HIGHLY ACCELERATED LIFE TEST AND ENVIRONMENTAL-3 ONGOING RELIABILITY TEST OPTIMIZATION

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ABSTRACT

Better reliability is the foundation of a faster and safer manufacturing process. It is one of the requirements of a good manufacturing process in order to consistently deliver an expected result that aligns with the customer and the company's internal requirements. In order to guarantee that the products are compliant with these requirements, one of the tools Knowles has set up is the Ongoing Reliability Test (ORT). Performing ORT involves a lot of resources. Samples for ORT can no longer be reused and are eventually scrapped causing an increase in the ORT scrap cost for the past 4 years.

This paper discusses the processes taken to identify, compare and eliminate ORT that has the same impact on products, consequently reducing the ORT scrap cost. Through the use of six sigma tools and methodologies, two tests were identified to have almost identical test conditions and criteria. This paper compares the effect of the Highly Accelerated Life Test (HALT) and Environmental-3 (E3) to balance armatures and by eliminating the less stringent test contributes to a reduction in the overall annual ORT scrap cost.

1.0 INTRODUCTION

Balanced Armature (BA) drivers are small and lightweight transducers that require less power to provide greater output. These drivers use an electronic signal to move a tiny reed that is balanced between two magnets inside a tiny enclosure. The motion of the reed is transferred to a diaphragm which in turn produces the sound waves.

Knowles as the leading BA manufacturer proactively monitors the performance of these balanced armatures through the Ongoing Reliability Test (ORT).

ORT as a test process is used by Knowles to ensure that the quality of the product is consistently within the specifications from the day it was qualified up to the present. The products for reliability testing are randomly selected with a specific sample size. These units are then subjected to environmental, mechanical and chemical tests which simulate the product's field performance. ORT as monitoring tool is performed on a monthly, quarterly, semi-annual, and annual frequency. These test frequencies were based on the customer and the company's internal test requirements.

With the introduction of new models, a significant increase in the ORT scrap cost was also observed. These contribute to a significant increase in an annual ORT scrap cost by 47% which is equivalent to 100K US dollars as shown in Figure 1.

Figure 1. ORT Scrap Cost for the recent years

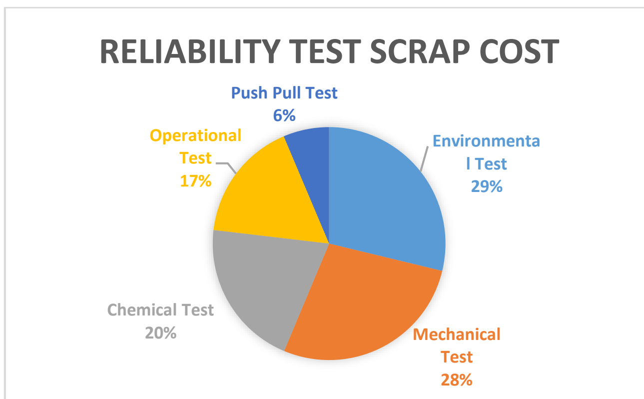


Figure 2. Reliability Test with the highest scrap cost contribution.

The top reliability test scrap cost is mainly contributed by Environmental test at 29% per Figure 2.

2.0 REVIEW OF RELATED WORK

2.1 Arrhenius-Peck Relationship

Arrhenius-Peck Relationship[3] was used for this study since the involved test conditions utilize elevated levels of temperature and humidity.

Humidity Testing can be used to accelerate the aging of products that are affected by ambient humidity. Increasing the humidity above the normal use level humidity can cause defects or failures to occur earlier than what would be observed in the field. Humidity testing is usually performed along with testing at elevated temperatures so that the acceleration factor is affected by both humidity and temperature. The Acceleration Factor (AF) which is the ratio of the life at use conditions versus the accelerated life at test conditions for temperature humidity testing is given by the following Arrhenius-Peck equation:

$$A_{TH} = A_T \, x \, A_H$$

$$A_T = Exp\left\{\frac{E_a}{K_B}\left(\frac{1}{T_{use}} - \frac{1}{T_{stress}}\right)\right\}$$

$$A_H = \left(\frac{RH_{stress}}{RH_{use}}\right)^m$$

Where:
E_a = Activation energy (0.7eV)
K_B = Boltzmann Constant (8.62E-05)
m = Humidity constant (2.66)
T_{use} = Nominal use temperature
T_{stress} = Test temperature
RH_{use} = Nominal use relative humidity
RH_{stress} = Relative humidity of test

Where A_T, as the Temperature acceleration factor is multiplied by A_H, as the Humidity acceleration factor to get A_{TH}, the Temperature-Humidity acceleration factor or AF.

