FROM CRACKS TO MARKET: A JOURNEY TO ELIMINATE DIE CRACK ON TURRET HANDLER

Joana Marie Q. Kintao
Lorenzo P. Melgazo
Ruel J. Mijares

Process Development and Equipment Engineering
Analog Device Inc. Gateway Business Park Barangay. Javalera General Trias Cavite | 4107
JoanaMarie.Kintao@Analog.Com | Lorenzo.Melgazo@Analog.com | Ruel.Mijares@Analog.com

ABSTRACT

Product qualification is vital for validating semiconductor device performance and ensuring regulatory compliance. This study examines a 2.5 × 2 × 0.55 mm package that initially had a 65% defect rate due to leakage failures caused by microcracks on the silicon die.

To address this, a cross-functional team used DMAIC methodology and turret machine technology to optimize processes and reduce stress factors, leading to stabilization and successful market introduction.

Since its launch in 2022, the package has had zero die crack defects, demonstrating the effectiveness of the corrections. This initiative is expected to generate $21.8 million in profit over nine years, with a 67% gross margin, highlighting the improvement strategy's value.

1. 0 INTRODUCTION

Product Qualification ensures that a product meets the required specifications and standards before market release or production. It involves testing, inspection, and documentation to verify performance.

Delays in product qualification can cause timeline slippage, increased costs, launch impacts, regulatory risks, supply chain disruptions, resource bottlenecks, missed opportunities, and customer dissatisfaction. Identifying and addressing the root causes of these delays is essential. This paper focuses on a specific cause of delay.

1.1 Product Qual problem

A potential delay during product qualification was identified as being due to leakage problems in both 100% QA and QA sampling tests, resulting in a 65% defect rate. Failure Analysis identified microcracks on the die as the cause.

1.1 Die crack Explanation

Die cracks are a significant issue in semiconductor manufacturing, impacting the reliability and performance of electronic components. They often occur at the die corners or edges due to the concentrated mechanical stress that occurs during handling and packaging.

2. 0 REVIEW OF RELATED WORK

No prior issues or reports exist for new product qualifications; this is the first occurrence.

3.0 METHODOLOGY

The Team applied the DMAIC methodology to address the die crack issue through the Define, Measure, Analyze, Improve, and Control phases, ensuring effective and lasting solutions.

3.1 Define Phase – Problem Identification

Two (2) units out of 24k devices from Lot# A were submitted for analysis after failing on MTF BIN9 (LEAKAGE_PS) at 100% QA room test. Automated Test Equipment (ATE) units were tested at room temperature (25°C), and electrical verification confirmed that units failed at BIN9 test parameters. Units were subjected to a Bench test using the Test Design Review (TDR), which was conducted to verify the failing test parameters. The leakage failure persisted on the units, as indicated in Table 1. Destructive Analysis on units revealed die cracking as the cause of leakage failure in the device during new product qualification, see in Fig. 1.

ITEM	LX_LX2_H	LX_LX2_L	LX_SEL_H	LX_SEL_S	I_SHDN
KGU	0.0389uA	-0.0001uA	0.00249uA	-0.0098uA	0.747uA
SN1	1.3519mA	0.1809uA	0.00328uA	-0.0013uA	20.3644mA
SN2	1.3403mA	-14.7816uA	0.00278uA	-0.1951uA	0.732uA
SPECS	Min = -1uA	Min = -1uA	Min = -1uA	Min = -1uA	Min = -0.2uA
	Max = 1uA	Max = 1uA	Max = 1uA	Max = 1uA	Max = 2uA

Table 1. Electrical Failure Summary of Bench Test Verification

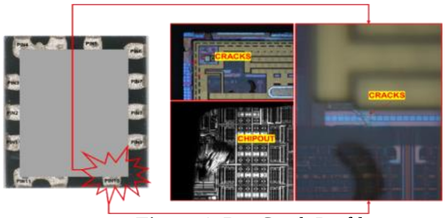


Figure 1. Die Crack Profile

3.1.1 Business Case, Project Impact

The project supports FY21 Asia Factory Operation (AFO) Priorities on Zero Die Crack. In addition, this also aided the market intro of a new product with a Lifetime profit of ~$21.8M and a product lifecycle of 9 years at a Long Term (LT) Gross Margin of 67%.

3.1.2 Goal Statement

Resolve and eliminate the corner cracks issue in the 2.5x2x0.55mm package of Product A using a Turret handler, ensuring readiness for market introduction by the end of Q1'22.

3.1.3 Key Organizational Goal

Figure 2. ADI Bech Mark Plan (BMP), This project aligns ADI BMP with key areas. By resolving the crack issue in new product qualifications, it enhances productivity and improves the consistency and reliability of the delivery process. Enhanced quality control ensures products meet customer expectations and standards.

