LIFT OFF DEFECT ANALYSIS IN WIREBONDING PROCESS

Final Project

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Politeknik Negeri Batam
2024

APPROVAL

The Final Assignment is prepared to fulfill one of the requirements for obtaining a degree in Bachelor of Applied Engineering (S.Tr.T)/Associate Degree in Engineering (AMd.T.)
in
Batam State Polytechnic

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Seminar Date: July 2024

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LIFT OFF DEFECT ANALYSIS IN WIREBONDING PROCESS

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***Abstract*— Lift off defect was occurred a lot in wirebonding area during September 2023, with fishbone and FMEA analysis, writer concluded that the main reason of it are ultrasonic force and clamp power failure. Ultrasonic force shear test is done to see how the forces affect the shape of the bonded wire and also the power of the wire itself. With 6 different parameters applied, writer gains different results for each parameter which are: 40KHz, 45KHz, 50KHz, 55KHz, 60KHz, 65KHz. The standard of wire strength is 1900g – 2900g or even more as long as there is no deformed bondfoot occur. 40KHz - 45KHz Ultrasonic force causing lift off defect the most, with only 1870g - 2010g wire strength, 50KHz – 60KHz is a stable parameter for bonding with wire power results between 1980g – 2890g with no liftoff, for 65KHz ultrasonic power the highest result of wire strength 3880g causing the wire to get deformed. Therefore, the range between 50KHz – 60KHz ultrasonic force is recommended. Meanwhile clamp power is divided into two, bolts clamp and vacuum clamp. Bolts clamp monthly failure is 3 while vacuum clamp is 7, the vacuum clamp receiving much more failure is caused by unstable vacuum pressure that happen sometimes while bolts clamp is less failed due to the stable hold by the bolts. After the rootcauses are found, the corrective action is made as a preventive way to avoid further failure, such as machine condition checking, one module checking, and further machine settings for technicians.**

Keyword: Lift off, Fishbone, FMEA, Rootcause, Corrective action.

I. INTRODUCTION

According to [1] Moreno, A. R., Graycochea Jr., E. M., & Gomez, F. R. I. “Specialized Wirebond Process Configuration on Advanced Multi-Die Package”, Journal of Engineering Research and Reports, 2020, pp. 1–5. Wirebonding process is one important assembly process responsible for providing electrical connections between the silicon die and the external leads of a semiconductor package or device. In power electronics, IGBT (Insulated Gate Bipolar Transistor) is used for switching application.

According to [2] Loncarski, J., Hussain, H.A., Bellini, A. In the article of “Efficiency, Cost, and Volume Comparison of SiC-Based and IGBT-Based Full-Scale Converter in PMSG Wind Turbine”, Electronics 2023, 12, 385. Wide-bandgap power electronics are of particular interest due to their superior voltage blocking capabilities and fast switching speeds.

In September 11th – 13th 2023, Wirebonding in the process line met a lot of lift off defect in 1 module type. The place of lift off occur is always in the same spot in every module, it is about 3 or 4 modules in total 7 module that reject caused by lift off defect. This is why the writer conducted an analysis to find out the reason behind this defect, that will be explained below.

Lift off Defect is the condition where the wire lifted from the surface due to several reasons, the most common reason is the force of ultrasonic power. The force of ultrasonic energy that pushes the wire to create the bond with the surface can sometimes to low making the bonding results weak and leave it lifted or even to strong and creates an initial crack to finally turned into liftoff wire.

According to [3] Kristian Bonderup Pedersen, Peter Kjær Kristensen, Vladimir Popok, Kjeld Pedersen. “Micro-sectioning approach for quality and reliability assessment of wire bonding interfaces in IGBT modules”, in Microelectronics Reliability, Volume 53, 2013, pp.1422-1426. The bond wire lift-off failure mechanism in IGBT modules is primarily due to fatigue crack propagation inside the wire material. This is due to the bonding quality, where the refinement of the granular structure results in a stronger interface than the material itself.

In addition, according to [4] Luo, D. Chen, M. Lai, W. Xia, H. Ding, X. Deng, Z. “A Study on the Effect of Bond Wires Lift-Off on IGBT Thermal Resistance Measurement”, Electronics 2021, 10, 194. Bond wires lift-off leads to a rise in power dissipation of remaining bond wires.

