ELIMINATION OF MIXING OF TESTED AND UNTESTED UNITS AT SENSOR FINAL TEST USING MECHANICAL ERROR-PROOFING

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ABSTRACT

Based on 2020 Q1 to Q3 data, mixed part in tube is the top contributor of mistake issue at Final Test. To address this, PMEE (Process and Maintenance Equipment Engineering) implemented the mechanical error-proofing solution which included the use of slotted red tubes for rejected units, use of shorter clear tubes for tested units, use of long clear tubes for untested units and use of yellow tubes for 2nd pass testing on Package A. Comparison of mixed part in tube data from 2020 to 2022 showed that mixed part in tube was eliminated since 2021. This solution was fanned out to Package B and Package C from 2021 to 2022. Zero mixed part in tube was encountered since the implementation on said packages.

1. 0 INTRODUCTION

1.1 Background of the Study

Allegro MicroSystems Phils., Inc. (AMPI) aims to deliver high quality products with zero mixed parts. To attain this, a comprehensive mechanical error-proofing solution for shipping tubes used in the test process was conceptualized to eliminate mixing of parts related to mishandling. The multidisciplinary team was tasked with accurately identifying the critical factors that usually cause the parts to mix up by employing effective Poka-yoke on the Test process.

On the first level pareto, the highest contributor for the Defects is Mixed Part at 35.3% (see Figure 1).

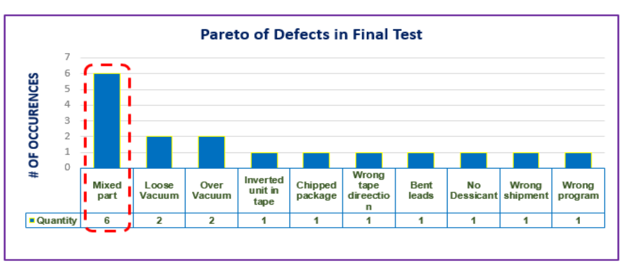


Figure 1. Pareto of Defects in Final Test

On the second level pareto, the top contributor for the mixed part is Tube at 66 % (see Figure 2).

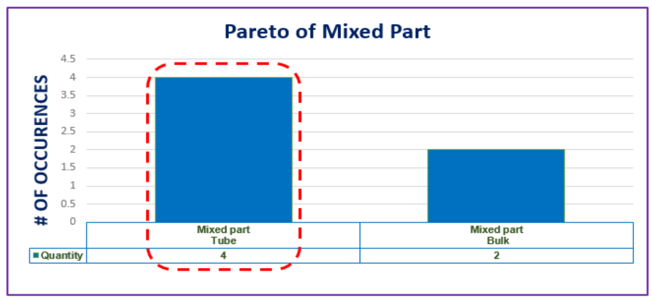


Figure 2. Pareto of Mixed Part

On the third level pareto, the specific top contributor for the pareto of package is Package A at 50 % (see Figure 3).

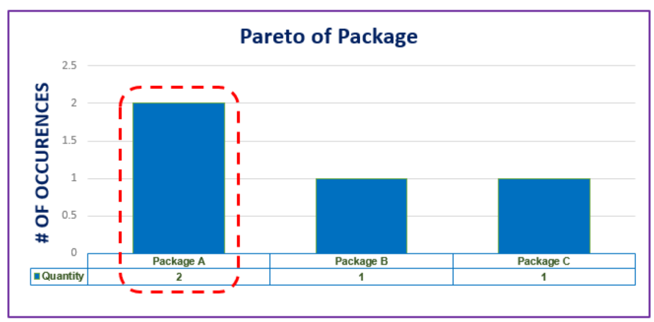


Figure 3. Pareto of Package

Figure 4 illustrates the overall process from Warehouse to Final Packaging. This flow was analyzed to detect the potential process where mixed parts could occur. And as a result, 1 out of the 12 major processes was found to be the most potential source of mixed parts. This was further validated through actual line investigation and simulation. Based on this, *Lot Testing in Test Handler* process was identified the cause of mix up of tubes and controllable by the team.