3.1.4 Project Scope

The project covers the qualification of 2.5x2x0.55mm package for market intro specifically on the elimination of microcrack on die corners using the turret handler. Excludes passivation crack resolution which is for fab-assembly further analysis. Lots assembled in qualified assembly subcon, Vendor A from Vendor B Bump Assembly.

3.1.5 SIPOC (Supplier, Inputs, Process, Outputs, Customers)

Shown below is the SIPOC which illustrates the entire business process from start to finish prior to initiating process improvement efforts.

Suppliers	Inputs		Process	Output		Customers
Providers of the required resources	Resources required by the process	(Numerical requirements on inputs **Requirements**	Top level Description of the activity	Deliverables from the process	(Numerical requirements on output) **Requirements**	Stakeholders
▪ Assembly ▪ Equipment Eng'g ▪ Contact Technology Group	▪ Fresh Lot ▪ Turret handler Machine ▪ Contact Socket	▪ Zero Die crack PPM on first pass ▪ Compliant with required settings based on DMRB checklist ▪ 0.8gF max spring force requirement to contact socket	Final Test	Electrically Good Units	▪ Zero Valid leakage failures during 100% QA and QA sampling ▪ Zero Die Crack PPM on 10% QA and QA sampling	▪ OQA ▪ Customer

Table 2. SIPOC Model

3.1.6 Why is it important or critical? (Critical to Quality)

The new product has a Lifetime Profit of $21.8M with a product lifecycle of 9 years with an LT Gross Margin of 67%. Eliminate die corner cracks issue on 2.5x2x0.55mm package using turret handler will ensure market product introduction by end of Q1'22.

3.1.7 Voice of Customer (VoC)

The Voice of Customer (VoC) is focused on discerning the needs, expectations, and perceptions of our customers to guide product improvement initiatives.

Customer	Voice of the Customer	Key Customer Issues(s)	Critical Customer Requirement	Category
Production (Final Test)	Leakage failure is detected during QA Test samples	Root cause of Die crack	Zero Die crack defect	Quality
Production (Final Test)	On Time Delivery	Customer production line down	No delay shipment due to visual mechanical issues	Delivery
Production (Final Test)	Additional rework process on the production line	Manpower and handler/ tester allocation	No additional cause incurred due to rework process	Cost

Table 3. Voice of Customer (VoC) Model

3.2 Measure

3.2.1 Process Mapping

The team employed process mapping to visually depict workflows and processes, identifying potential points where die crack might occur. Remarkably, we found cracks only on certain handlers, and the pattern held true no matter where the assembly site.

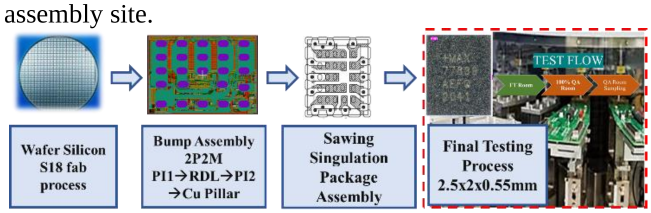


Figure 3. Process Mapping

3.2.2 Die Crack PPM by Lot ID

Various data was gathered when the issue was encountered, and these are Die Crack Parts Per Million (PPM) by Lot ID and it is ranging from 70 to 296 PPM see in Fig.4.

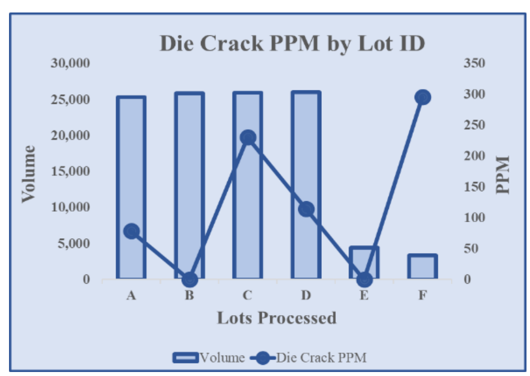


Figure 4. Die Crack PPM by Lot ID

3.2.2 Die Crack PPM by Lot ID

Die cracks are evident on die corners, all the die crack locations are found in corners of the die (PIN4, PIN10, PIN11, PIN6). The majority or 40% of the die crack are located at the corner of PIN4. If two corners are affected, crack locations are on the same side see in Fig.5.