Here below is the standardization of a good bonding result and its difference with bad bonding result:

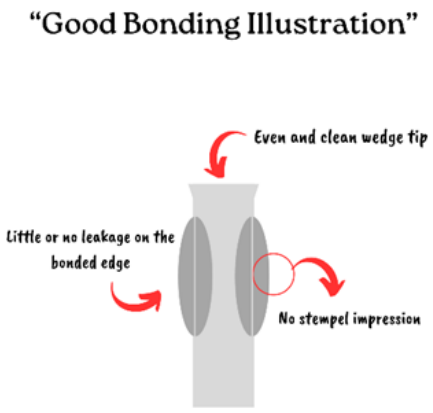

Figure 1. Good Bonding illustration

- On the edges of the wedge, there is no stemple impression left.
- Clean, and even tip on the cutted wedge.
- Little or no visible leakage at the edge of the wedge.

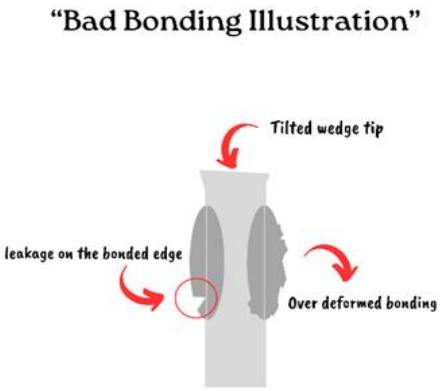

Figure 2. Bad bonding Illustration

- Wedge tip is tilted.
- Big leakage on the bonded edge.
- Over deformed bonding.

II. METHOD

A. Flowchart

To portray the structure of the research activity, writer use flowchart to simplify the groove, according to [5] Ensmenger N. in the journal of "The Multiple Meanings of a Flowchart". Information & Culture (2016). From the very earliest days of electronic computing, flowcharts have been used to represent the conceptual structure of complex software systems.

The research groove is explained through this flowchart below:

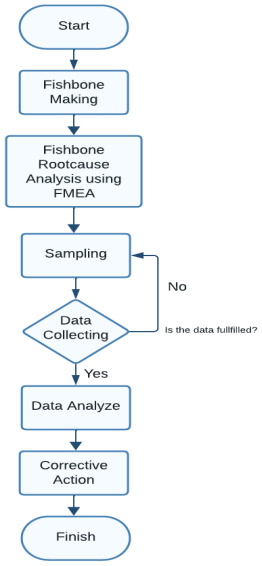

Figure 3. Process Flowchart

The research started from fishbone making to identify the rootcauses of the problem, the rootcauses are ultrasonic force and also clamp position. Both of the problem is observed with sampling technique where different ultrasonic forces applied to see the difference between one and another, the clamp position between the machine using vacuum power and with the convenience one using bolts to be installed are observed to see the difference. If the data collected is enough and fulfilled to do the data analysis and making the report conclusion then the research is done, but if it is not the data must be collected again.

B. Fishbone Diagram

To help in solving the problem, writer use cause and effect diagram or commonly known as fishbone to identify the rootcause and solve it directly and reduce the defect significantly. Fishbone diagram is a technique used to find possible causes of defect. The defect causes will be shown on the fish body to simplify the writer to find the main problem, it is also used to make the readers understand what the writer explains by simply look at the diagram groove.

According to [6] Gartlehner, G., Schultes, MT., Titscher, V. et al. In the article "User testing of an adaptation of fishbone diagrams to depict results of systematic reviews", BMC Med Res Methodol, 2017, 17, 169. The usage of fishbone diagrams as graphical displays could offer researchers an effective approach to simplify content for readers with limited epidemiological training.

By using the fishbone, writer will mention some of the defect causes from each aspect (machine, method, material, environment).

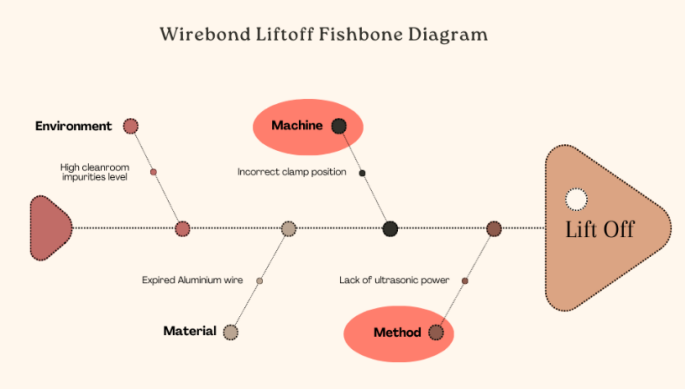

Figure 4. Fishbone Diagram of Liftoff Defect

As the main intention of Fishbone diagram, the cause and effect are written down to find the root cause. Lift Off, is the "effect" on the fish head, and the "causes" on the fish head are coming from the Environment, Machine, Material and Method. But the one that will be explained are Machine and Method.

