X-ray Inspection for PCBA – Challenges and New Developments

By David Geiger, Elbert Suen, Zhen (Jane) Feng, Ph. D., Weifeng Liu, Ph. D., Anwar Mohammed, Ph. D., Mike Doiron, Evstatin Krastev, Ph. D., Peter Chipman

Abstract

X-ray inspection systems are key tools for quality control, yield enhancement, and failure analysis of advanced printed circuits board assemblies (PCBA). The electronics industry has witnessed significant improvements in the X-ray inspection capabilities (AXI, 2DX, 3D CT, Large Board CT) during the last twenty years. These advancements have aided in the development of new high performance packages and PCBA processes. In many cases, X-Ray inspection is the only non-destructive technique to inspect optically hidden components and solder joints such as BGA, POP, QFN, flip chips, through holes, etc.

Automated X-Ray inspection (AXI) has been available since 1999 at our manufacturing sites, and plays very important role to assure high quality SMT process. Along the way, manual X-ray systems (2DX and 3D CT) have been providing invaluable testing capabilities for verifying the AXI results, fine tuning the AXI parameters, process development, and X-ray inspection that is out of the scope of the AXI equipment.

Through the years these capabilities have been significantly improved and best practices have been developed on how to jointly use the AXI, 2DX(MXI), and 3D CT X-ray equipment to achieve best possible testing results and speed. In this paper, we will summarise the extensive experience we have accumulated while working on real problems together with our customers, X-ray inspection vendors and R&D teams. These projects include BGA HIP (head in pillow), solder charge connector, Package on Package, package 03015. In addition, we will discuss how to optimize test coverage and eliminate defect escapes during PCBA testing. These studies have been performed using variety of X-ray inspection systems at several production sites and lasted several years.

We will also discuss the X-ray inspection capabilities that are considered most important to the PCBA manufacturing process including: 1. Highest resolution X-ray images and clear distinction between good and defective pins; 2. Measurement data from inspection output; 3. Operator independent automated results for pass/fail condition; 4. Non-destructive e-cross section; 5. Easy and intuitive operation and programing; 6. Real time data feedback; 7. Flexible automated algorithms that are easily adjustable by the machine operator; 8. Zero defect escape with reasonable false call PPM.

Keywords: X-ray technology, AXI, 2DX(MXI), 3D CT, Large Board CT, Optimization.

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Introduction

The importance and the utilization of X-ray inspection (AXI and MXI) within the PCBA manufacturing process has been continuously growing during the last 20 years. This is especially the case for high density/high complexity PCBAs and new sophisticated packages. In manufacturing, we all agree that "Prevention is better than Detection"1, but this is only possible if the high-quality test data is available promptly. At beginning, we had good experience for activities by using X-ray machine due to AXI highlights of non-destructive, wide testing coverage, pinpoints the exact location of defects, measurement data available2. Later, we realized MXI 2DX are also capable of providing the test data needed via their advanced capabilities including completely non-destructive testing, wide testing coverage, exact defect pinpointing, especially with good quality images. SMT assembly process is very complex and requires many parameters and operations to be varied. As a consequence we also use X-ray inspection (AXI and MXI) as a very effective tool for SMT process improvement.

In the following chapter, we share our experiences on how to setup and tune the AXI parameters and analyze the AXI data. These are key milestones during testing and for SMT process improvement. We also discuss when to use AXI and how to use AXI together with SPI and AOI in order to optimize the testing process and coverage3-5.

In the Case Studies chapter, we will share our experience with HIP detection, solder charge connector verification, and package 03015 X-ray testing6-10. The 03015 package was previously studied using SPI and AOI 11-12.

Our experience shows that MXI (including 2DX and 3D CT) provides additional capabilities that complement the AXI and in many cases which are used for AXI results verification and parameter tuning. Thus, we are looking forward to AXI machines that incorporate high quality 3D CT capabilities for PCBA testing applications.

In the final X-ray capabilities & Conclusions chapter, we will discuss critical capabilities of contemporary and future X-ray machines. Our team including Customers, X-ray vendors, and Flex engineers have been working together on new inspection algorithms, threshold settings optimization, that are aimed at effective X-ray inspection of new sophisticated packages, new SMT process, technologies. Several main achievements and improvements will be discussed in detail.

AXI Optimization with DADA Analysis

Since 1999, many complex boards have been tested using AXI machines at Flex manufacturing sites. Typically, about 80-90 percent of all defects found were structural or process related. It's easy to see a significant reduction in ICT (In Circuit Testing) and FT (Functional Test) failures once the PCBAs were first screened using AXI equipment.

Our experimental data indicated that AXI detects over 90% of all defects on printed circuit boards2. However, the AXI equipment will not reduce the SMT defects by itself. It is critical to properly analyze the AXI data and promptly feedback to manufacturing in order to improve the SMT process and decrease defects. Therefore, testing is not increasing board's value; but testing data brings very important values for PCBA process improvement.