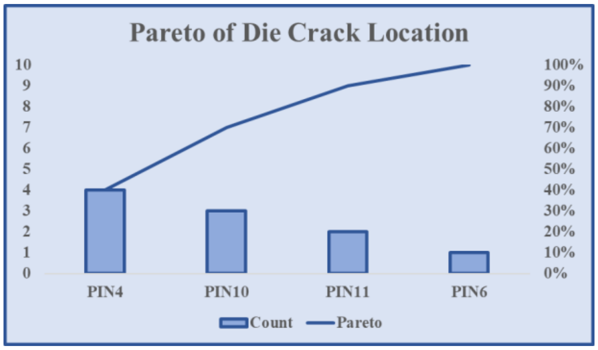
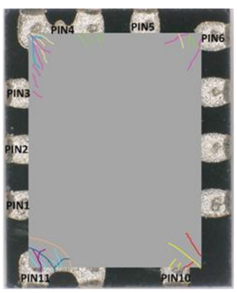


Figure 5. Die Crack PPM by Lot ID

3.3 Analyze Phase – Identification of Root Causes

3.3.1 Die Crack Mapping



Die crack mapping is the systematic process of identifying and recording the locations and occurrences of die cracks within a specific product. During this process, it was found that approximately 40% of the die cracks are concentrated at one corner of PIN4.

Figure 6. Die crack location

3.3.2 Turret Base Machine

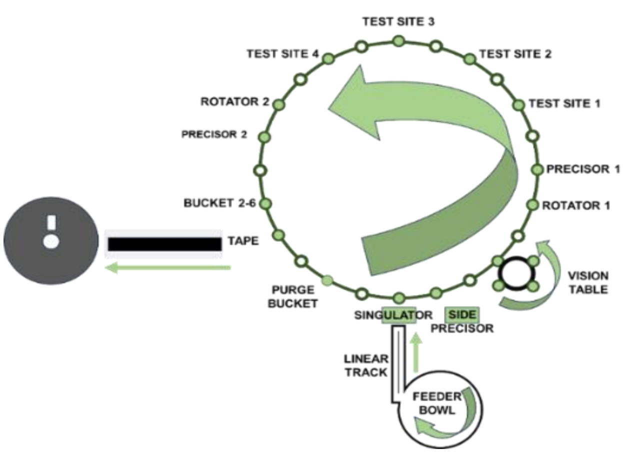


Figure 7. Turret Handler Mapping, mapping out the handler parts involved in the die crack issue entails identifying and understanding how equipment modules or parts work and processes contribute to or mitigate the occurrence of die crack during manufacturing process.

3.3.3 Turret Handler Historical Set-Ups

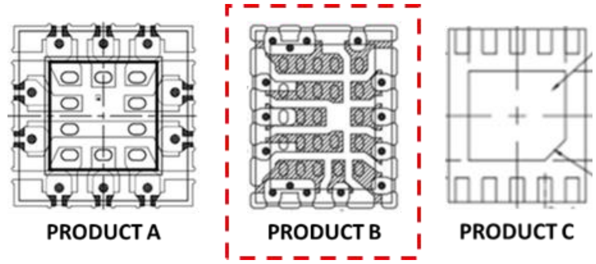


Figure 8. Package Comparison, there were 3 packages that could be compared, only Product B has reported die crack issue. Same thickness of 0.55 but 2x2 in size, no die crack. Same package size of 2.5x2 but thicker at 0.75, no die crack. Only 2.5x2x0.55 has die crack.

3.3.4 Turret Handler (Test Site Module)

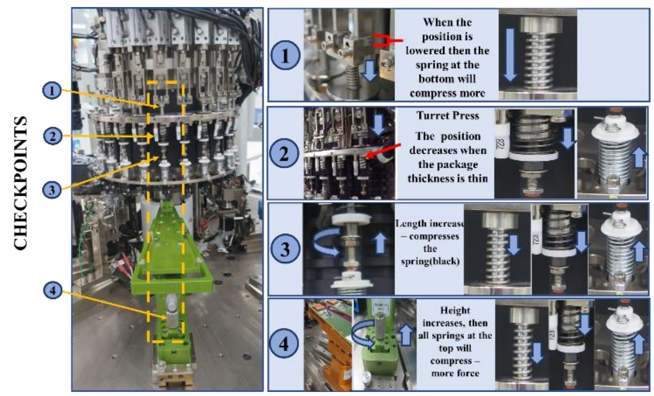


Figure 9. Test Site Module (Checkpoints), This checkpoint is utilized to evaluate the tools or handler components that may contribute to applying excessive force on the device at the test site