C. FMEA

To find the rootcause, writer use FMEA (Failure Mode and Effect Analysis), According to [7] Sharma K. D.Srivastava S. "Failure Mode and Effect Analysis (FMEA) Implementation: A Literature Review", Copyright Journal of Advance Research in Aeronautics and Space Science J Adv Res Aero SpaceSci (2018). FMEA is a systematic method of identifying and preventing system, product and process problems before they occur.

Based on [8] Kadena, E., Koçak, S., Takács-György, K., Keszthelyi, A. In the article of "FMEA in Smartphones: A Fuzzy Approach", Mathematics 2022, 10, 513. The F-FMEA method was applied to prioritize the potential failures based on their Severity (S), expected Occurrence (O), and the likelihood of Detectability (D).

FMEA below explains how the method and machine become the main rootcause to solve, with its function to analyse the risk priority number of each failure.

Table 1. FMEA

POTENTIAL ROOTCAUSE							
No	Aspects	Failure	Potential Effect of Failure	Sev	Occ	Det	RPN
1	Method	Insufficient or Excessive Ultrasonic power	Liftoff because of Weak bonding or initial crack	8	7	1	56
2	Machine	Incorrect Clamp Position	liftoff due to shaky grip	8	2	3	48
3	Environment	High Cleanroom Impurities Level	liftoff due to dirty pad surface	8	2	1	16
4	Material	Expired Aluminium wire	liftoff caused by low quality wire	8	1	1	8

Based on [9] Zandi P.Rahmani M.Khanian M.Mosavi A. "Agricultural risk management using fuzzy topsis analytical hierarchy process (Ahp) and failure mode and effects analysis (fmea)". Agriculture (Switzerland) (2020). In a typical FMEA, there are three risk factors for each failure modes: Severity (S), occurrence (O), and detectability (D). These will be included in calculating a risk priority number (RPN) multiplying the three aforementioned factors.

All the aspects severity rates are 8 because liftoff causing major disruption in operations (100% scrap), Insufficient or excessive ultrasonic power has the highest RPN (Risk Priority Number) due to the occurrence rate, the rate 7 (high) indicate the failure happens 1 in 20 or 5% defective, the defect usually happen when the bonding program is changed, but the detection rate is 1 (almost certain) because when the module is changed, the last module will be the "one module" or a module used as the initial bonding and will be checked in visual inspection before the next module is getting bonded, so if there is a failure or defect we can overcome it right away.

Incorrect clamp position is a little rare to occur (rate 2) but the detection is a little bit higher than method failure (rate 3), because when this failure happened, the reason will likely unknown but after 2 or 3 failure the machine will be checked and incorrect clamp position will be the cause of it and after that the problem will be solved.

III. Results

From both tests that writer has done, here below the results and discussion from ultrasonic force shear test and also clamp power test.

A. Ultrasonic Force Test Result

The testing is done by applying 6 different parameters to see the difference between them. The ultrasonic force is started from the lowest to the highest with 30 bonded wires on balcon area as experiment object or 6 in each parameter change. The result is checked under the wire shear tester to see the best result and the defect.

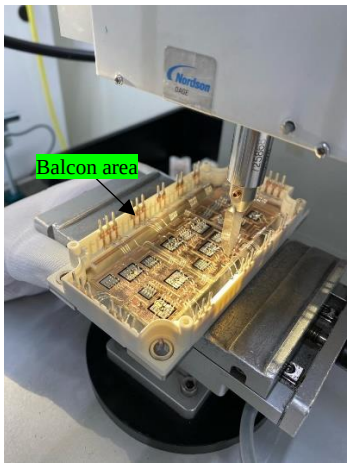

Figure 5. Balcon Sheartest

In each of the module, applied a different ultrasonic bond force, start from 40KHz, 45KHz, 50KHz, 55KHz, 60KHz, 65KHz to see how strong the force to bond the wire.

