FAULT TREE ANALYSIS OF PNP HEAD LINEAR MOVEMENT FAILURE ON X-PITCH ASSEMBLY

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ABSTRACT

Manufacturing semiconductor components demands precise equipment functioning, with Pick-and-Place (PnP) heads being pivotal in semiconductor device placement. Ensuring their consistent performance is essential to the reliability of the manufacturing process.

However, our customer claim highlighted irregularities in the X-Pitch Assembly where the linear movement of the bearing block is reported to be neither smooth nor free from jamming within the PnP head.

This study aimed to investigate and address the issue. Through fault tree analysis and series of functional testing, the root cause was traced to a defective X-PitchB Stepnet Module. It revealed compatibility issues, leading to the recommendation of replacing the faulty module. This comprehensive analysis highlights the significance of systematic fault diagnosis in ensuring the reliability of semiconductor manufacturing equipment.

1. 0 INTRODUCTION

Manufacturing semiconductor components is a detailed and complex process that depends on the smooth operation of different assemblies of an equipment, each with an important role in guaranteeing the quality and effectiveness of the end product. One crucial assembly in this process is Pick-and-Place (PnP) head of a test handler, utilized by our end-customer, which play a key role in accurately placing semiconductor devices onto trays.

1.1 Test Handler Pick and Place Head

A test handler's Pick and Place Head (PnP) is shown in Figure 1. It precisely pick devices from a tray or boat having one XY Pitch spacing between device pockets and then precisely place the devices in a tray or boat having a different XY Pitch spacing between pockets. The head contain 2 rows of pick tips. The front row tip spacing is adjustable in X Pitch, but fixed in Y Pitch. The rear row is adjustable in both X and Y Pitch. The two rows have independent X Pitch.

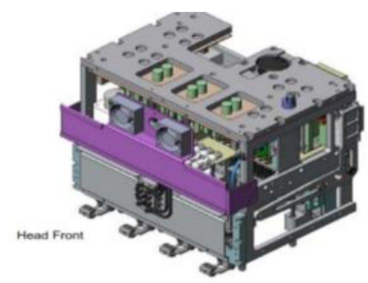

Fig. 1 Pick and Place Head of Test Handler

1.2 X-Pitch Assemblies and Pick Bodies

The PnP head feature eight Pick body assemblies, organized into two X-Pitch rows, with four pick bodies per row. Each of these X-Pitch rows is equipped with its own X-Pitch motor, operating independently of each other as shown in Figure 2. The front row of pick bodies, termed the "Master X-Pitch Assembly," consists of individual pick bodies labeled B1 through B4, arranged from left to right. This assembly maintains a fixed Y-Pitch, with its frame serving as the front frame of the entire head. In software, this row is denoted as "X Pitch B."

Contrarily, the rear row of pick bodies is dubbed the "Slave X-Pitch Assembly," with pick bodies designated as A1 through A4 from left to right. This assembly's Y-Pitch spacing is adjustable via a single Y-Pitch motor, enabling flexibility in picking from and placing in two separate rows of trays or boats with distinct Y-Pitch spacings. Notably, both X-Pitch and Y-Pitch adjustments occur concurrently during pick-and-place operations. In software, this row is identified as "X Pitch."

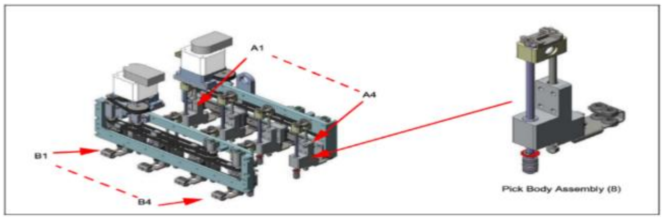

Fig. 2 X-Pitch Assemblies and Pick Body

1.3 X-Pitch Drive

Each pick body is affixed to a bearing block, which travels along an X-Pitch linear rail, as depicted in Figure 3. Changes in X-Pitch spacing are facilitated by a mechanism involving belts, pulleys, and a reduction gear. This system fulfills two essential criteria for Pitch adjustment: firstly, the inner pick bodies must move in opposing directions while the outer pick bodies must do the same; and secondly, the outer pick bodies must move twice the distance of the inner pick bodies to maintain consistent Pitch spacing across all pick bodies. Figure 4 illustrates the realization of these requirements. Notably, distinct drive belts are employed for the inner and outer pick bodies. Additionally, a reduction gear is interposed between the motor and the drive belt for the inner pick bodies to diminish the movement per motor revolution, contrasting with the non-reducing gear used for the outer belt. Furthermore, the two inner pick bodies are clamped on opposite sides of the drive belt to ensure opposing movement, related to the arrangement for the outer pick bodies on the outer drive belt.