Figure 3. Acceleration factor formula

3.0 METHODOLOGY

This paper utilizes the PDCA cycle and used its methods in comparing set-up conditions, evaluating results and validating actions which is aligned with the goals of this study.

3.1 PDCA - Plan Phase

Among the environmental ORT, the top five scrap cost contributors are: Highly Accelerated Life Test (HALT), Composite Temperature-Humidity Cyclic Test (IEC-60068-2-38), Dry Heat Test (IEC 60068-2-2), Environmental-3 (E3), and Thermal Shock Test. These tests can either induce both temperature and humidity or just temperature in cyclic conditions to gauge the product's reliability.

3.1.1 Test Condition Comparison

Table 1 shows the commonality between the five top environmental reliability tests where HALT and E3 have the most numbers of stress factors; Temperature, Humidity and steady test set-up.

Table 1. Test set-up and conditions

Test Item	Temperature	Humidity	Powered	Set-up
HALT	63 deg C	95%	YES	Steady
COMPOSITE TEMP-HUMIDITY	Per profile	Per profile	NO	Cyclic
DRY HEAT	63 deg C	Not applicable	NO	Steady
E3	63 deg C	95%	NO	Steady
THERMAL SHOCK	-40 deg C, 63 deg C	Not applicable	NO	Cyclic

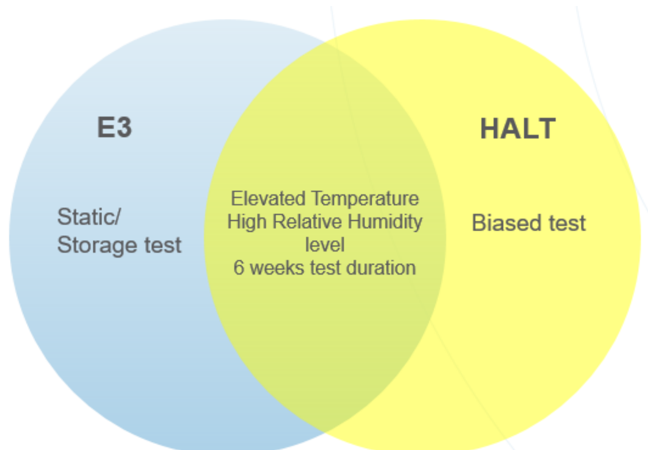
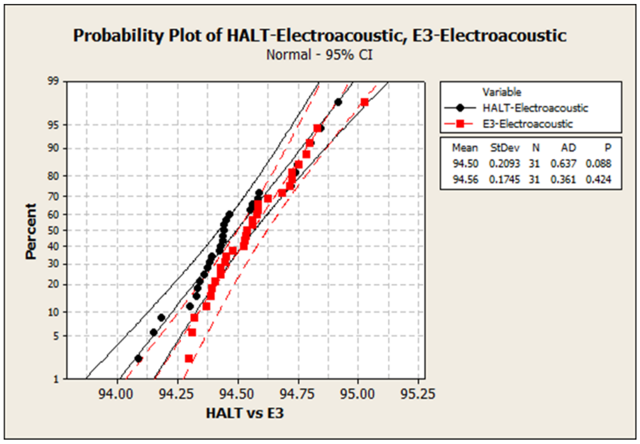


Figure 4. HALT and E3 test condition and set-up

3.2 PDCA – Do and Check Phase

Two lots coming from the same part number and job number were subjected to HALT and E3 at the same time and the electroacoustic value at 1 kilo hertz was measured. The probability plot concludes that the sets of data follow a normal curve, with P-values > 0.05. The 2-sample t-test (where the null hypothesis $H_0 = 0$) returns a P-value of 0.185 which is > 0.05, accepting the null hypothesis and indicating that both sets of data have comparable means as shown in Figure 5.



Two-Sample T-Test and CI: HALT-Electroacoustic, E3-Electroacoustic

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Two-sample T for HALT-Electroacoustic vs E3-Electroacoustic

                      N    Mean  StDev  SE Mean
HALT-Electroacoustic  31  94.497  0.209    0.038
E3-Electroacoustic    31  94.563  0.174    0.031


Difference = mu (HALT-Electroacoustic) - mu (E3-Electroacoustic)
Estimate for difference:  -0.0657
95% CI for difference:  (-0.1637, 0.0322)
T-Test of difference = 0 (vs not =): T-Value = -1.34  P-Value = 0.185  DF = 58
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Boxplot of HALT-Electroacoustic, E3-Electroacoustic