Table 2. Ultrasonic Force Test Results

Ultrasonic Force Shear Test Results						
No	Param 1 (40KHz)	Param 2 (45KHz)	Param 3 (50KHz)	Param 4 (55KHz)	Param 5 (60KHz)	Param 6 (65KHz)
1	0 (Liftoff)	1870g	2223g	2289g	2700g	2890g
2	0 (Liftoff)	1958g	2405g	2576g	2308g	3100g
3	1267g	2010g	2127g	2600g	2890g	3670g (Bondfoot deformed)
4	0 (Liftoff)	1847g	1980g	2278g	2677g	3880g (Bondfoot deformed)
5	0 (Liftoff)	1960g	2150g	2345g	2546g	2998g

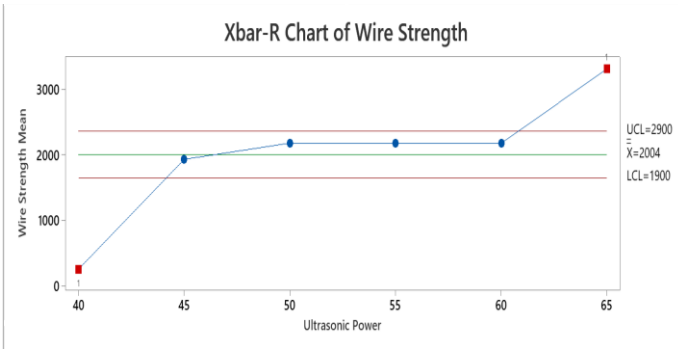

Figure 6. Wire Strength Chart

The wire strength chart shows that ultrasonic power for 40KHz and 45KHz is under the LCL (Lower Control Limit) and uncapable to be used, while 50KHz – 60KHz ultrasonic power is tend to get stable strength result, and also still within the standard, meanwhile for the 65KHz result is out of UCL (Upper Control Limit) as a sign of uncapable parameter to make a good bonding result.

The standard for good bonding shear test results is from the range of 1900g-2900g. If the results higher than 2900g (as long as the bondfoot is not deformed is allowed but the data range from the minimum to maximum results must not higher than 1000gF, or else the data spreads will be too high causing the standard deviation is getting high too.

B. Clamp Power Test Result

In this testing, writer collects the data of performance between vacuum clamp and bolts clamp in sector 1 of wirebonding area, each failure found and the reason of it will be reported in the table below. The data is observed in January 2024.

Table 3. Clamp Failure Data Results

Clamp Failure Data Results				
No	Vacuum Clamp		Bolts Clamp	
	Condition	Date	Condition	Date
1	Shaky grip	4 January	Shaky grip	4 January
2	Unable to grip	6 January	Shaky grip	12 January
3	Shaky grip	15 January	Shaky grip	24 January
4	Shaky grip	19 January	-	-
5	Shaky grip	22 January	-	-
6	Shaky grip	22 January	-	-
7	Shaky grip	27 January	-	-

Shaky grip stands for the condition where the clamp is loose and the module is moved while being bonded making the bonding process unstable and leading to lift off defect. Unable to grip is a condition where the clamp is totally malfunctioned and uncapable to grip or even to move.

The data gained in this test shows that the significant difference between both of the clamp can be a reason to enhance the stability of vacuum clamp since the monthly failure is higher than bolts clamp.

IV. Discussion

A. Ultrasonic Force Test Discussion

The standards for good bonding are 1900g for Lower Spec Limit (LSL) and 2900g for Upper Spec Limit. Here are the histograms of bonding result based on each parameter:

1. Process Capability Report for 40KHz Frequency of Ultrasonic Force

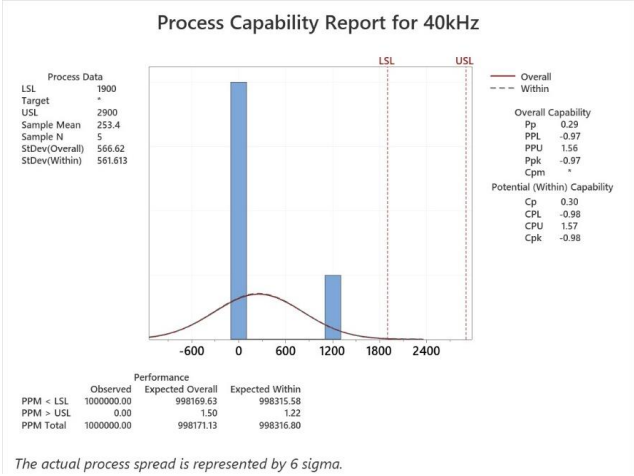

Figure 7. Histogram for 40KHz Frequency

The histogram shows that the bondforce results are far away from the minimum standard causing lift off on each wire meaning that the ultrasonic force is too weak to do the proper bonding.