There are two data types available as an output from the AXI equipment: attribute data, and measurement data. The attribute data is a simple pass or fail call. The measurement data that usually resides in the AXI data base, comprises of the measurements that the AXI system performed in order to generate the pass/fail call.

Attribute Data Analysis

All of us familiar with AXI1 (5DX) know that it was first designed for solder defect detection, and consequent repair through a paperless rework station. Further analysis was difficult as the original system was only providing pass or fail output. Before similar functionality was made available by the AXI vendor, our team developed a database using Microsoft Excel in order to record and analyze the results from all boards tested. The tool combined individual files into a single database, which automatically generated Paretos and specific statistical information about defects2. By using the generated defects summary our engineers focused on the top three main defective locations. We call this a reactive mode of operation. In this way, we were able to increase the SMT yield insignificantly in just days.

Despite that certain level of improvement had been accomplished, we were not able to further improve the process and switch into preventive mode of operation as the attribute data that we had was not enough to develop the predictive tools needed for a robust manufacturing process.

In order to further improve we needed measurement (parametric) data, which is the base of a preventive system using SPC. The parametric data was not available, but we decided to perform Gage R&R (repeatability and reproducibility) study using the available attribute data first. This way we hoped to better understand how useful the parametric data would be in order to achieve our process improvement goals. We carried GR&R studies for main packages especially when new process was introduced.

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AXI is usually the bottleneck at the SMT line sometimes due to its testing time. We studied the topic of eliminating this bottleneck via reducing AXI test coverage13 using the following two approaches:

1. Reduce AXI inspection times.
2. Improve yields with real time process defect feedback.

As a first step, we analyzed the AXI data for 3-6 months in order to determine which components had no history of failure. These became our candidates for removal from AXI test. Next, we made sure to utilize 100% AOI testing and use the AXI test for only hidden joints (BGA, QFN, PTH, etc.) and all Fine Pitch Gullwing devices. We also made sure the removed parts were not critical as per Functional test.

The key steps are below:

1. Review the AXI, ICT and FT history data.
2. AXI program revised to include critical parts.
3. Establish AXI real time feedback system.
4. Monitor process to ensure that real time defect feedback is being analyzed and process is adjusted accordingly.

The AXI coverage for pins was significantly reduced (about 50%), and same or improved yields were achieved due to the above activities. All these were discussed in detail with our customers in order to make sure everybody understands the benefits and approves the changes.

Measurement Data Analysis

Current AXI machines usually generate measurement data that is used to qualify the solder pin as pass or fail based on the Algorithm Threshold settings. We can use the measurement data for process improvements including NPI experiments and AXI Algorithm Threshold settings optimization. To accomplish these, we conducted extensive Gauge R & R studies so that Engineering could make process modifications decisions based on dependable data14-15. The Gauge R & R study helped us understanding the AXI system better, and modify our AXI programs in order to make them more efficient. Below is one example for how to use measurement data for setting Threshold for detecting void for single small pin of a QFN device 15.

Three years ago, one of our customers requested AXI testing to verify that voiding does not exceed 20% for the small pins of a QFN device and 40% for the center pin (Figure 1). The solder pad size of the small pin was 12 mils X 37 mils (1 mil = 0.001 inches). Such pins are not usually evaluated for voiding percent using AXI due to small size. 2DX system is usually used in this case as it provides much higher resolution and better image quality than the AXI equipment because of its result more accurate voiding calculations.

To meet the AXI testing requirement, we first performed Gage R&R study using 9 sets of AXI data collected by 3 different operators. The AXI parameters were tuned with the help of 2DX MXI inspection system.

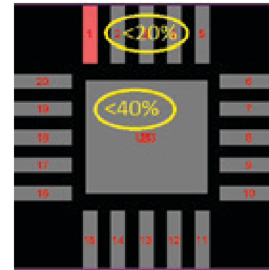

Figure 1. Void % requirements for pins of QFN device

The particular AXI system had two Algorithms for Void Calculation: 1. Variable Pad Border Sensitivity (a), and 2. Variable Pad Voiding Sensitivity (b) (See Table 1).

We tested 4 different configurations of AXI parameters and compared them with the data from the 2DX system (Table 2): Setting I(3,8), offset 0; Setting II(3,9) offset 0; Setting II (3,9) offset 3, Setting III (3,10), offset 0. The results are presented on Figure 2. The light blue line represents the data obtained using the 2DX system. We are looking to identify which of the AXI sets will be the closest match to the light blue line. It is obvious that Setting II (3,9) with offset 3 did not detect any voiding. The best match is offered by Setting II (3,9) with 0 offset (green line).