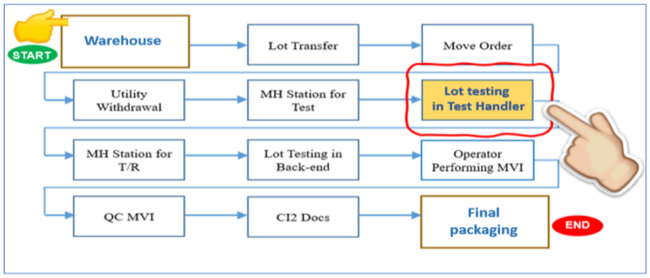


Figure 4. Process Mapping

The team identified and revealed areas of weakness in a Test process (see Figure 5-6). Using Ishikawa diagram and Why-Why analysis, data revealed that the main contributors to mix up of *Tested and Untested units in Tube* are a) Clear and red tubes were interchanged; b) Both tested and untested units had the same length of tubing; c) wrong tubes were used; and d) Tube sensor was unable to detect the faded tube color. These were verified and validated that the causes of mixed parts problem at Sensor Test area as shown in Table 1.

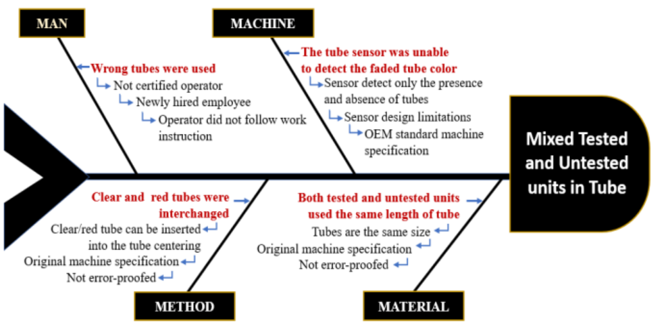


Figure 5. Ishikawa Diagram

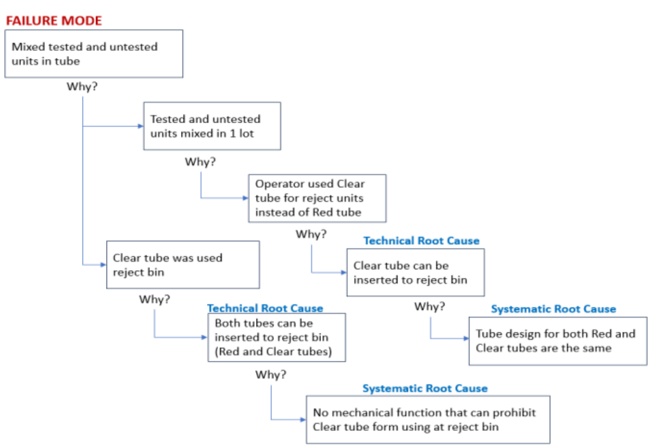


Figure 6. Five-Why Root Cause Analysis

The team drilled down the potential root causes as shown in Table 1. Based on the list of potential root causes, the team was able to identify eight potential causes under man, machine, material, environment, and method contributors. These were verified and validated by the team if these were the true causes of Mixed Part problem at Sensor Test area.

Table 1. Potential Root Causes

Process	What can go wrong in the process that will cause Mixed Device?	Contributor	Why1	Why2	Why3	Why4	Why5
Lot Preparation	Manual transfer of units	Man	Unit orientation in the tube was different to the machine requirement				
Lot Preparation	Wrong Lot retrival	Man	Lot verification was not performed prior testing				
Material Preparation	Used tube for Bin1 has stuck up units	Materials	Tubes were not checked before loading				
Start of Lot	Stray units within machine vicinity	Enviroment	Housekeeping not properly performed	No vacuum available in the machine	OEM (Original Equipment Manufacturer) design		
Electrical Testing	Presence of stray tubes with units	Enviroment	Tubes thrown by the machine	No defined standard pressure on cylinder topper			
Electrical Testing	Wrong tubes used	Man	Not Certified operator	Newly hired employee	Operator did not follow work instruction		
Electrical Testing	Interchanging of tubes	Method	The unloader assembly used same length of tubes for tested and untested parts	OEM (Original Equipment Manufacturer) design			
Electrical Testing	Interchanging of tubes	Method	The loader assembly used identical clear tubes for first and 2nd pass testing	OEM (Original Equipment Manufacturer) design			
Electrical Testing	Undetected mixed part in manual tube unloader	Machine	Sensor detects presence and absence of tubes	OEM (Original Equipment Manufacturer) design			