2. Process Capability Report for 45KHz Frequency of Ultrasonic Force

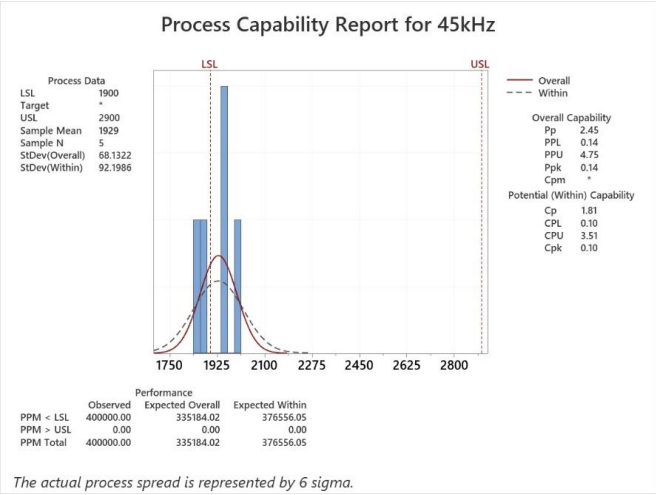

Figure 8. Histogram for 45KHz Frequency

Although there is no liftoff occur, the ultrasonic force is still too weak for the bonding, the histogram shows that some of the results is still under the Lower Spec Limit (LSL) meaning the force should be a little bit higher.

3. Process Capability Report for 50KHz Frequency of Ultrasonic Force

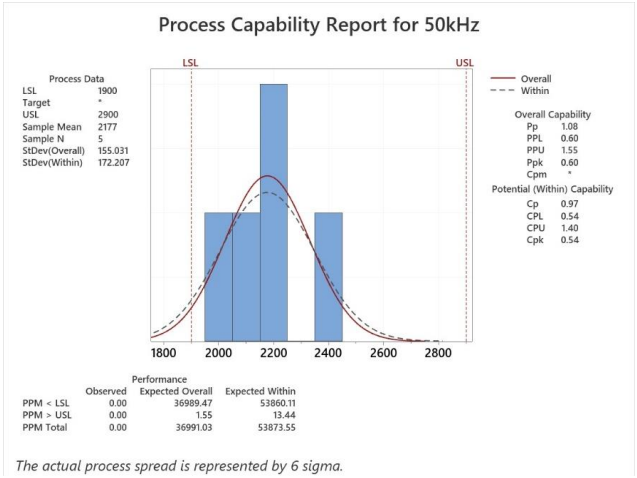

Figure 9. Histogram for 50KHz Frequency

The results are now within the specs. But still the data is too close to Lower Spec Limit causing the CpK value low. In Capability Process Control all the data must be near the center of both specs, it means that the data is stable and ready to run as a continuous process. When the data results are tend to get a little too close to the specs boundaries, there is a chance for them to be out of specs.

4. Process Capability Report for 55KHz Frequency of Ultrasonic Force

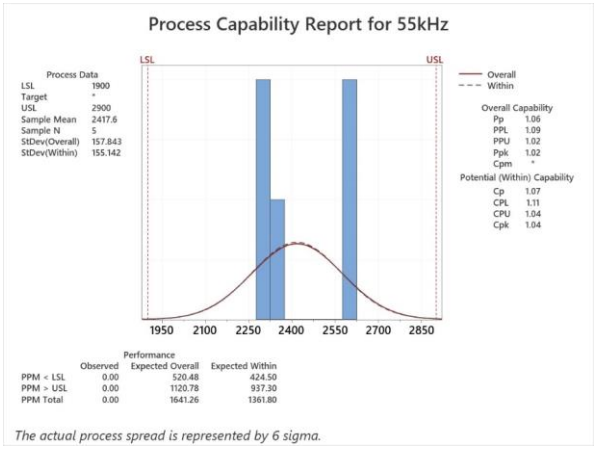

Figure 10. Histogram for 55KHz Frequency

The data is within the specs, they are in the center of the specs even though the data spread is high, it means the results are stable and good to go. The Cpk is high shows that the parameter is capable to use.