3.3.5 Turret Handler (Measurement of Force)

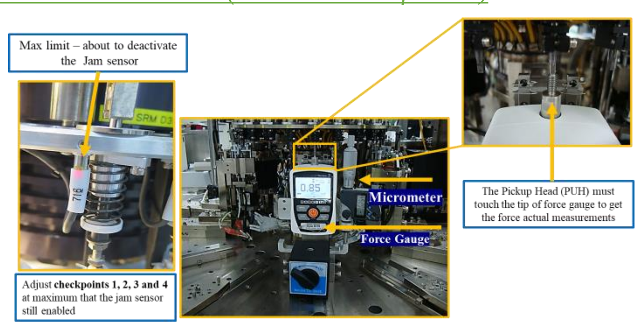


Figure 10. Force Testing Preparation

The height and the gap will be measured using the micrometer in the assembly. Moreover, the force gauge measurements will be recorded during the test. Force gauge stand will be used to check the force of the Pickup Head (PUH) when plunged at the test site. Its height replicates the axis stand height

3.3.6 Turret Handler (Finding)

Figure 11. Force Testing Preparation
Spring under observation will be elongated with actual measurement of 47.34mm and out of specs vs. Spring free length of 41+/- 0.10mm.

3.3.7 Spring Force Test Result

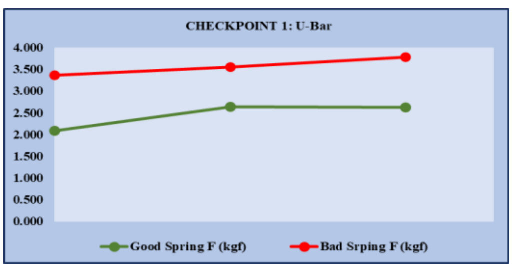


Figure 12. Checkpoint 1: U-Bar As the position of the spring is lowered, then spring at the bottom encounter greater compression.

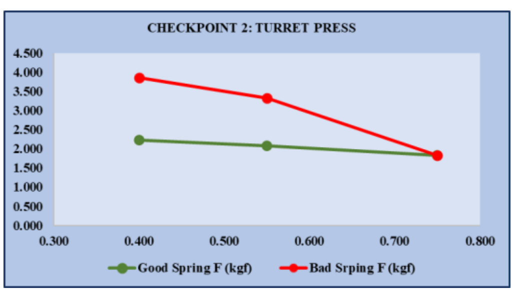


Figure 13. Checkpoint 2: Turret Press, as the thickness of the package decreases or becomes thinner, the position of the package in a stack might be decreased

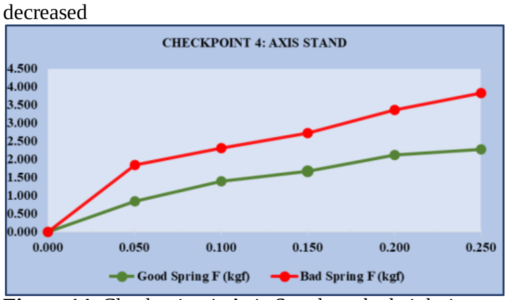


Figure 14. Checkpoint 4: Axis Stand, as the height increases, the springs at the top undergo compression, which can result in the creation of a greater force.

3.3.8 How the Spring Work

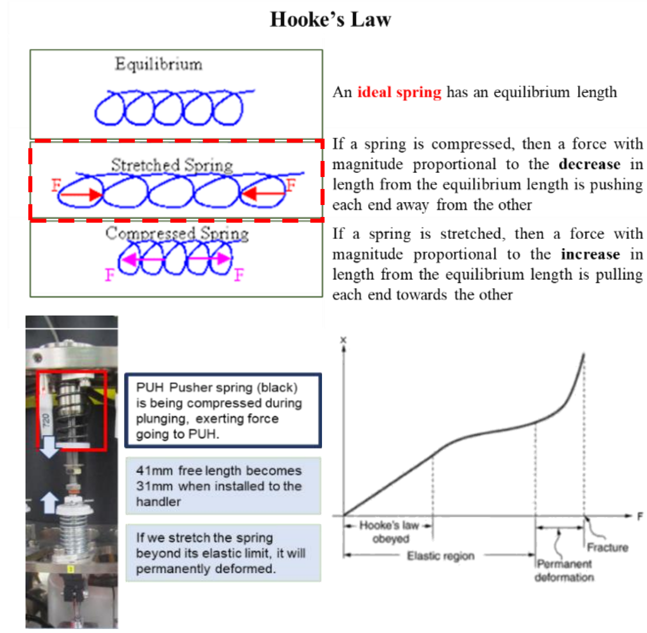


Figure 15. Hooke's Law Model, when a spring is compressed, it employs a force that is proportional to the decrease in its length from the equilibrium state, pushing both ends apart.