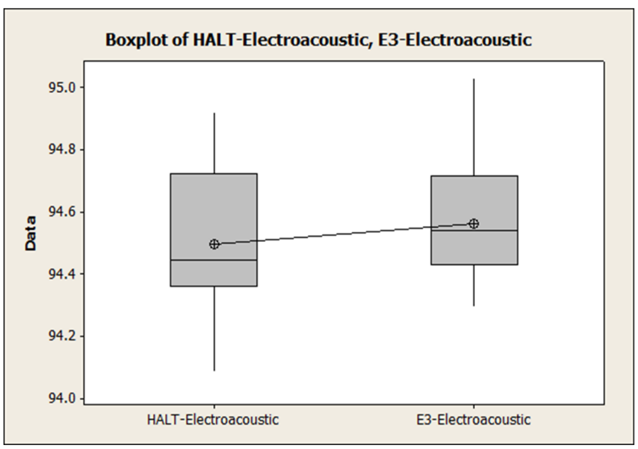

Figure 5. HALT vs E3 comparison

3.2.1 HALT and E3 Acceleration Factor Comparison

The Acceleration Factor (AF) is the ratio of the life at use conditions at the end user to the accelerated life at test conditions (reliability) for temperature-humidity testing. It typically results in applying a higher stress in reliability test compared to that experienced in the field, which allows for a shorter time in test to demonstrate an equivalent failure-free time period in the field.

Fig 3 shows the acceleration factor formula for AF where A_T, as the Temperature acceleration factor is multiplied by A_H, as the Humidity acceleration factor to get AF or A_{TH}-the Temperature-Humidity acceleration factor.

Since HALT and E3 have the same temperature and humidity test points they have an equivalent acceleration factor of 43.309.

4.0 RESULTS AND DISCUSSION

4.1 PDCA – Check Phase

The acceleration factor value of 43.309 was used to check and compare the products' survival rates given their number of warranty years. The Mean Time to Fail (MTTF) of models with 1 warranty year is equivalent to 8.43 days. Comparing the survivability of the two lots, we got a survival rate of 98.78% for HALT and 99.29% for E3, respectively.

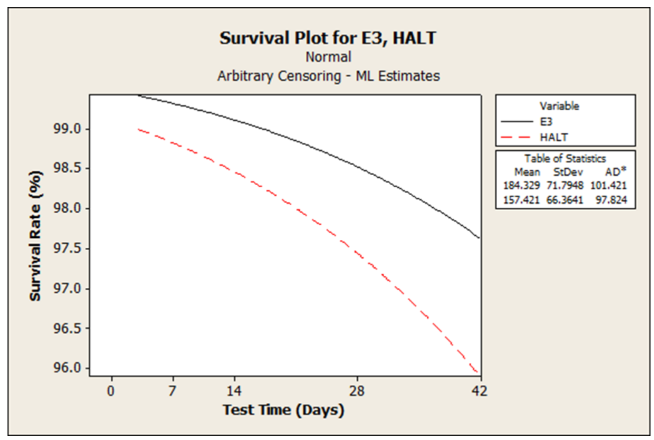

Figure 6. Survival Plot Comparison of HALT and E3

HALT	Survival Rate (%)	E3	Survival Rate (%)
4	98.9606	4	99.3993
6	98.8745	6	99.3502
8	98.7824	8	99.2976
10	98.6838	10	99.2412
12	98.5783	12	99.1809
14	98.4657	14	99.1164
16	98.3455	16	99.0476
18	98.2173	18	98.9741
20	98.0807	20	98.8956
22	97.9353	22	98.8121
24	97.7807	24	98.7231
26	97.6165	26	98.6283
28	97.4422	28	98.5276
30	97.2573	30	98.4206
32	97.0614	32	98.3070
34	96.8540	34	98.1864
36	96.6346	36	98.0586
38	96.4028	38	97.9233
40	96.1582	40	97.7800
42	95.9001	42	97.6285

Figure 7. Survival rate of HALT and E3

The results showed that survival rates are comparable for both HALT and E3 tests. To summarize, HALT and E3 have the same test set-up, testing conditions, and acceptance criteria, but there is an additional stress factor that is included during the HALT test. HALT is a biased test as mentioned in Table 1. This makes HALT a more robust and effective ORT that can accelerate the test even further compared to E3.