Table 1. The AXI Algorithm Settings

Algorithm Setting (a, b)	Setting I (3, 8)	Setting II (3, 9)	Setting III (3, 10)
1. Variable Pad Border Sensitivity (a)	3	3	3
2.Variable Pad Voiding Sensitivity (b)	8	9	10

Table 1. The AXI Algorithm Settings

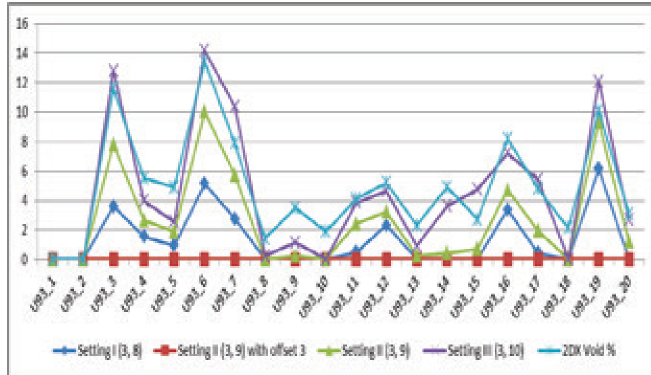

Figure 2. The Voids Measurement Data for the AXI and MXI 2DX

We used Minitab statistical software to analyze the AXI vs. 2DX data16. The Minitab method used was Star > Regression > Fitted Line Plot. Figure 3 shows the 2DX versus AXI data for different Algorithm settings: Setting I (3,8), Setting II (3, 9), and Setting III (3, 10).

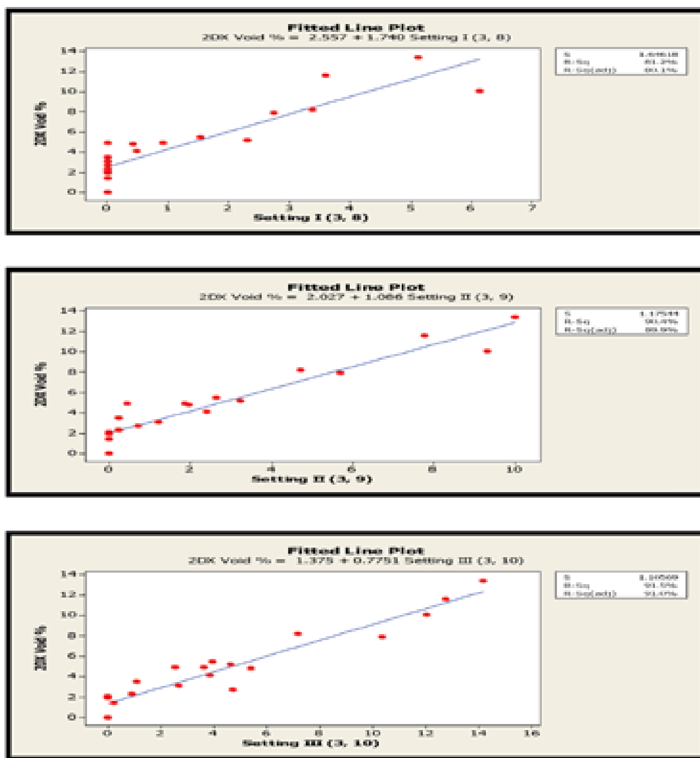

Figure 3. Minitab Results: 2DX versus AXI

Based on the results from the Minitab statistical software, three equations were obtained:

2DX void % = 2.557+1.740 x data of AXI Setting I (3, 8)

… equation1

2DX void % = 2.027+1.086 x data of AXI Setting II (3, 9)

… equation2

2DX void % = 1.375+0.7751 x data of AXI Setting III (3,10)

… equation3

The first term in the equations is representing the intercept and the second one is the slope.

Equation 2 corresponding to Setting II (3, 9) represents best fit as the slope is very close to 1. Therefore, we concluded that setting will give us accurate voiding calculation when using the AXI equipment.

Using the AXI Setting II (3, 9) at the production line we tune the AXI performance resulting in detecting all signal pins that have 20% voiding or more. Using the AXI data, our process team made DoE to reduced voids % effectively: AXI yield increased from 95.6% to 99.5%, and ICT, FT yields improved also. The False calls were reduced from about 7000 to 0.

This is also an excellent example on how to use MXI 2DX equipment to set and fine tune the AXI parameters. We have actively used X-ray highlights in such capacities through the years to optimize X-ray applications at our manufacturing sites.

Case Studies

AXI, MXI 2DX, MXI pCT, and recently AXI with pCT are all non-destructive methods. Because of that we have used them individually or jointly to tackle many challenging projects during the last twelve years. In this chapter, we report case studies recently that correspond to three different packages: BGA, Solder Charge Connector, and 03015 resistors.

We have been seeing significant improvements of X-ray inspection capabilities (AXI, MXI 2DX, MXI 3D CT, MXI 3D pCT) during the last twenty years. These advancements have aided in the development of new high performance packages and PCBA processes.

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1. BGA

More and more BGA devices are being mounted on double sided of PCB assemblies (PCBAs), so effective test method is needed to identify common BGA defects on double-sided PCB assemblies for meeting the challenging goal of having zero defects on the manufacturing line.

X-ray inspection is the only non-destructive method for testing optically hidden joints for the most time. As pointed above BGA, QFN, POPs and flip chips are currently being used more than ever before. Because of that the X-Ray inspection (both MXI and AXI) has a critical role for quality assurance and SMT process improvement.