3.3.9 Spring Free Length vs. Plunge Force Experiment

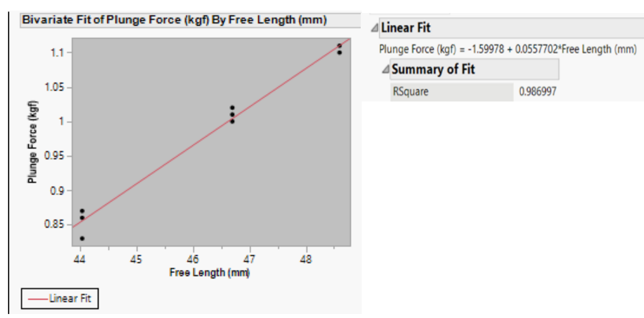


Figure 16. Plunge Force by Free Length
The force exerted by a spring is directly proportional to its length. This means that as the length of the spring increases, the force it applies also increases linearly. In other words, a longer spring will exert a greater force.

3.3.10 PUH Spring Length and Plunge Force Correlation

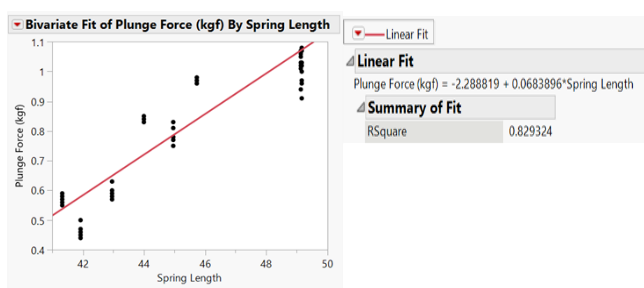


Figure 17. Spring and Force Correlation
Strong positive correlation of plunged forced to spring length with summary of 0.82 RSquare.

3.3.10 Finite Element Analysis

A total of 8 possible mis-aligned scenarious using thr Finite Element Analysis (FEA) was determined. When device is shifted, the stress point is obeserved to be on the area where the pogo pins hits the device pad without the counter force from the die or turret head. Stress is lower at the die center, greater on the die edges, and worst on the die corner.

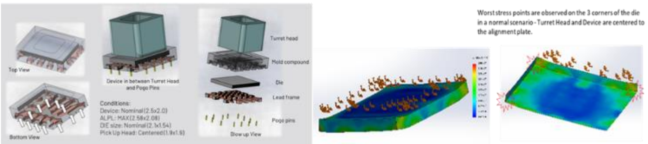


Figure 18. Assembly Simulation

3.4 Improve Phase – Selection of Best Solution and Implementation

3.4.1 Design of Experiment (DoE)

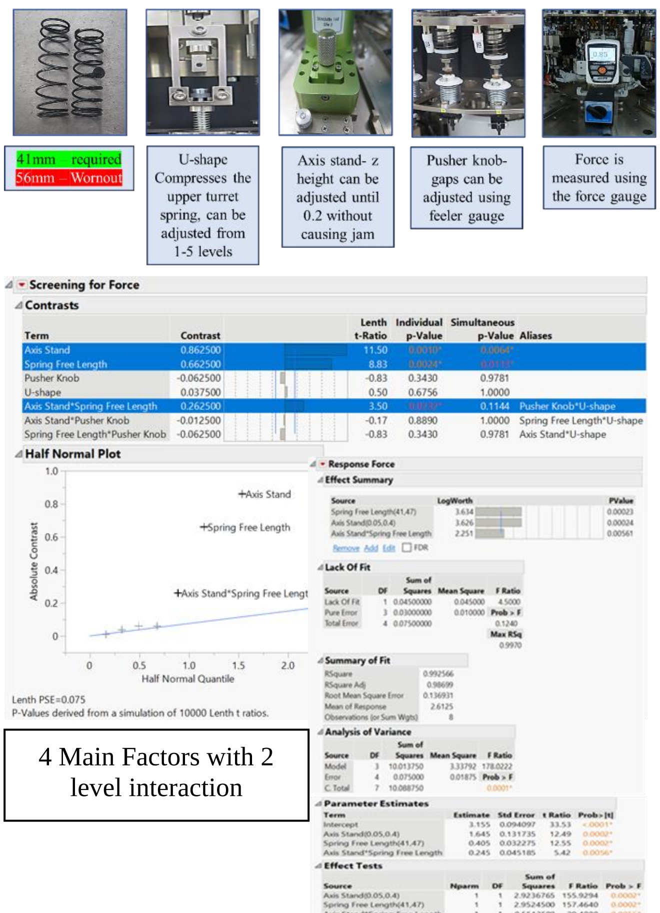


Figure 19. Factional Factorial Screening, by this approach, we can better understand the influence of each factor and their interactions on the response during screening. This helps in identifying the most significant factors and interactions, guiding further experimentation and optimization.

3.4.2 Handler Requalification

Transferred the conversion kit from Turret Handler B. Perform fine tuning and Jam rate (10k), Set up index time to 200ms (10k UPH). Peel Back Force Test (PBFT) passed during requalification. Accomplished Defect Material Review Board (DMRB) checklist. Replaced Press Turret Springs for Test Site1 and Test Site 5 due to >43mm of free length see in Table 4.