5. Process Capability Report for 60KHz Frequency of Ultrasonic Force

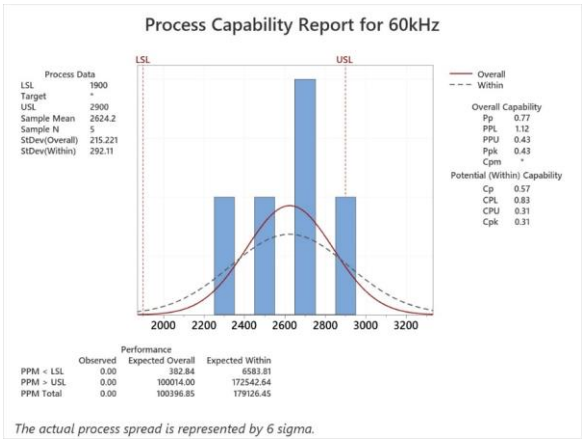

Figure 11. Histogram for 60KHz Frequency

Some of the results are out of specs, causing the bondfoot to get deform. It means that the ultrasonic bond force is too strong. The bonding is still occurred and there is no liftoff, but the deformed bondfoot is considered as defect, not only it is not good in visual and cosmetic aspects but also the lift off will happen sooner or later as the module is being used.

B. Clamp Power Test Discussion

The vacuum powered clamp (Figure 14) which is controlled by a switch has 7 failures in 1 month while bolts clamp which is equipped with bolts (Figure 15) has only 3 failures. The vacuum getting more failure is caused by the vacuum supplies that needs to constantly powered all the machines and the vacuum condition is not always in stable condition sometimes

there might be a technical issue causing it to get weaker resulting the clamp to unable to grip the modules tightly.

In other hands, bolts clamp is less troubled because it is manually installed, it means that we can set the bolts tightly to avoid shaky grip. But the vacuum clamp sure has its own advantage, the installation downtime Is way faster than bolts clamp. The vacuum powered clamp takes 30 seconds while the bolts powered one needs at least 3 minutes for the installation. The conclusion is, the vacuum powered clamp is need to get maintenance monthly to make sure the power supply is in a good condition, while the bolts clamp need to be changed if the clamp or bolts condition is already in a bad condition and the machine is also need to be cleaned regularly to avoid the wire debris or other particle interfere the mechanism of the machine.

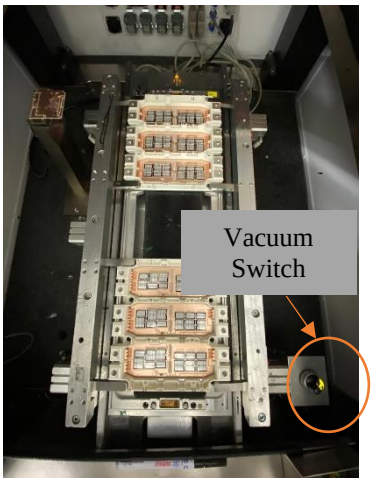

Figure 12. Vacuum Powered Clamp

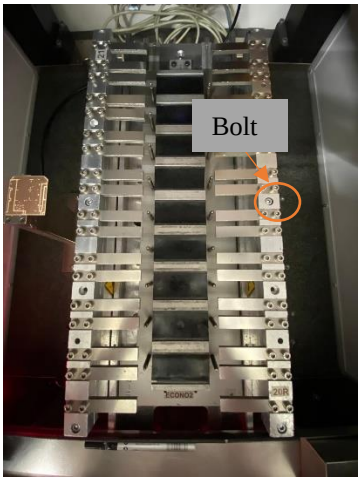

Figure 13. Bolts Powered Clamp

V. Conclusions, Recommendations, and Improvement

A. . *Conclusions*

The conclusions for both Ultrasonic Force test and Clamp Power Test is explained below.

1. Ultrasonic Force Test Conclusion

The ultrasonic force is playing a really important role in wirebonding, based on the information made by company, the vibration of ultrasonic is the one that make the bonding to happen. The problem is, it must be on the right frequency to allow the good bonding result. Hence, the experiment that writer has done before shows that not all of the frequency is good and suitable for the bonding.

The 40KHz - 45KHz Frequency is not showing a good result, the frequency is too low to perform a good bonding, wire lift off is occur a couple times and completely not capable to do the process.

For 50KHz – 55KHz is capable to do the process, especially for 55KHz. the result is within the standard and no lift off happened. Sometimes there are external reason for wire to have a lift off, if the installation of the pin is not good, we can increase and decrease the frequency on the value between 50KHz - 58KHz (as long as the result is good).