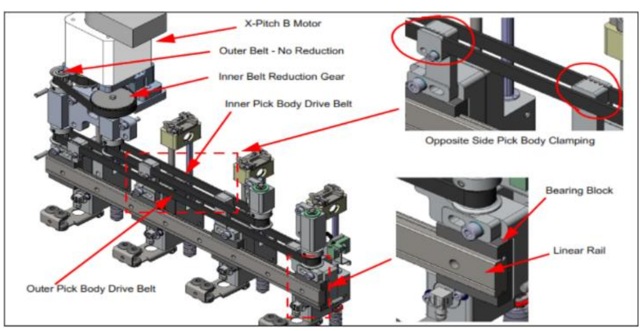

Fig. 3 X-Pitch Drive

1.4 Motion Control

The PnP Controller Assembly oversees motion control for the PnP head, functioning as its motherboard as illustrated in Figure 4. It hosts two Copley Stepnet modules: the X-PitchB Stepnet module for the "Master X-Pitch Assembly" and the X-Pitch Stepnet module for the "Slave X-Pitch Assembly." These modules facilitate motion control for motors in the X-Pitch assemblies.

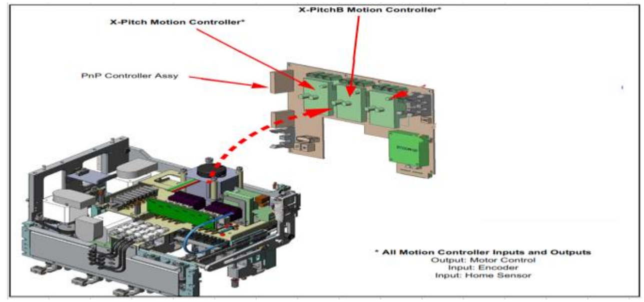

Fig. 4 PnP Head Motion Control

However, a customer claim has highlighted an issue with the PnP head specific to X-Pitch Assembly where the linear movement of the bearing block is reported to be neither smooth nor free from jamming within the PnP head. It can't complete its movement which is characterized by the pick bodies initiating movement from zero to the home position but failing to complete it as shown by the actual unit which was returned to P.IMES as shown in Figure 5.

These quality issues raise significant concerns regarding potential defects within the PnP head assembly, necessitating a comprehensive failure analysis. This study is initiated in response to the customer's claim, aiming to pinpoint the root cause of the observed quality deviation and propose effective corrective actions. Through fault tree analysis, our objective is to uncover any underlying factors contributing to the malfunction of the X-Pitch Assembly and the associated irregularities in linear movement.

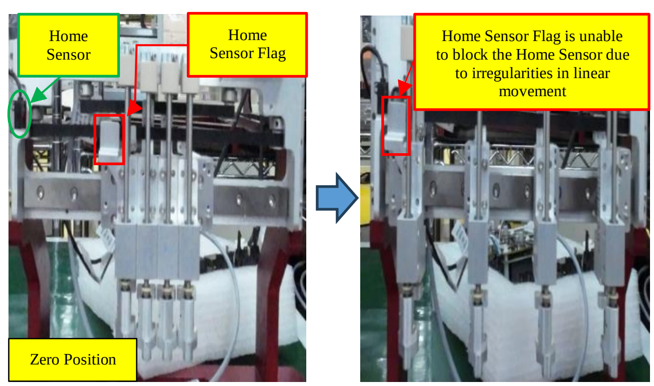

Fig. 5 X-Pitch Linear Movement Irregularity

2.0 REVIEW OF RELATED WORK

Not applicable.

3.0 METHODOLOGY

Fault tree analysis is employed to identify the root causes of the quality issue or undesired event (the top "event") by deconstructing the event into its contributing factors, or "faults".

3.1 Definition of Top Event

During standard operation, the linear movement of X-Pitch assemblies is expected to function based on the set parameters without encountering binding or becoming stuck during changes in X-Pitch spacing. The initial problem statement shared by our customer for the encountered quality issue is "Head linear block bearing is not smooth". With this,the top event could be defined as "Bearing block linear movement is not smooth or jammed in the PnP head".