MODULE	SPRING FREE LENGTH		PLUNGE FORCE	
PART	BEFORE	AFTER	BEFORE	AFTER
Side Precisor	40.85mm	40.85mm	0.41gF	0.41gF
Vision table	41.17mm	41.17mm	0.45gF	0.45gF
Rotator 1	40.62mm	40.62mm	0.37gF	0.37gF
Precisor 1	40.93mm	40.93mm	0.42gF	0.42gF
Site 1	**46.03mm**	**40.66mm**	**0.92gF**	**0.38gF**
Site 2	41.45mm	41.45mm	0.49gF	0.49gF
Site 3	41.52mm	41.52mm	0.49gF	0.49gF
Site 4	41.61mm	41.61mm	0.51gF	0.51gF
Site 5	**44.96mm**	**40.94mm**	**0.84gF**	**0.42gF**
Site 6	42.96mm	42.96mm	0.66gF	0.66gF
Site 7	41.93mm	41.93mm	0.55gF	0.55gF
Site 8	41.33mm	41.33mm	0.47gF	0.47gF
Rotator 2	40.80mm	40.80mm	0.40gF	0.40gF
Precisor 2	41.74mm	41.74mm	0.52gF	0.52gF

Table 4. Replace Turret Spring

3.4.3 Turret Handler Mechanical Over Stress Run (MOS)

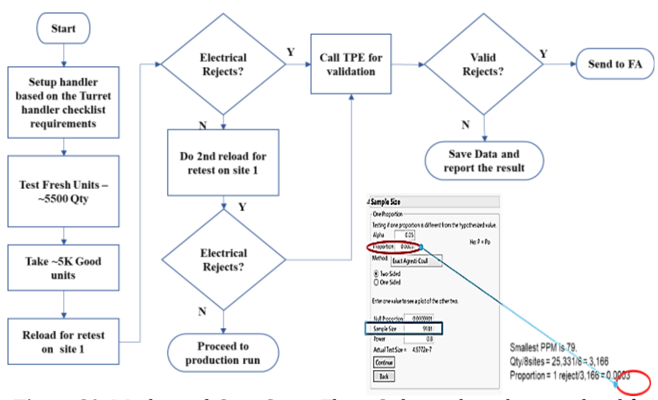


Figure 20. Mechanical Over Stress Flow, Only one kit is being utilized for both handlers, thus, only handler and parameter settings can be compared.

3.4.4 Mechanical Over Stress Evaluation Result

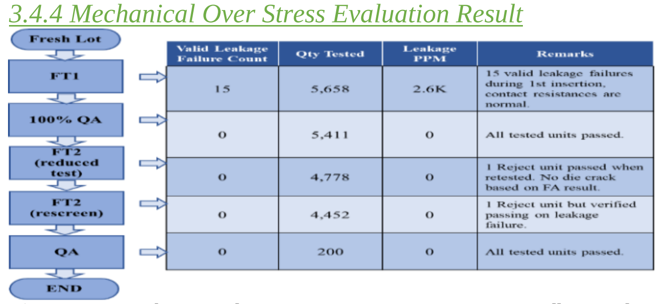
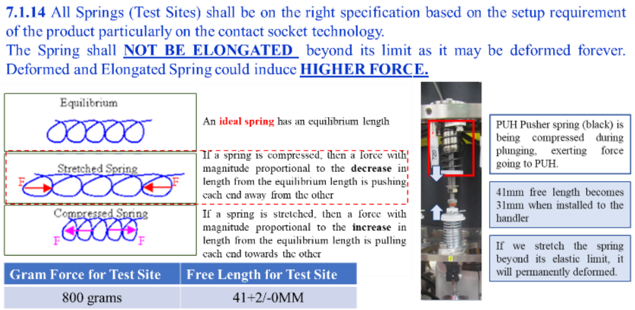


Figure 21. Leakage Failure set as NRB, Tester B/ Handler B, lot# JCISXXAll with total quantity of 6,593 set as No Reload Bin (NRB). Tested units passed. No Die Crack encountered the NRB lot.