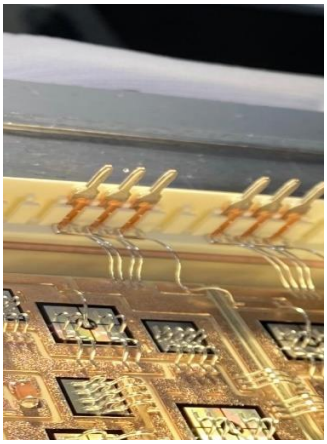

Figure 14. Pin and Pad

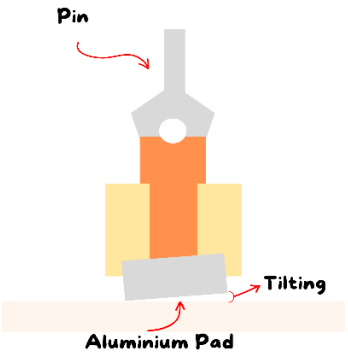

Figure 15. Tilting Illustration

But still, all parameter changing is done with visual inspection and shear test before the process production is started to avoid mass defect.

And for 60KHz frequency and above is uncapable to do the process because the wire is deformed (see figure 2. Bad Bonding Illustration) and could lead to wire lift off defect.

Finally, the conclusions for ultrasonic force test are:

- The recommended Ultrasonic Force is between 50KHz – 58KHz (depends on the condition).
- Don't set the ultrasonic force too low or high it can lead to Liftoff.
- If any small anomaly found, inform to the technologist for further check and solve.

2. Clamp Power Test Conclusion

Both the clamps have their own advantages and disadvantages. Bolts clamp is strong and stable while vacuum clamp is fast and simple but the shaky grip seems to happen for both, it means we need to do the improvement for the vacuum power source and also do a quality control for both clamps to assure the clamp has no malfunction and causing defect in the process.

B. . Recommendations

To prevent further failure and to short the time that being used while you facing the lift off defect, here is the recommended corrective action for you:

LIFT OFF DEFECT CORRECTIVE ACTION

Corrective action is very important, according to [10] Tashi T.Mbuya V. B.Gangadharappa H. V. in the journal of "Corrective action and preventive actions and its importance in quality management system: A review", International Journal of Pharmaceutical Quality Assurance (2016). Every organization should have a written standard operating procedure (SOP) establishing the provisions for corrective and preventive actions. Instructions for how they should be handled within the organization in case of potential product problems, customer complaints or action to eliminate the cause of a detected Nonconformities or incident.

Therefore, writer make a corrective action for efficient defect failure handling and also to minimize the time taken while dealing with the lift off problem, here below the steps to prevent further failure of lift off defect:

Step 1.

If a liftoff occurs, you can stop the machine and change the status of the machine into "machine setup". The machine status is detected in the main system, make sure you always aware of the machine status.

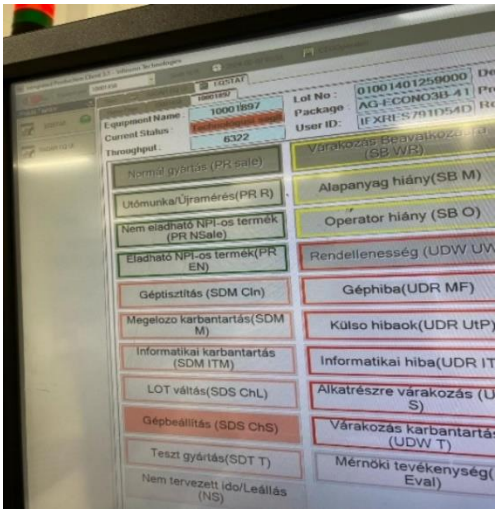

Figure 16. Machine Setup Status

Step 2.

Check the clamp condition, sometimes clamp with vacuum power tend to loosen because of the lack of vacuum pressure or even leakage, whereas the bolt clamp can be loosened because of the wrong installation technique or bad quality clamp.

Figure 17. Clamp Check

Step 3.

When the module is moving while it is still under the clamp, it means there is something wrong with the clamp power source, you can try to tighten the bolt or change the clamp if it uses a vacuum power. But if the anomaly is still occurred call the technician by changing the machine status into "waiting for maintenance", just like in the picture here.