1.2 *Objective of the Study*

The aim of this project is to eliminate the interchange of tubes for tested and untested parts both externally and internally in the Final Test process at the end of year 2022.

1.3 *Scope and Limitations*

This project will cover only the mixed part in tubes. It does not cover electrical-related machine errors such as blown fuses, test program errors, and software limitations.

1.4 *Countermeasures*

Brainstorming was executed to select the best alternative solutions. Several improvement actions were identified but not all of them can be implemented due to some considerations. Selection Matrix (see Table 2) was used to judge what actions need to be implemented.

Table 2. Selection Matrix

SELECTION MATRIX			
Criteria	Score		
	3	2	1
Quality (Q)	No MPE	1 - 2 MPEs	> 2 MPEs
Delivery (D)	High Impact on Delivery	Medium impact on Delivery	Low Impact on delivery
Cost (C)	Zero Investment	Low Invesment	High Investment
Safety (E)	No Impact on Safety	Minor Impact on Safety	Major Impact on Safety
Handling (H)	Easy to Implement	Need Assistance	With High Effort

Decision based on total Score : 10- 15-GO; 5-9 - NO GO
Formula : Total Score = Q + D + C + E + H

Further validated the solutions using the Level of Control Criteria as guiding principle (see Figure 7). This is the process of anticipating, preventing, and detecting errors, defects, abnormalities, and hazards which adversely affect our customers, our company, our people, and result in losses. It has four levels: 1- Error elimination, 2- Error prevention, 3- Error detection/defect prevention, and 4- Detection at source.

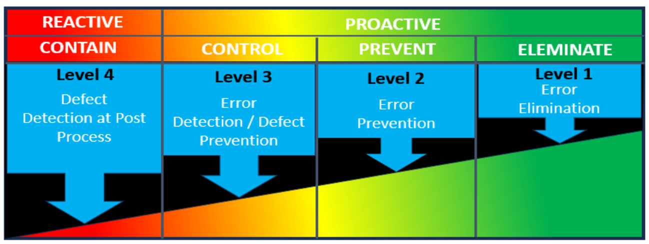


Figure 7. Level of Error-proofing Control Criteria

There were four error-proofing solutions selected for implementation (See Table 3).

Table 3. List of Error-proofing Solution

Item No.	True Rootcause	Solution	Q	D	C	S	H	Total Score	Level of Control	Decision
1	Clear and red tubes were interchanged	Install tube guides and Red tube slotting	3	3	1	3	2	12	1	GO
2	Tested and untested units used the same length of tubes	Use longer tube for untested and shorter tube for tested	3	3	1	3	2	12	1	GO
3	Wrong tubes were used	Use yellow tube for 2nd pass testing	3	3	1	3	2	12	2	GO
4	Color sensor is unable to detect faded tube color	Upgrade sensor	3	3	1	3	2	12	1	GO

2.0 REVIEW OF RELATED WORK – NOT APPLICABLE

3. 0 METHODOLOGY

To determine the reason for the mixed parts in the test process, the team started with a Gemba walk. Observations on the actual flow versus what is in the document were summarized. The team reviewed the Control Plan, FMEA, OPL, and Work Instructions used in the test process. Operators, technicians, supervisors, and logistics expediters were interviewed and discussed how mixed parts occurred in the testing process. Conduct process mapping to visually map out workflows in the test process. Use 5-why root-cause analysis to find out the root causes of mixed parts and identify the appropriate solutions. Generate FMEA and fault-tree analysis to review the failure modes of the system and their causes and effects.