One very common BGA defect is Head in Pillow (HIP) as shown in Figure 4a. The reflow process at certain BGA pins does not occur properly, thus resulting in open or intermittent joins.

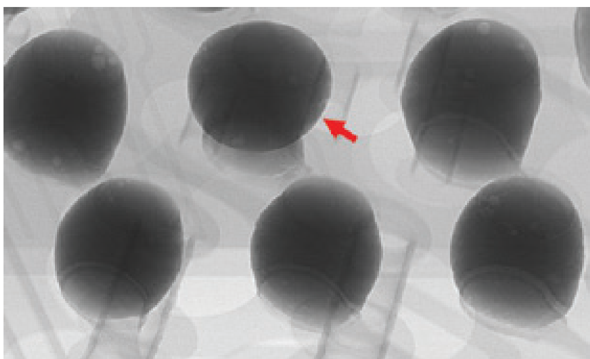

Figure 4a. MXI 2DX Image of HIP defect

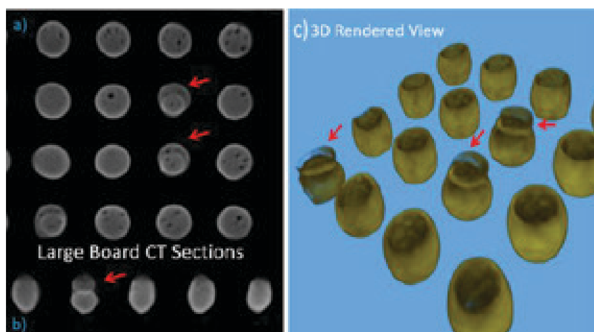

Figure 4b MXI 3D pCT e-sections of HIP defect

HIP defect had often been a challenge for some AXI machines for the last 15 years. Advanced MXI 2DX machines with oblique viewing can easily identify HIP defect reliably and quickly in manual mode. MXI Large Board CT (or pCT) is used to provide virtual cross sections (e-sections), and 3D volume rendering of the HIP defect shown in Figure 4b. However, 2DX and MXI Large Board CT are manual test model which based on operators' operation and judgment. Therefore, we usually used a MXI 2DX system to verify HIP that time 10 years ago6.

The first time for us to see AXI equipment that can identify HIP defect (about 5µm gap) was in November 2008 at a manufacturing site in Europe. This AXI system used a patented Slice Filter Technology and off axis imaging of 50 degrees. In 2012 we used 4 different AXI systems7 at four manufacturing sites to study automatic HIP detection. AXI parameters were significantly adjusted and verified using input form MXI 2DX system. AXI measurement data analysis is also key for optimizing the AXI parameters for detecting HIP. All four AXI machines have capability to detect BGA HIP defect with varying success level of 50% to 90%. However, a significant drawback is that there are no clear image differences between good solder and HIP for some contemporary AXI machines for the most time.

In summary, the algorithm threshold settings are very critical for detecting HIP. We need to have a good balance between HIP defect escapes and false calls. MXI 2DX/Large Board CT system provided invaluable assistance for AXI algorithm tuning and verification of results due to its clear deference on X-ray image between good and bad (HIP) pins.

In 2016 we conveyed another BGA HIP study together with customers and vendors involving AXI/pCT systems. These AXI systems use Tomosynthesis to generate 3D and slice data for the inspected pins. The main AXI algorithms used were Volume Ratio and HIP Shape. For this study, a BGA package with more than 3000 pins was automatically examined. The AXI/pCT images of four HIP defective pins (BU14, F50, BR23, and BN23) are shown on Figure 5. The AXI/pCT images are clearer than images obtained using regular AXI system and it is easier for our confirmation. The results were also verified using an MXI 2DX shown in Figure 6.

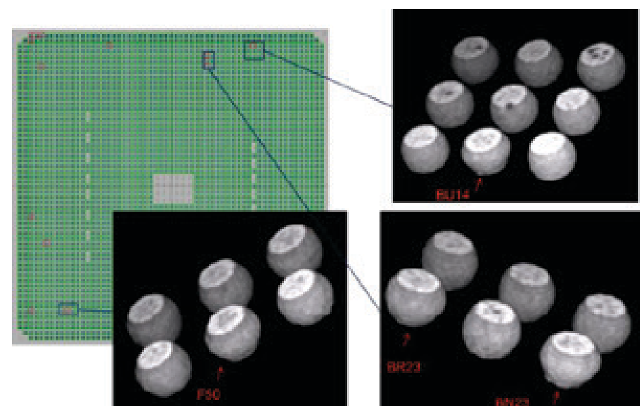

Figure 5. Some HIP 3DX (pCT) Images

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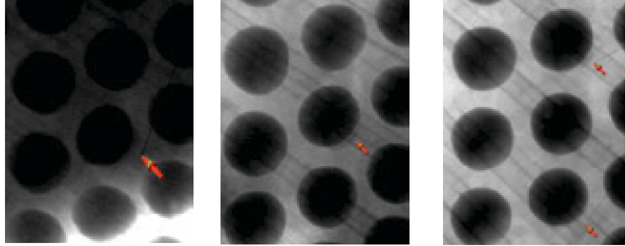