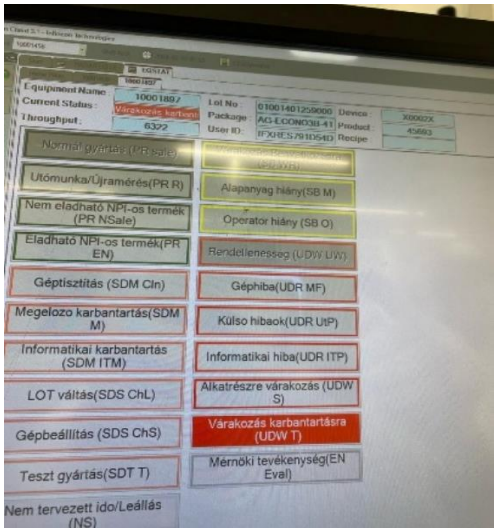

Figure 18. Machine maintenance Status

Step 4.

If the clamp condition is normal, the liftoff can be occurred by the excessive or insufficient ultrasonic force, change the machine condition into "waiting for technologist", after that call the technologist around the line and ask them to make sure the problem cause of that. Usually, they will immediately change the value of the ultrasonic and leave it for one module to check it again under microscope in precap area.

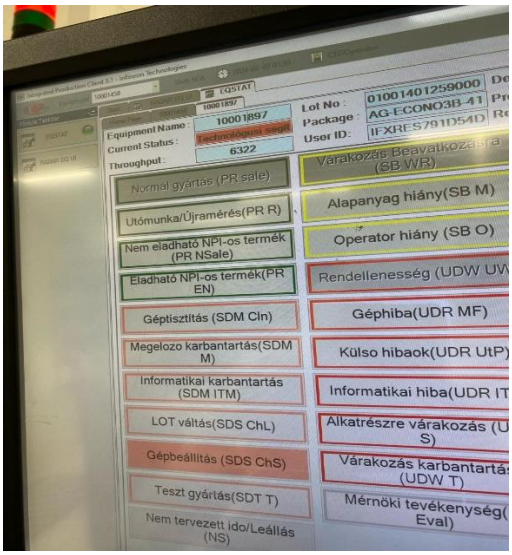

Figure 19. Machine waiting for Technologist Status

Step 5.

If the module is all good then you can continue the process. Never act across your authorities, if you have no idea of what you do you can waste the time and possibly making more failure, ask for some help to the technologist or the technician.

C. Improvement

The improvement in this project is in rundown time, the recommendations of what to do when you facing the lift off problem is indeed minimize the time consumption, here are the proves of how recommendations shorten the times being used.

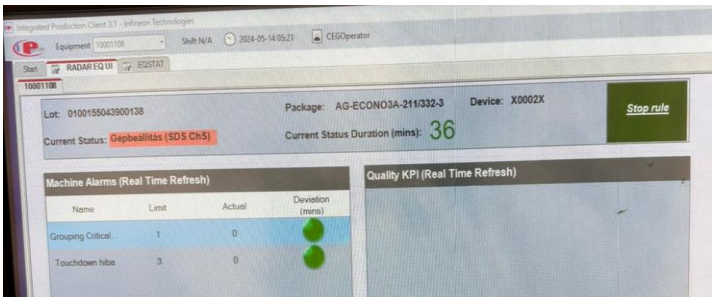

Figure 20. Rundown time before improvement

This photo was taken in before any research and recommendations applied, the time used to find the reason of lift off defect takes 36 minutes.

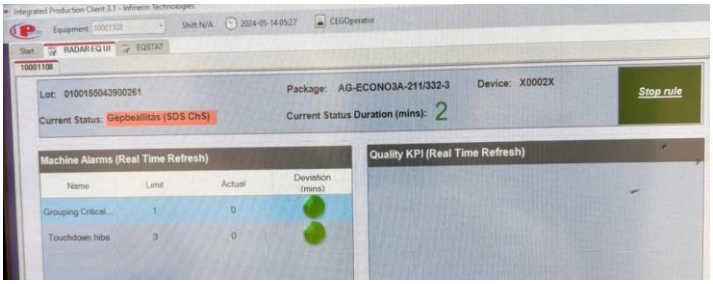

Figure 21. Rundown time after improvement

By knowing the reasons of lift off and what to do when you face it, the time consumptions only take 2 minutes, even though the time might take longer depends on what is the reason behind, but it will be 10 minutes maximum.

When the time consumption is reduced, the productivity will be more effective, with less lift off defect occur, high quality product can be produced and the profit of wirebonding area can also be increased.

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