3.1 Clear and red tubes were interchanged

Simulations confirmed that the clear tube with untested units and the red tube with rejected units can be interchanged in the manual tube unloader (see Figure 8). In humans, part mixing is unavoidable.

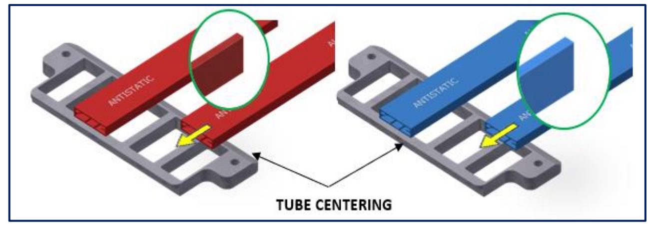


*Figure 8. (**BEFORE**) Non-slotted clear and red tubes can be interchanged in Manual Tube Unloader*

In order to ensure that the right tube can be inserted into manual tube unloader, tube guides and slotted red tubes were implemented (see Figure 9). Non slotted tubes can't be inserted.

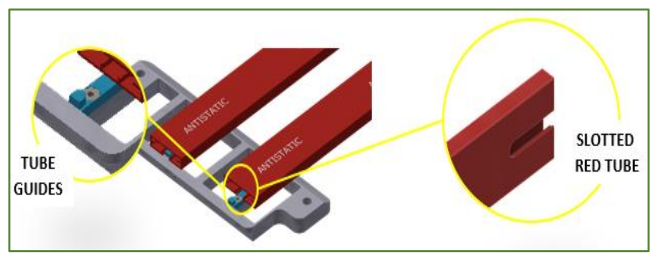


*Figure 9. (**AFTER**) Used slotted red tube for reject units*

3.2 Both tested and untested units had the same length of tube

The second contributor to the tube mixed part is both tested and untested units had the same length of tube. The tube cannot be visually distinguished when placed side by side in such cases. Unintentionally, tubes with untested units were picked up from the working table and assumed to be tubes with good, tested units (see Figure 10).

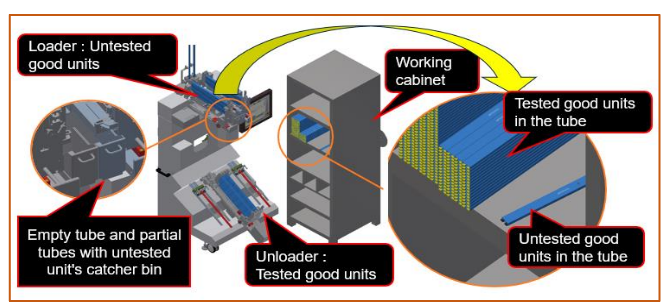


Figure 10. Tubes mixing simulation in tubes cabinet and machine

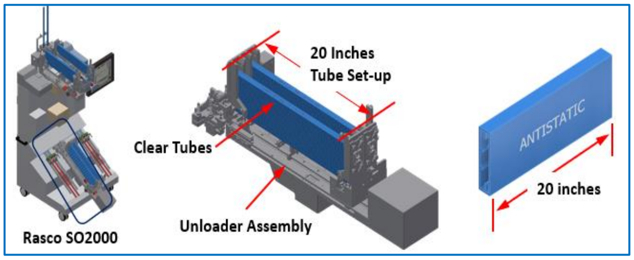


*Figure 11. (**BEFORE**) Unloader assembly used longer (20-inch) clear tubes for tested and untested units*

The clear tube used in the loader and unloader assemblies of the test machine are the same length. The operator faces a dilemma when determining which parts have been tested and which have not. Figure 11-12 illustrates the use of longer and shorter tubes application in the unloader assembly.