Figure 6. 2DX Image for Pin # BU14, F50, BR23, BN23

HIP Inspection measurement data (Volume Ratio) for all 3280 pins on the BGA are shown in Figure 7, where Y axis represents the Volume Ratio, and the X-axis represents BGA pin number. The threshold setting are as follows: < 0.72, pin below orange line – HIP fail; > 0.86 pin above yellow line - pass. Based on this graph, it is easy to carry the optimization for threshold settings. Figure 8 shows the Attribute Gage R&R data for the BGA. The results are larger than 99% for Appraisers, and Appraisers versus Standard.

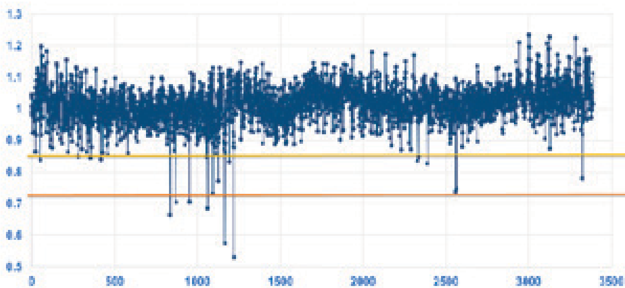

Figure 7. Volume Ratio Data for all 3280 pins on a BGA

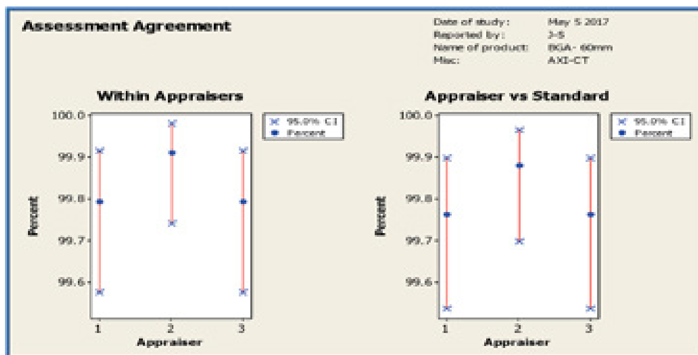

Figure 8. Attribute Gage R&R for AXI/pCT

In summary, the AXI/pCT machine performed better than a regular AXI machine (Table 2). The more important thing is HIP pins based on measurement data which can make false calls reduced significantly. We believe that the AXI/pCT machine is applicable for engineering applications, but it needs further evaluations in order to be used in manufacturing environment.

Total HIP#	Total HIP # Escaped	Total False call #	HIP Escaped%	False Call PPM
10	0	1 ~ 8	0	295 ~ 2360

Table 2. AXI/pCT HIP Testing Results

2. Solder Charge Connector

In 2015, we completed a project titled “Optimization of X-ray Inspection for Solder Charge Connectors”9. The solder charge connector is a SEARAY connector which has 400 pins and pitch size of 50 mils. Total two MXI (2DX 1 and 2DX 2), and four AXI (AXI 3, AXI4, AXI 5, AXI6) machines were used for the experiments, AXI4, AXI5, and AXI6 machines with different pCT capabilities (Manuel or Auto model).

As shown in Figure 9, the primary side of a terminal is the side that solder charge is mounted to before reflow. As indicated on Figure 9: 1 is the connector lead, 2 is the land, and 3 represents the solder charge. The preferred solder joint formation is that the solder charge fully wets the primary side of the terminal, flows through and also wets the secondary side of the terminal. This way it results in 360 degrees’ pad wetting and a uniform shape. The solder charging directions of the connector are alternating for odd and even rows.

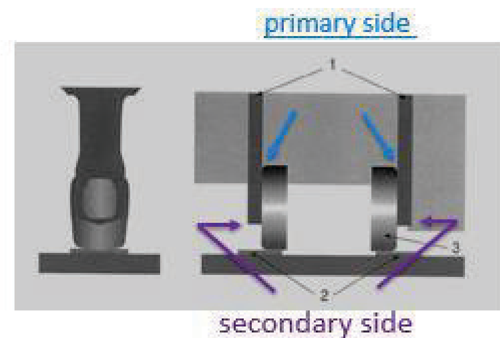

Figure 9. Solder Charge Connector

The different AXI machines exhibited different benefits. In this paper, we would like to list AXI 5 (AXI/pCT) results as shown in Figures 11 and 12. The images reveal each pin from four sides. It is straightforward to see the difference between good and not good solder joints from using images secondary, right, and left directions. The good solder should display similar images from both secondary and primary directions, see pin 7 on Figure 12.