3.5 Control Phase – Standardization and Fan-out

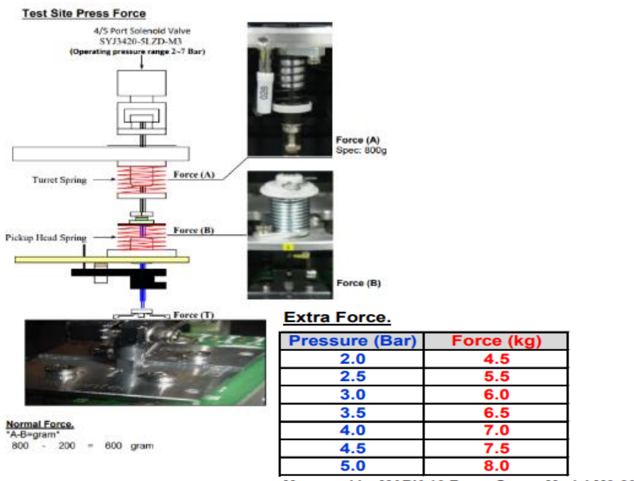
3.5.1 Update Applicable Specs and Documents



Gram Force for Test Site	Free Length for Test Site
800 grams	41+2/-0MM

Figure 22. Update Turret Base Handler Specification, to prevent the occurrence of the problem, all applicable documents and specs were updated.

3.5.2 Information Dissemination



Pressure (Bar)	Force (kg)
2.0	4.5
2.5	5.5
3.0	6.0
3.5	6.5
4.0	7.0
4.5	7.5
5.0	8.0

Measured by MARK-10 Force Gauge Model M3-20

Figure 23. Spring Information, Information regarding spring requirement was disseminated to test manufacturing.

4.0 RESULTS AND DISCUSSION

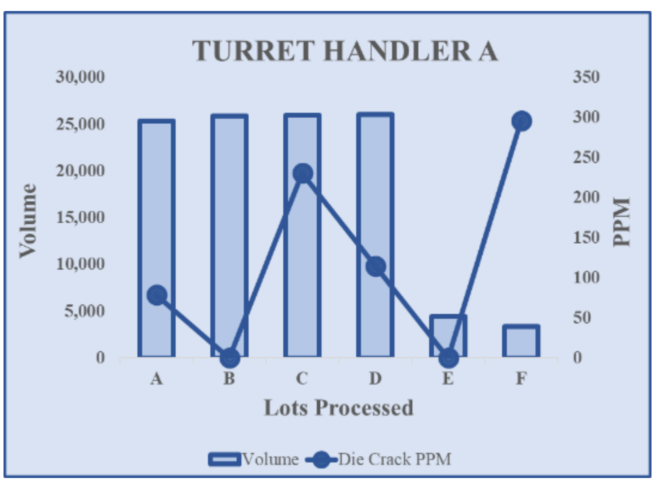


Figure 24. Evaluation Result on Turret A

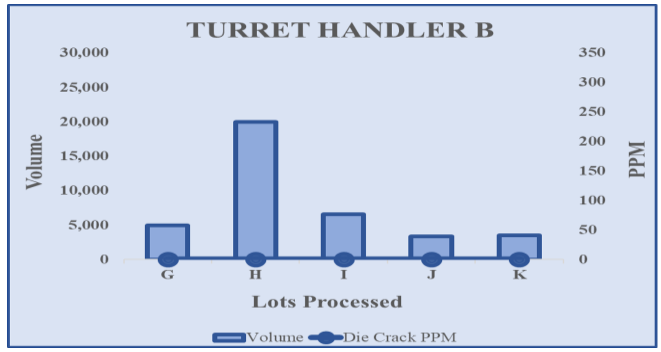


Figure 25. Evaluation Result on Turret B

As illustrated in Fig. 24, the use of the existing defective spring resulted in occasional die cracks in the evaluation lots. However, upon replacing the defective spring with the new spring, no die cracks were observed in the evaluation lots, as shown on Fig. 25. This demonstrates the effectiveness of the new spring in preventing die cracks and ensuring the integrity of the product during evaluation.

Furthermore, this solution was promptly put into action, and a comprehensive product qualification was successfully completed. This led to the seamless introduction of the product to the market, effectively eliminating the die cracks caused by the turret handler machine. The swift implementation and thorough qualifications ensured that the product met all quality standards and was ready for market launch without the risk of mechanical-induced defects.

5.0 CONCLUSION

The experiment showed that elongating a spring beyond its elastic limit increases the plunge force. Key factors include the spring's free length and axis stand height. Handler requalification and replacement of out-of-spec springs were necessary. Mechanical Overstress (MOS) flows were created and successfully implemented, resulting in no failures. Spring type and specifications are crucial for various qualifications. Springs must not be elongated beyond their elastic limit to avoid permanent deformation. If greater force is needed, springs can be replaced or additional force features activated. The required spring force can be calculated using a specific formula.