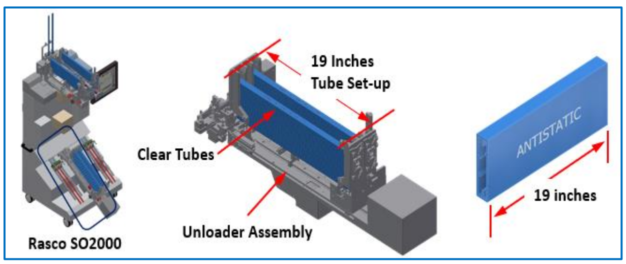


*Figure 12. (**AFTER**) Unloader assembly used shorter clear tubes for tested units only*

3.3 Wrong tubes were used

The loader assembly used identical 20 inches clear tubes for both first and second pass testing are vulnerable to mixing of tubes (see Figure 13).

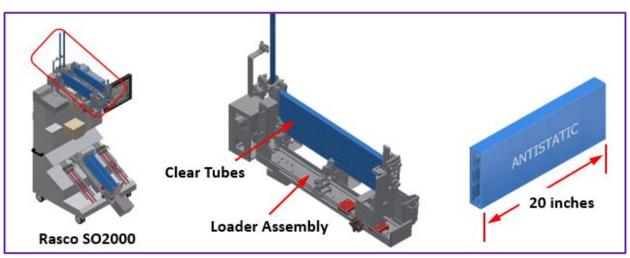


*Figure 13. (**BEFORE**) Loader assembly used clear tubes for first pass and second pass testing*

Figure 13 shows that the yellow tube easily helps the operator to identify the first and second pass tubes. It is a visual warning to stop the machine operator from using the wrong tube in the process.

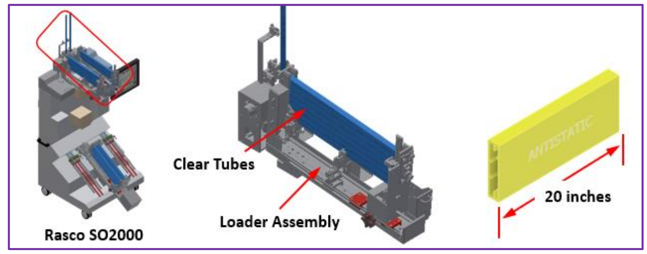


*Figure 14. (**AFTER**) Loader assembly used yellow tubes for second pass testing only*

3.4 Color sensor is unable to detect the faded tube color

The translucent color of the tube allows for immediate visual inspection of units within the tube. Such construction makes this tube susceptible to machine error. Excess temperature, excess current or voltage, mechanical stress, shock or impact, and contamination affect the reliability of the color sensor to detect the discolored and faded tubes.

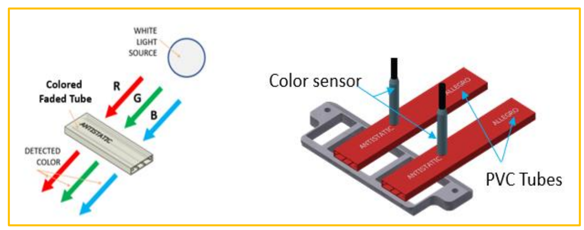


*Figure 15. (**BEFORE**) Sensor used to detect the absence and presence of tubes*

For a white object, all three colors of red, blue, and green are reflected. The ratio of the red, green, and blue reflections varies according to the color of the object.

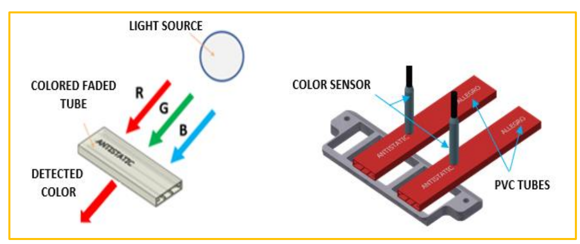


*Figure 16. (**AFTER**) Colored sensor used to detect any type of tubes*

If light containing the red, blue, and green wavelengths is shown on a red object, only red light will be reflected (see Figure 16).