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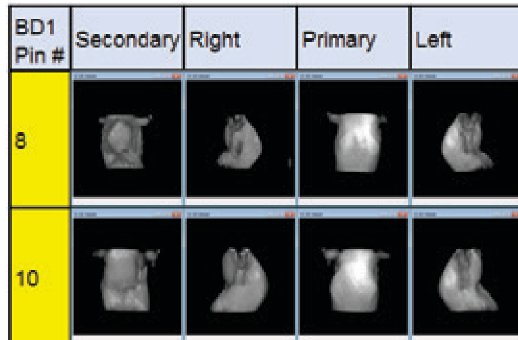

Figure 11. AXI5 Four Images for the Pins on Board #1

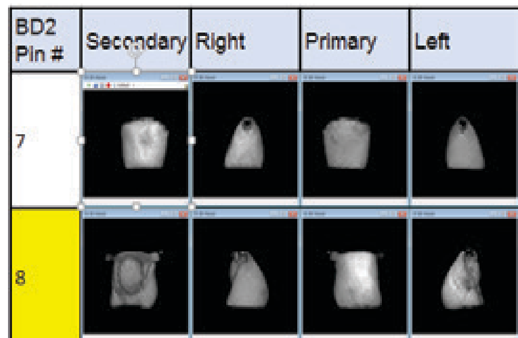

Figure 12. AXI5 Four Images for the Pins on Board #2

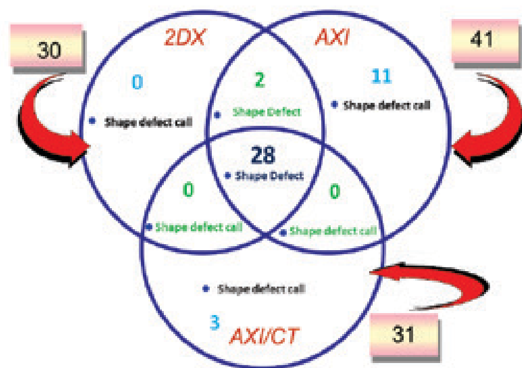

Figure 13. Correlation between MXI 2DX, AXI (AXI3), and AXI/CT (AXI4) with Board #1

The other two machines, AXI4 and AXI6, also provided good images with clear difference between good and bad solder joints although only one of the machines used automatic mode in the last year. The results are summarized on Figures 13 and 14 showing the correlation between MXI 2DX and AXI and between various AXI machines, respectively. In summary, we see definite benefits in using the AXI/pCT equipment as compared to a regular AXI equipment due to its X-ray good quality images.

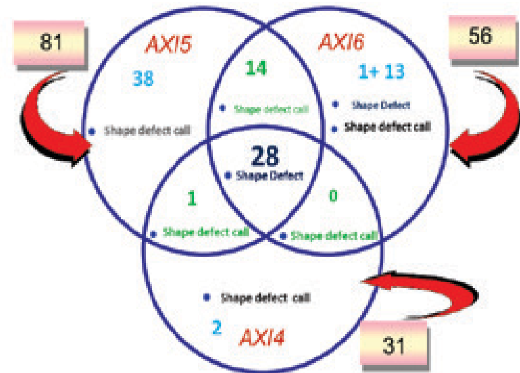

Figure 14. Correlation between AXI4, AXI5, and AXI6 with Board #1

Figures 13 show correlation between MXI/pCT, AXI (AXI3), and AXI/pCT (AXI4), and figure 14 shows correlation between AXI4, AXI5, and AXI6 for board 1. Figure 13 reveals that MXI/pCT, AXI, AXI/pCT have good correlation for shape defect: 28/30 = 93.33%. Figure 14 shows that the three AXI/CT machines (AXI4, AXI5 and AXI6) also have good correlation for Shape Defect: 28/30 = 93.33%. These results show very good correlation for all six X-ray inspection systems.

3. Package 03015

The new advanced package 03015 is presenting significant challenges not only for the SMT process, but also for the SPI, AOI, and AXI inspection. We did a series of studies using SPI, AOI, and AXI to inspect 03015 package. We used two test vehicle designs for SPI (Figure 15) and AOI & AXI (Figure 16). The resistor 03015 is extremely small: 292µmX143µmX100µm, and its pad size is 150µmX150µm.

a. SPI

In 2015 we studied the SPI inspection capabilities for package 03015. We had 12 groups of pads (1000 pads per group) within 2 rectangles as shown on Figure15. Each group has different pad's direction on the fab. Two SPI machines (SPI 1 and SPI 2) were selected for this project. We performed 840,000 measurements, Gage R&R, orientation test, and Cp & Cpk.

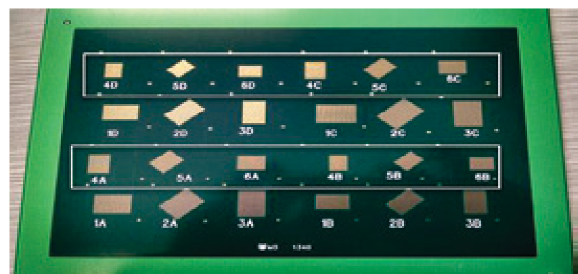

Figure 15. SPI project Board for Package 03015

For the orientation test, each board was tested four times with 0o, 90o, 180o, and 270o direction for pad height, area, and volume. We calculated the average for each test, and total average of four tests. The percentage difference was calculated using an equation below:

Percentage Difference
=100%(max. average – min. average) / Total average where maximum average and minimum average readings are taken from the four tests.