3.2 Specification for the Fault Tree (FT)

- Top Event: Bearing block linear movement is not smooth or jammed in the PnP head.
- Boundary of the FT: The affected PnP head unit and components related to operation of X-Pitch assemblies containing the bearing block, linear rail, belts, pulleys, reduction gear, frame, adapter bearing, belt clamp, pick bodies, X-PitchB motor assembly, X-Pitch motor assembly, PnP controller assembly, X-PitchB Stepnet Module, and X-Pitch Stepnet Module.
- Resolution of the FT: The basic components which is related X-Pitch assemblies operation excluding the wiring.
- Initial State of System: Normal cycle – Operating during a pick-and-place cycle with supplied parts.

3.3 Fault Tree

The fault tree is constructed based on the defined specification. Refer to Appendix A – Fault Tree of Linear Movement Issue.

3.4 Analysis of Fault Tree

The fault tree will be analyzed based on criticality of each event or combination of events leading to the top event. Performing functional test of the defective unit will help to identify the most significant basic events to the top event.

3.4.1 Functional Test of the Defective Unit

The focus of the functional test will be on the linear movement issue specific to Master X-Pitch assembly (X-PitchB) and Slave X-Pitch assembly (X-Pitch). Test handler's software will be utilized to perform a normal cycle test in an attempt to replicate the issue found in our end-customer site for data gathering.

3.4.2 Materials for Functional Test of the Defective Unit

- Defective PnP head assembly
- Test system cart
- Test cable assemblies
- PnP head test fixture
- Pneumatic test tool
- Pneumatic hoses and fittings

3.4.3 Procedure

Preparations are made for the unit to be tested, including mounting the unit on the test fixture, gathering all necessary materials and tools for the functional test. Once gathered, electrical and pneumatic connections are established using suitable test tools. Basic setup files are then installed, and the setup within the unit is verified accordingly. The functionality of fans and home sensors is assessed at this stage. Subsequently, the unit undergoes testing under a normal cycle using test handler's software from test system cart. To ensure comprehensive evaluation, this testing procedure is repeated at least 10 times. Lastly, record the gathered result.

Table 1 displays the outcomes of the functional test performed on the tested unit.

Table 1. Test Summary of the PnP Head Assembly

Trial	Result
1	Failed
2	Failed
3	Failed
4	Failed
5	Failed
6	Failed
7	Failed
8	Failed
9	Failed
10	Failed

Across all 10 trials, failures were consistently observed, particularly concerning the PnP head.

The error prompt encountered in all 10 trials on the PnP head assembly, leading to failure, is "Output PnP X-PitchB Axis unable to complete move." Figure 6 illustrates this error prompt captured from the software. Based on the data from the initial functional test, it is evident that the issue is localized within Master X-Pitch assembly.

Fig. 6 Error Prompt on the PnP head assembly.

3.4.4 X-Pitch Assembly Offline Exercise

To further investigate the issue, Master X-Pitch assembly unit is isolated from the PnP head to facilitate an offline exercise test. The objective of this test is to observe the linear movement of X-Pitch along with its associated parameters throughout the movement process.

3.4.4.1 Materials for Offline Exercise

- Master X-Pitch assembly extracted from PnP head
- PnP controller assembly extracted from PnP head
- Test system cart
- Test cable assemblies
- X-Pitch test fixture

3.4.4.2 Procedure

The Master X-Pitch assembly and PnP controller assembly are extracted from the PnP head assembly, this process does not disrupt any mechanical alignment. Subsequently, the unit is prepared for testing with all required materials and tools. The Master X-Pitch assembly is affixed to the test fixture, and electrical connections are established utilizing the PnP controller assembly. Following this, the offline exercise file is installed, and the setup is confirmed before commencing the offline exercise test using the CME software. Testing is repeated at least 10 times to ensure comprehensive evaluation. Finally, record the gathered result.

Table 2 shows the outcomes of the functional test performed on the tested unit.

Table 2. Test Summary of the Master X-Pitch Assembly

Trial	Result
1	Failed
2	Failed
3	Failed
4	Failed
5	Failed
6	Failed
7	Failed
8	Failed
9	Failed
10	Failed

Across all 10 trials, failures were consistently observed, particularly concerning the assembly.

The failure observed during the offline exercise test mirrors that observed during the functional test of the PnP head, whereby X-PitchB is unable to complete its movement. The incomplete movement is characterized by the pick bodies initiating movement from zero to the home position but failing to complete it. Additionally, it is unable to initialize the exercise.