3.5 Implementation of Shipping Tubes in Production

Table 4 illustrates the comparison of tube inputs and outputs in the test process. The tubes improvement illustration will serve as an OPL (One-Point Lesson) or special work instruction in test production as a reference for engineers, technicians, and operators.

Table 4. Summary of Implemented Tubes Before and After Results.

PROCESS	BEFORE		AFTER	
	INPUT	OUTPUT	INPUT	OUTPUT
1ST PASS	20-inch Clear End Plug : Black - White	20-inch Clear End Plug : Yellow - White	20-inch Clear End Plug : Black - White	20-inch Yellow End Plug : Yellow - White
2ND PASS	20-inch Clear End Plug : Yellow - White	20-inch Clear End Plug : Green - White	20-inch Yellow End Plug : Yellow - White	19-inch Clear End Plug : Green - White
REJECTS		20-inch Red Tube End Plug :		Slotted Red Tube End Plug :
TAPE AND REEL	20-inch Clear End Plug : Green - White		19-inch Clear End Plug : Green - White	

3.6 Validation of 25 Lots

To further validate the effectiveness, 25 lots were qualified after installation. Validation results showed zero untested parts caught by CI (Electrical testing) program on all lots processed, (see Table 5). Therefore, the error-proof tubes are effective in preventing the mix up of untested and tested parts in tube in the Final Test process.

Table 5. Analysis of 25 Qualification Runs Processed After the Installation of Mechanical Error-proofing Solution.

No	Lot No.	Item	Validation Results
1	Lot 12345	12345BE-JEN123	Zero untested parts caught by CI (Electrical testing) program
2	Lot 12346	12345BE-JEN124	Zero untested parts caught by CI (Electrical testing) program
3	Lot 12347	12345BE-JEN125	Zero untested parts caught by CI (Electrical testing) program
4	Lot 12348	12345BE-JEN126	Zero untested parts caught by CI (Electrical testing) program
5	Lot 12349	12345BE-JEN127	Zero untested parts caught by CI (Electrical testing) program
6	Lot 12350	12345BE-JEN128	Zero untested parts caught by CI (Electrical testing) program
7	Lot 12351	12345BE-JEN129	Zero untested parts caught by CI (Electrical testing) program
8	Lot 12352	12345BE-JEN130	Zero untested parts caught by CI (Electrical testing) program
9	Lot 12353	12345BE-JEN131	Zero untested parts caught by CI (Electrical testing) program
10	Lot 12354	12345BE-JEN132	Zero untested parts caught by CI (Electrical testing) program
11	Lot 12355	12345BE-JEN133	Zero untested parts caught by CI (Electrical testing) program
12	Lot 12356	12345BE-JEN134	Zero untested parts caught by CI (Electrical testing) program
13	Lot 12357	12345BE-JEN135	Zero untested parts caught by CI (Electrical testing) program
14	Lot 12358	12345BE-JEN136	Zero untested parts caught by CI (Electrical testing) program
15	Lot 12359	12345BE-JEN137	Zero untested parts caught by CI (Electrical testing) program
16	Lot 12360	12345BE-JEN138	Zero untested parts caught by CI (Electrical testing) program
17	Lot 12361	12345BE-JEN139	Zero untested parts caught by CI (Electrical testing) program
18	Lot 12362	12345BE-JEN140	Zero untested parts caught by CI (Electrical testing) program
19	Lot 12363	12345BE-JEN141	Zero untested parts caught by CI (Electrical testing) program
20	Lot 12364	12345BE-JEN142	Zero untested parts caught by CI (Electrical testing) program
21	Lot 12365	12345BE-JEN143	Zero untested parts caught by CI (Electrical testing) program
22	Lot 12366	12345BE-JEN144	Zero untested parts caught by CI (Electrical testing) program
23	Lot 12367	12345BE-JEN145	Zero untested parts caught by CI (Electrical testing) program
24	Lot 12368	12345BE-JEN146	Zero untested parts caught by CI (Electrical testing) program
25	Lot 12369	12345BE-JEN147	Zero untested parts caught by CI (Electrical testing) program

3.7 Implementation Project Cost

Table 6 demonstrates the implementation costs of mechanical error-proofing solution for package A (Pilot-run), which are 140,216.70.

