time of cement adhesives used were identified. Given that the Trial lots condition specified skipping the Aging process, the results were subsequently compared to the current state (refer to Table 5).

Table 5. Curing Time versus DSC Requirement

PROCESS	CEMENT ADHESIVE	OVEN TEMP	CURING TIME, Hr						
			Process 7 Curing Time	Total Oven Time w/ 12Hrs Aging	DSC	Excess Curing Time (Current)	Proposed Aging Time	New Total Oven Time	Extra Curing Time (After)
PROCESS 1	PN 3	65ºC	1	16.3	1.28	15.0	3.0	7.3	6.0
PROCESS 2	PN 2	110ºC	1	16.8	3.67	13.1	3.0	7.8	4.1
PROCESS 3	PN 1	65ºC	1	15.8	2.67	13.1	3.0	6.8	4.1
	PN 1	-	1	15.8	2.67	13.1	3.0	6.8	4.1
PROCESS 4	PN 1	65ºC	1	15.3	2.67	12.6	3.0	6.3	3.6
PROCESS 5	PN 1	65ºC	1	15.3	2.67	12.6	3.0	6.3	3.6
	PN 4	65ºC	1	14.7	2.67	12.0	3.0	5.7	3.0
PROCESS 6	PN 1	65ºC	1	14.0	2.67	11.3	3.0	5.0	2.3
PROCESS 7	PN 1 PN 1	65ºC	1	13.0	2.67	10.3	3.0	3.0	0.3
AGING	N/A	65ºC		12.0	-	-	3.0	-	

At this point, the most crucial process is the last process involving cement adhesive application, Process 7 with a 1 hour curing time. Process 7 ensures that all gaps of the conjoined parts are properly sealed to avoid leak test failures that could lead to functional defects. Removing the 12hours Aging, will not comply with the DSC requirement of 2.67 hours which could lead to uncured cement adhesives.

The team proposed that instead of removing the 12Hours Aging time, it will only be reduced to 3Hours minimum. The proposed curing time is designed to fully cure the cement adhesives used in the previous processes, and it also includes provisions for stabilizing temperature fluctuations during the product loading and unloading in the oven.

With the current oven capacity, the ovens used for Process 7 and Aging processes was reduced from 2 to 1. With this, power consumption cost was also reduced. This merging of processes leads to a significant improvement in Work in Progress (WIP) inventory and Process Lead Time (see Table 6).

Table 6. Before and After Aging Time Reduction Comparison

Product A	Before	After
Aging Time	12 hours	3 Hours
Aging % Lead Time Contribution	34.70%	10.18%
Number of Ovens	6	5
Over-all Lead Time	4.32 Days	3.12 Days
Product A	Before	After

Comparing the Current and After process lead time for Product A, we can say that Aging process is greatly improved after the implementation of the reduced Aging time (see Figure 9).

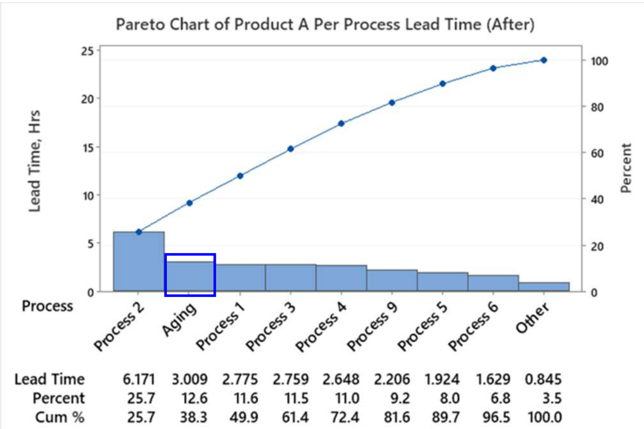


Figure 9. Product A Per Process Lead Time (Current)

Through the successful implementation of our streamlined production lines, we were able to achieve a remarkable annual WIP inventory savings totaling $147.9K, a testament to our commitment to operational excellence and cost effective practices.

5.0 CONCLUSION

Balanced armature transducer Aging Time can be reduced from 12Hours minimum to 3Hours minimum. Reducing the Aging time based on the DSC test results have no significant impact on the Product performance with comparable yield and acoustic response versus the 12Hours Aging time. With Aging Time reduction, the over-all processing lead time for Product A is reduced by 27.76%.

6.0 RECOMMENDATIONS

3Hours Aging time will be used as a standard time for Product A, B, C, D, E and F families, and will be leveraged to other lines with reference to the DSC test results. By applying of the Lean Principles, it can methodically and iteratively improve manufacturing processes, reduce waiting time, and deliver products or services more efficiently.

7.0 ACKNOWLEDGMENT

We would like to thank the cross-functional team of Product A Balanced armature transducer assembly lines of Knowles Electronics Philippines who were involved in the execution of this process improvement initiative. To Knowles Electronics Senior Management, for all the support in making this project successful.

8.0 REFERENCES

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9.0 ABOUT THE AUTHORS

Meilin P. Torralba received her B.S. in Electronics and Communications Engineering from University of St. La Salle – Bacolod in 2003, and is a licensed ECE. She gained her first manufacturing experience in Taiyo Yuden (Phils.) Inc. as a Product Engineering Supervisor. She is currently connected in KNOWLES ELECTRONICS PHILLIPINES CORPORATION as a Sr. Process Engineer.

10.0 APPENDIX

N/A