We had good SPI results for Gage R&R and Percentage Difference: all SPI machines' Gage R&R results are less than

< 30%, where one SPI machine is less than < 15%; the most orientation test results are less than 4%. However, we didn't achieve good Cp & Cpk results (> 1.6) for all groups per 48,000 pad readings for pad volume11.

b. AOI
In 2016 we conveyed an AOI study of 03015 package using reflection and non-reflection parts. We used 5 different AOI machines for the testing (AOI 1, AOI2, AOI 4 AOI 5, and AOI 6); however, only three machines provided data for the boards with non-reflection parts

The test vehicle is shown in Figure 16. The pad size (Length X Width) is 150µm X 150µm. Three different sample groups with spacing 200µm, 150µm, and 100µm were used (see Figure 16) These had 78, 81, and 87 components respectively.

Although four machines with 3D AOI capabilities, but only 2D AOI functional Algorithm was used due to component reflection. The results were published in reference 11 for the boards with reflection components.

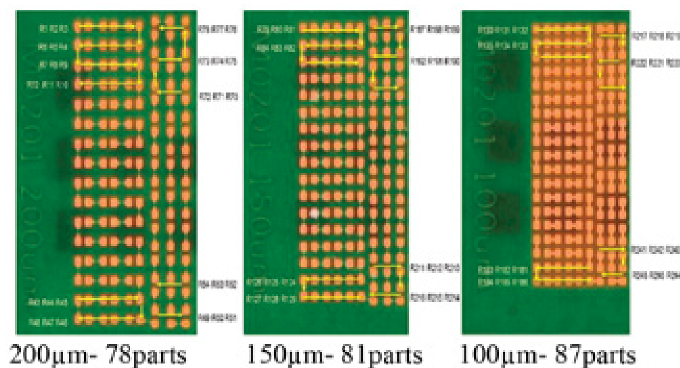

Figure 16. AOI & AXI Project Board for Package 03015

Further in this paper we would also like to share our AOI results with non-reflection parts on two boards using three different AOI machines (AOI2, AOI4, and AOI5). These are 3 of the same machines used in for the study in reference 11. All these AOI machines have 3D AOI function.

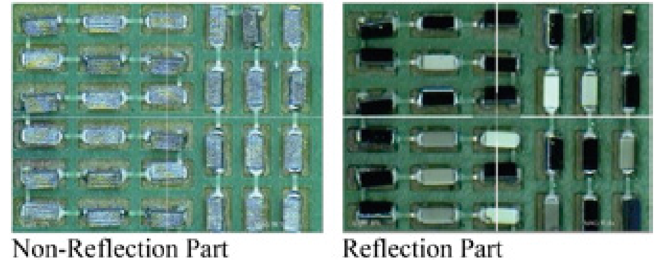

Figure 17. Optical Gauging Product (OGP) Pictures

Figure 17 shows Optical Gauging Product (OGP) pictures for reflection, and non-reflection packages 03015. The defective list was based on AOI images and optical pictures. The defect escape rate was ≤ 30%; however, false call PPM was very high (>30000) as shown in Table 3.

Table 3. 3D AOI Testing Results for Non-Reflection Parts

Machine	Defect Escaped %	Total False Call #	False Call PPM
AOI 2	30.00	36	73137
AOI 4	6.67	16	32520
AOI 5	26.67	39	79268

Figure 18 shows results for parts of R5 and R77 on board #1, and R145 on board #2. These are 3D AOI images from AOI 2, AOI 4, and AOI 5, and optical images from manual optical tool. The R77 (spacing 200 µm) is misaligned, R5 (spacing 200 µm) is tilted. R145 (spacing 100 µm) shows short solder. All testing was performed using 3D AOI functional algorithm for z-height.

This was just an initial study; we plan a larger study incorporating larger set of boards for getting good assess the AOI 3D functionality.