Items	HALT	E3
Temperature: 63±2°C	✓	✓
Humidity: 95±3% RH	✓	✓
Voltage supply: +9dB above nom Drive	✓	✗
Duration: 6 weeks	✓	✓
Acceptance Criteria	✓	✓
Test Results	Comparable	Comparable
Acceleration factor: 43.309	✓	✓
Survival rate	Comparable	Comparable

Figure 8. Compare chart for HALT and E3

Computing the acceleration factor of HALT with an additional voltage stress factor will give us A_{THv} of 121.8 (AF) and a shortened MTTF of 3 days per 1 warranty year for the specific model used for this evaluation with a survival rate of 98.96% versus the 8.43 days using only the temperature-humidity factor of E3. Figure 9 shows the formula of AF multiplied by A_v.

$$A_{THv} = A_T \; x \; A_H \; x \; A_V$$

$$A_v = \left(\frac{V_{stress}}{V_{use}}\right)^N$$

Where:
A_v = Voltage acceleration factor
V_{stress} = High drive test voltage
V_{use} = Nominal drive voltage
N = Type of technology use (2~4 common, typical 3)

Figure 9. Acceleration Factor (Temperature-Humidity-Voltage)

HALT	Survival Rate (%)
4	98.9606
6	98.8745
8	98.7824
10	98.6838
12	98.5783
14	98.4657
16	98.3455
18	98.2173
20	98.0807
22	97.9353
24	97.7807
26	97.6165
28	97.4422
30	97.2573
32	97.0614
34	96.8540
36	96.6346
38	96.4028
40	96.1582
42	95.9001

Figure 10. HALT survival rate

4.1 PDCA – Act Phase

With the result from Fig ,10, it has been proven that HALT is more effective ongoing reliability test. Keeping HALT as an ORT and eliminating E3 will result to a 50% reduction on the sample size of models with both HALT and E3 requirement and consequently reducing the annual ORT scrap cost by 17% which contributes to an annual cost savings of 16.4k USD.

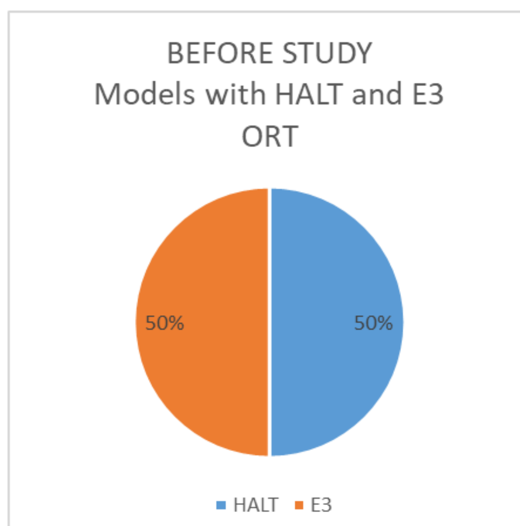

Figure 11. HALT and E3 comparison before the study

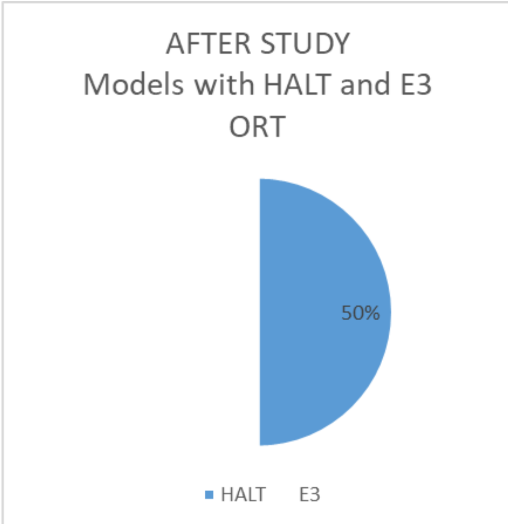

Figure 12. HALT and E3 comparison after the study

5.0 CONCLUSION

From this study, it can be concluded that E3 test can be eliminated from the annual ORT plan since the intent of the test is already covered by HALT. HALT has been assessed to be a more effective test as compared with E3 with more stringent stress factors that can capture abnormalities during reliability testing.

6.0 RECOMMENDATIONS

Based on the results of the study, it is highly recommended that the E3 test be eliminated from the ORT plan of all balanced armature drivers having both HALT and E3 requirements. This recommendation is applied to the execution of the ORT plan of mature, mass-produced parts at Knowles Electronics Philippines.

Since reliability qualification during the NPI process is not part of the scope of this study, it is recommended to assess the applicability of the ORT optimization study during the early stage of product development.

7.0 ACKNOWLEDGMENT

The author would like to thank the Reliability team of Knowles Electronics Philippines who were involved on the execution of this ORT optimization resulting to scrap cost reduction initiative.

8.0 REFERENCES

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9.0 ABOUT THE AUTHORS

Gle-Ann A. Sumalinog is a graduate of Technological University of the Philippines – Visayas with a degree in B.S. in Electronics and Communications Engineering in 2011 and a licensed Electronics Engineer. She is currently a Reliability and Failure Analysis engineer handling ORT and Failure Analysis at Knowles Electronics (Philippines) Corporation.

10.0 APPENDIX

Not applicable.