Given the consistent results obtained from the offline exercise test, a comparative analysis of the parameters specific to Master X-Pitch assembly during the failure will be conducted against those of a known-functional unit which passed all the functional testing aligned with customer's requirement of PnP head assembly. The parameters to be compared are the initialization parameters instead of the running parameters, as failures occur during exercise initialization.

A Master X-Pitch assembly will be extracted from this known-functional PnP head assembly and subjected to the same procedure for an offline exercise test.

Table 3. Initialization Parameters of Defective Versus Functional X-Pitch Assembly

Trial	Bus Voltage (V)		Amplifier Temperature (°C)		Actual Current (A)	
	Defective X-pitchB	Functional X-pitchB	Defective X-pitchB	Functional X-pitchB	Defective X-pitchB	Functional X-pitchB
1	47.7	47.7	35	35	0.56	2.5
2	47.7	47.7	35	35	0.56	2.5
3	47.7	47.7	35	35	0.56	2.5
4	47.7	47.7	35	35	0.56	2.5
5	47.7	47.7	35	35	0.56	2.5
6	47.7	47.7	35	35	0.56	2.5
7	47.7	47.7	35	35	0.56	2.5
8	47.7	47.7	35	35	0.56	2.5
9	47.7	47.7	35	35	0.56	2.5
10	47.7	47.7	35	35	0.56	2.5

All parameters across 10 trials are identical except for the actual current; Defective = 0.56 A; Functional = 2.5 A.

3.4.5 Electrical-Related Issues

The analysis suggests prioritizing the investigation of basic events under the intermediate event of electrical-related issues specific to Master X-Pitch assembly. These basic events include the defective X-PitchB motor assembly or X-PitchB stepnet module. This focus aims to ascertain if either of these issues is indeed the root cause of the problem.

3.4.6 Combinatorial Testing Related to X-PitchB Motor and X-PitchB Stepnet Module

Using combinatorial testing, the different combinations of motors and boards installed in different sub-assemblies will be systematically tested to identify any defects or interactions between these components. A functional Master X-Pitch assembly, along with its motor and stepnet module, will be combined with the defective master X-Pitch assembly and its corresponding motor and stepnet module, and vice versa.

3.4.6.1 Input Parameters

- Motor Assembly A – Motor assembly from defective unit
- Motor Assembly B – Motor assembly from known functional unit
- Stepnet Module A – Stepnet module from defective unit
- Stepnet Module B – Stepnet module from known functional unit
- Master X-Pitch Assembly A – Defective unit
- Master X-Pitch Assembly B – Functional unit

3.4.6.2 Level of Parameters

- Motor Assembly:
  - Level 1: Motor Assembly A (from defective unit)
  - Level 2: Motor Assembly B (from known functional unit)
- Stepnet Module:
  - Level 1: Stepnet Module A (from defective unit)
  - Level 2: Stepnet Module B (from known functional unit)
- Master X-Pitch Assembly:
  - Level 1: Master X-Pitch Assembly A (Defective unit)
  - Level 2: Master X-Pitch Assembly B (Functional unit)

3.4.6.3 Test Cases

Two levels are available for each factor, resulting in 8 combinations for the test case as shown in Table 4.

Table 4. Test Matrix for Test Cases

Test Case	Motor Assembly	Stepnet Module	Master X-Pitch Assembly
1	Motor Assembly A	Stepnet Module A	Master X-Pitch Assembly A
2	Motor Assembly A	Stepnet Module A	Master X-Pitch Assembly B
3	Motor Assembly A	Stepnet Module B	Master X-Pitch Assembly A
4	Motor Assembly A	Stepnet Module B	Master X-Pitch Assembly B
5	Motor Assembly B	Stepnet Module A	Master X-Pitch Assembly A
6	Motor Assembly B	Stepnet Module A	Master X-Pitch Assembly B
7	Motor Assembly B	Stepnet Module B	Master X-Pitch Assembly A
8	Motor Assembly B	Stepnet Module B	Master X-Pitch Assembly B

Eight possible combinations of 2x2x2 parameters level.

3.4.6.4 Execution of Test Cases

The test cases within the test matrix will be executed in accordance with the X-Pitch assembly offline exercise test. Table 5 displays the result of each test cases. The failed test cases also exhibit the incomplete movement issue and is unable to initialize the exercise.

Table 5. Test Result for Test Cases

Test Case	Motor Assembly	Stepnet Module	Master X-Pitch Assembly	Result
1	A	A	A	Failed
2	A	A	B	Failed
3	A	B	A	Passed
4	A	B	B	Passed
5	B	A	A	Failed
6	B	A	B	Failed
7	B	B	A	Passed
8	B	B	B	Passed

Out of eight test cases, four passed the offline exercise test.