The total implemented costs for the three packages (A, B, & C) derived to Php 420,650.10

Package A	= PHP 140,216.70
Package B	= PHP 140,216.70
Package C	= PHP 140,216.70
Total expenses	**= PHP 420,650.10**

The annual re-occurring cost of the project is zero cost since the parts being used were one time acquisition only.

Table 6. Implemented Cost for Package A.

Item#	Description	Supplier	Quotation #	QTY	UOM	Cost	Cost X	Total Cost	Note/s	Note/s
1	Hard Stopper	Alpha	DV-19-119	1	set	9,780.10	2	19,560.2	Engineering Cost (One time only)	Mecanical error-proofing for Package A
2	Red Tube Centering	NSB	190373-R1	1	set	10,319.40	2	20,638.8	Engineering Cost (One time only)	
3	Punch Tool (for Red Tube)	ITW	X20-AMP044-00	1	set	100,000.00	1	100,000.0	Engineering Cost (One time only)	
4	20 Inches Yellow Tube (DWG-0000832)	ITW	X20-AMP043-00	1	pc	5.50	1	5.5	Consumable	
5	19 Inches Clear Tube (DWG-0000835)	ITW	X20-AMP023-00	1	pc	5.20	1	5.2	Consumable	
6	Slotted Red Tube (DWG-0000828)	ITW	X20-AMP022-00	1	pc	7.00	1	7.0	Consumable	
Total Cost						**PHP 140,216.7**				

3.8 Full Error-proofing Solution Implementation

A total of 60 test handlers were successful mechanical error-proofing solutions installed as of July 2022, as shown in Table 7.

Table 7. Summary of Implemented Full Error-proofing Solution.

Item#	Activities	# of Machines	Responsible	Date Completed	Remarks
1	IMPLEMENTATION (PACKAGE A)	24	BENJIE/JEN	Nov-21	PILOT LINE/COMPLETED
2	FAN OUT (PACKAGE B)	13	BENJIE/JEN	Dec-21	COMPLETED
3	FAN OUT (PACKAGE C)	23	BENJIE/JEN	Jul-22	COMPLETED

3.9 Implementation and Improvement Action

Table 8 indicated that the potential risk for mixed parts was eliminated after the implementation of effective poka-yoke.

Table 8. Implemented Solutions Risk Results

Item No.	True Rootcause	Solution	Level of Control	Results	Remarks
1	Clear and red tubes were interchanged	Install tube guides and Red tube slotting	1	Eliminated Risk	**EFFECTIVE POKA-YOKE**
2	Tested and untested units used the same length of tube	Use longer tube for untested and shorter tube for tested	1	Eliminated Risk	**EFFECTIVE POKA-YOKE**
3	Wrong tubes were used	Use yellow tube for 2nd pass testing	1	Eliminated Risk	**EFFECTIVE POKA-YOKE**
4	Color sensor is unable to detect faded tube color	Upgrade sensor	1	Eliminated Risk	**EFFECTIVE POKA-YOKE**

3.10 Cost Avoidance

Figure 17 showed the cost avoidance of $2,744 potential increase of expense annually for RMA (Returned Material Authorization) and contained lots .

Tag	Occur	Units/Lot	Yearly	Pkg	Rwk Operation + Descriprtion	Cost / unit	2022	2023	2024	2025
							Cost Avoided based on RMA returns + Contained in AMPI			
Contained at AMPI	4 occur in a year	14000	56,000	A	8461 RWK TUBING-NO COST 8151 RWK AMBIENT/HOT-NO COST	0.00909	$ 509.04	$ 509.04	$ 509.04	$ 509.04
					8301 RWK T&R-NO COST	0.01051	$ 588.56	$ 588.56	$ 588.56	$ 588.56
						Total	**$ 1,097.60**	**$ 1,097.60**	**$ 1,097.60**	**$ 1,097.60**