Force per pin×number of pins×1.3=spring force

6.0 RECOMMENDATIONS

The specifications of springs, including their free length and axis stand height, should be carefully considered during new contact technology qualifications, kit conversions, and package thickness qualifications to control the plunge force effectively. Regular requalification of handlers should be conducted to replace out-of-spec springs and maintain the integrity of the testing process. Mechanical Overstress

(MOS) runs should be performed as part of confidence runs during the qualification of thinner packages (less than 0.75mm) to ensure reliability. The required spring force should be calculated using the formula: **Force per pin x number of pins x 1.3 = spring force**. The position of the spring should be carefully monitored, especially with thinner packages, to ensure that the springs at the bottom encounter greater compression and maintain consistency in the testing process. Springs should not be elongated beyond their elastic limit to avoid permanent deformation. If greater force is needed, springs can be replaced or additional force features activated. Further studies may explore additional factors influencing plunge force and develop refined control methods.

7.0 ACKNOWLEDGMENT

The team extends their gratitude to Eng'r. Jennifer Sanidad for her consistent support in Failure Analysis. Special thanks to Eng'r. Jazerael Mercado, Ronald Payod, and Erwin Decal from the Equipment and Central Engineering team for their assistance with the design and force measurements on the turret handler machine. Appreciation also goes to Eng'r. Hitler Estores for his work on Electrical validation and reporting. Lastly, thanks to Eng'r. Noel Sapitanan and from the Process Engineering team for their efforts in product rejection validation.

8.0 REFERENCES

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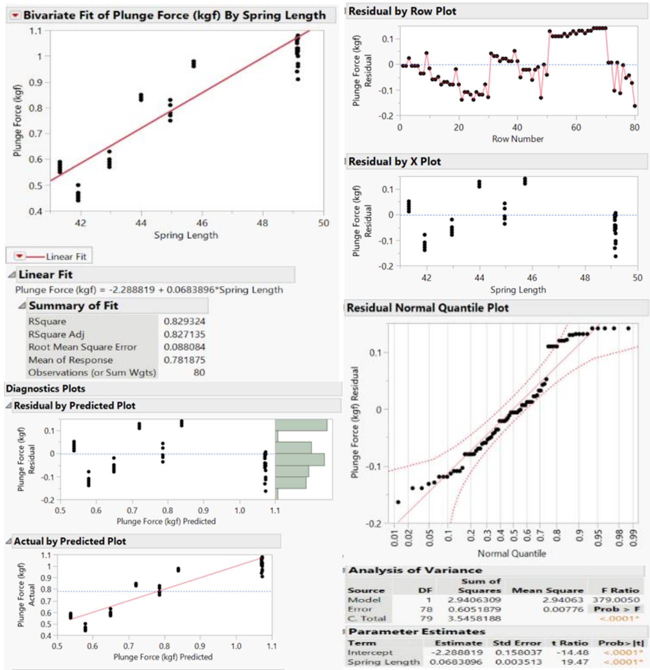
9.0 ABOUT THE AUTHORS

Joana Marie Q. Kintao is an Engineer in Process Development Engineering for Internal Backend Factories at Analog Devices Inc. Philippines, where she has been working since 2017. She is a member of the Automation Development team and advocates for Package and Die Crack prevention. She holds a bachelor's Degree in Computer Engineering from the National College of Science and Technology.

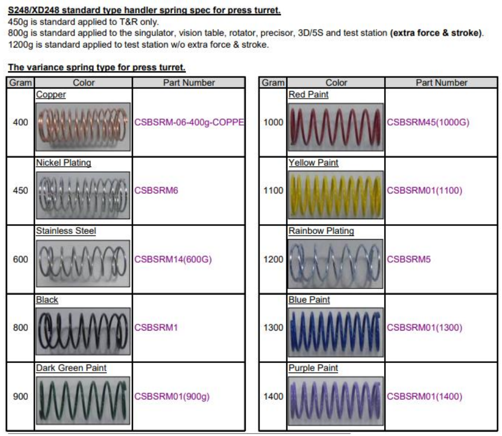
Lorenzo P. Melgazo Jr. is an Engineer specializing in Equipment Engineering and Manufacturing Operations, with focus on Turret Handler**.** He has dedicated 25 years to Analog Devices Inc. Philippines. Lorenzo studied Electronics at the Eulogio "Amang" Rodriguez Institute of Science and Technology (EARIST).

Ruel J. Mijares is a Manager of Process Sustaining Engineering from Internal Backend Factories. He holds a bachelor's degree in Mechanical Engineering from the Technological University of the Philippines Visayas and he is a Six Sigma Black Belt. With 22 years of experience in the semiconductor industry, he has been with Analog Devices since 2017, spearheading automation in Final Test and Tape & Reel. His expertise encompasses TQM (DMAIC), Best Tool Matching, and ML-based monitoring.

10.0 APPENDIX



Appendix A. PUH Spring Length and Plunger Force Correlation
The relationship between spring length and plunger force can be described by Hooke's Law, which states that the force exerted by a spring is proportional to its compression (or extension).



Appendix C. Standard Spring Type for Press Turret