3.4.7 Functional Test of Defective PnP Head Assembly Using the Test Cases

The cases or combinations of motor assembly, stepnet module, and Master X-Pitch assembly will be integrated into the defective PnP head assembly. Subsequently, the assembly will undergo a comprehensive functional test aligned with the customer's requirements. The objective of this process is to verify the outcomes of the combinations and their individual components through testing of the final product.

Table 6 presents the results of the functional test conducted on all combinations. The failed test cases also encountered an error of "Output PnP X-PitchB Axis unable to complete move."

Table 6. Result of Defective PnP Head Assemblies Functional Test with All Combinations

Test Case	Result
1	Failed
2	Failed
3	Passed
4	Passed
5	Failed
6	Failed
7	Passed
8	Passed

Out of eight test cases, four passed the functional test of PnP Head.

4.0 RESULTS AND DISCUSSION

The series of functional tests conducted aided in identifying the root cause of the issue. Table 7 illustrates the interaction results of Motor Assembly A with all other components, as well as the interaction of Stepnet Module A with all other components for all conducted test cases.

Table 7. Result of Test Cases and its Component Failures

Test Case	Components						Result
	SM^{A}	MA^{A}	MA^{B}	XPA^{B}	XPA^{A}	SM^{B}	
1			-	-		-	Failed
2			-		-	-	Failed
5		-		-		-	Failed
6		-			-	-	Failed
3	-		-	-			Passed
4	-		-		-		Passed
7	-	-		-			Passed
8	-	-			-		Passed
CFR	100%	50%	50%	50%	50%	0%	

SM stands for "Stepnet Module", MA stands for "Motor Assembly", XPA stands for "X-Pitch Assembly" while CFR stands for "Component Failure Rate". The superscript "A" signifies components which are from the defective unit while superscript "B" signifies components which are coming from a known-functional PnP head. The red cell signifies a no-good outcome of a component. Meanwhile, the green ones represent a good result.

When matched with Stepnet Module A/B and Master X-Pitch Assemblies A and B, Motor Assembly A exhibits favorable results (Good) in test cases 3 and 4, while showing unfavorable outcomes (No Good) in test cases 1 and 2, resulting in a total of 2 failures across 4 test cases.

On the other hand, when Stepnet Module A is paired with Motor Assemblies A/B and Master X-Pitch Assemblies A/B, it consistently generates negative outcomes (No Good) across all its test cases, namely 1, 2, 5, and 6, resulting in a total of 4 failures across 4 test cases.

Motor Assembly A exhibits variable compatibility when paired with Stepnet Module B and Master X-Pitch Assemblies A/B, with a 50% failure rate. However, when Stepnet Module A is included, Motor Assembly A consistently fails to produce positive outcomes across all test cases, resulting in a 100% failure rate. During all failures, the top event is observed to be replicated.

In contrast, Stepnet Module A consistently yields negative outcomes across all test cases when matched with Motor Assemblies A/B and Master X-Pitch Assemblies A/B. Identical issues were also observed in these test cases, mirroring the top event. **This suggests significant compatibility issues or functional limitations, implying that the root cause of the problem lies with the defective X-PitchB Stepnet Module**.

The recommended corrective action involves replacing it with a known functional X-PitchB Stepnet Module (Stepnet Module B), which has demonstrated

effectiveness during functional testing in PnP head assembly, aligned with the customer's requirements. The effectiveness observed in functional testing also resulted in the elimination of all other basic events.

5.0 CONCLUSION

The key findings of the study highlight the successful identification of the root cause of the problem utilizing a top-to-bottom approach in fault tree analysis, which identified the defective X-PitchB Stepnet Module. This analysis also revealed the dependencies and contributions of this component to the failure of the PnP head assembly.

6.0 RECOMMENDATIONS

Performing fault detection or conducting further component-level troubleshooting on the defective X-PitchB Stepnet Module is advisable to identify the specific component or defect responsible for its malfunction. Additionally, understanding the root cause of the problem from the end-user perspective is crucial to prevent similar occurrences in the future.

7.0 ACKNOWLEDGMENT

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8.0 REFERENCES

1. Customer's Product Technical Manual, **2023**

2. Bill Vesely, **Fault Tree Analysis (FTA): Concepts and Applications**, **2002**.

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10.0 APPENDIX

Appendix A – Fault Tree of Linear Movement Issue.