		2022	2023	2024	2025
Total Cost Avoidance (RMA + Contained)		$ 2,744	$ 2,744	$ 2,744	$ 2,744
One Time Cost	$ 8,685.29	$ (5,941)	$ (3,197)	$ (453)	$ 2,291
	$ (8,685.29)	$ -	$ -	$ -	$ -

	Cost in Peso	FY22	Cost
One Time Cost	420,650.10	$ 48.43	$ 8,685.29

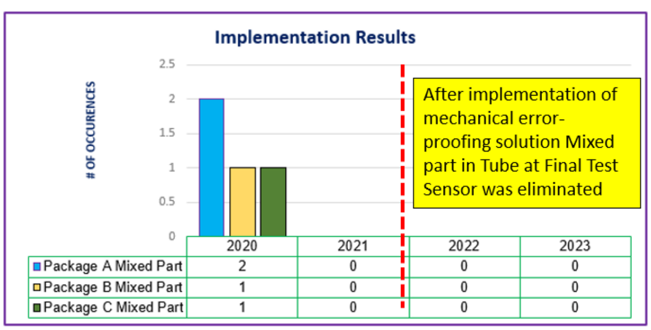
No. of Years where Cumulative Cash Flows are Negative	**3.0**
Partial Year(s) where Cumulative Cash Flow is Negative	-
Total Payback Period in Years	-

***Cost is based on FY24 Std Cost per operation (excluding fixed cost)**

Figure 17. RMA and Contained Lot Cost Avoidance

4.0 RESULTS AND DISCUSSIONS

The aim of this project is to eliminate the interchange of shipping tubes for test and untested parts both externally and internally in the test process by the end of 2022. After the implementation of the mechanical error proofing solution, the mixing of part of a tube-based products on the packages A, B and C were eliminated and resulted to zero occurrence from August 2022 to August 2023 (see Graph 1).



Graph 1. Actual Mixed Part Trend Before and After Implementation of Mechanical Error-proofing Solution

To ensure that these changes will be sustained, new procedures that were introduced in this project were documented. Work Instruction (WIN-0000665), Control Plan (CPL-0000136), Failure Mode Effect (FME-0000317), Slotted Red Tube (DWG-0000828), 19 Inches Clear Tube (DWG-0000835), 20 Inches Yellow Tube (DWG-0000832), Tube Re-dipping (SPE-0000137), and Tube Handling (WIN-0000452).

Table 9 displayed the intangible impact of mechanical error-proofing solution to the company.

Table 9. Intangible Impact

Culture	Mindset was changed. They are now ready to accept process change that would lead to process improvement. They were transformed into employess that cooperate to company's initiatives in ensuring only excellent product are shipped to the customer.
Skills	The team members competency to solve problem were magnified. They were equipped with tools to analyze and solve quality issues in the production. The member's confidence level to be part of a problem solving team was improved.
Morale	After the error-proofing improvements were implemented, team members were motivated to do even better on their assigned task. Made them realized that they are one of the key players in achieving the company's goal which road to zero defects.
Quality	Individual performance of members were improved. Considering that mixed part control enhanged, they can now delivering defect free parts and internal and external customer satisfaction.

5.0 CONCLUSION

The successful application of effective mechanical error-proofing solutions in Rasco SO2000 and SO2000DT test handlers eliminated the mixed part problem in shipping tubes from 66% to zero percent internally and externally. The company was able to avoid $2,744 annually in retesting and administrative costs associated with possible customer returns.

6.0 RECOMMENDATIONS

It is highly recommended to apply the concept of mechanical error-proofing solution which included the use of slotted red tubes for rejected units, use of shorter clear tubes for tested units, use of long clear tubes for untested units and use of yellow tubes for 2nd pass testing on the other applicable machines in Assembly operation.

7.0 ACKNOWLEDGMENT

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9. Rasco SO2000 and 2000DT Manual

9.0 ABOUT THE AUTHORS

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10.0 APPENDIX – NOT APPLICABLE