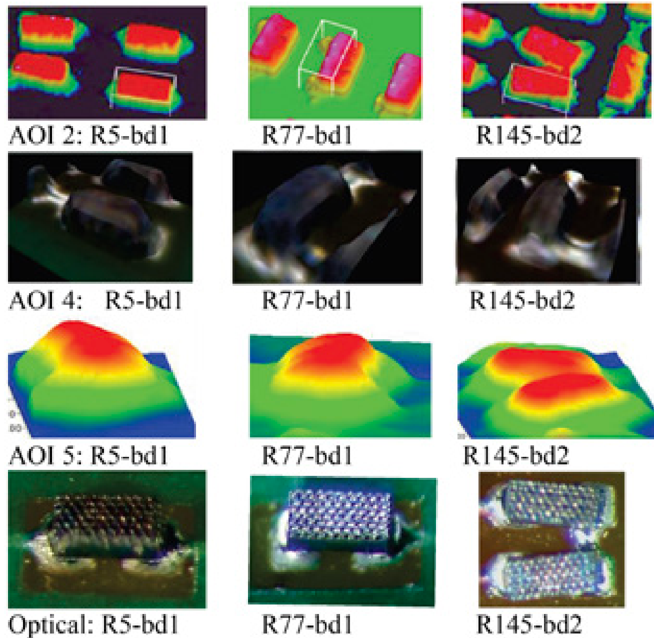

Figure 18. Some AOI & Optical Pictures

c. AXI/pCT
At the beginning of 2017 we started a study of the package 03015 using three AXI machines that have pCT capability (AXI/pCT). This study is within a project for developing AXI capabilities for non-reflection 03015 package. The testing is challenging due to the very small size of the 03015 package. We are using 2 types of samples spacing 200µm with 78parts, and spacing 150µm with 81parts (see Figure 16). We focus on solder insufficient and open defects. Each AXI vendor's R&D lab had tested the boards for at least two times in the last several months.

The image resolution of AXI 3 was adjusted down to 6µm (from 11 µm) for the testing. This resulted in improved image quality for the package 03015. The main algorithms used by AXI 3 are Clear Open Signal and Minimum Fillet Thickness. The Clear Open Signal calculates the difference in solder thickness between Upper and Lower Fillets.

For instance, if the minimum clear open signal is set at 0.5 mils, the result value which is above 0.5 mils is considered as good joint while below 0.5 mils is considered as bad joints/ open (Figure 19). The left side is good solder joint, and right side is insufficient solder joint. Joint passes if measured value is above the threshold (minimum Clear Open Signal).

Figure 19. AXI 3 Algorithm – Clear Open Signal

Another algorithm used was by AXI3 is Minimum Fillet Thickness. This is used to detect insufficient solder. The solder joint passes if measured value is above the pre-set threshold for Minimum Fillet Thickness. For instance, if the minimum fillet thickness is set at 70%, the result value which is above 70% is considered as good joint while below 70% is considered as insufficient joint.

However, if the component is 0201 and larger, there is significant fillet at the side termination for good joint as shown Figure 20 left image. If the joint is showing offset or tombstone defects, there is no fillet presence most of the time. The X-ray image will display the difference as shown in Figure 20 at right image. The package 03015 is a challenge for AXI machines without pCT capability due to it is bottom termination.

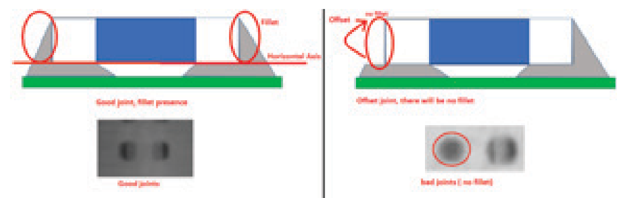

Figure 20. AXI 3 Algorithm – Minimum Fillet Thickness

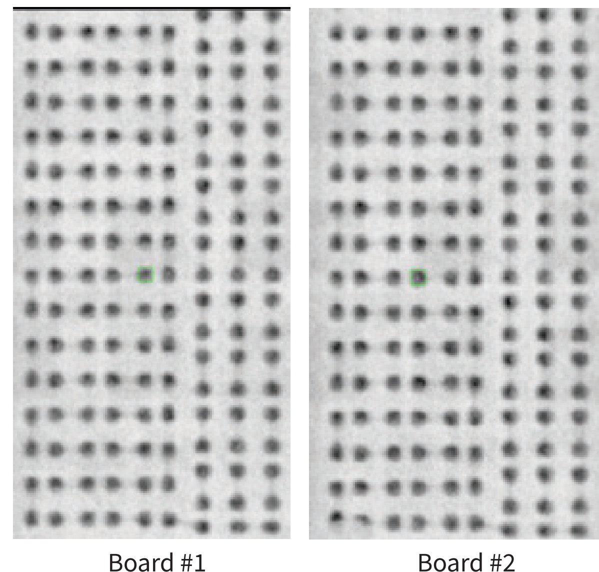

Figure 21. AXI 3 Images for Spacing 200µm with 78parts

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Board #1 Board #2

Figure 22. AXI 3 Images for Spacing 150µm with 81parts

Figure 21 and 22 show AXI 3 images (2D) for the boards with spacing 200µm and 150µm. Because 03015 is a bottom terminated component, there is no clear indication for offset or tombstone defect (solder changes in the horizontal plane Figure 23). Therefore, to gain maximum detection, AOI and AXI are recommended to be used during the inspection with the above reasons.

Recently AXI3 was upgraded with CT capability and will be used in our manufacturing due to its CT quality. AXI 3 Attribute Gage R&R is excellent at 100% for both boards as listed in Table 4.

Figure 23. Package 3015 on AXI 3

AXI 4 adjusted its machine resolution to 3.5µm for the testing It used 3 camera modules for this project. The main algorithms used by AXI 4 for this application are Solder Thickness N, Solder Area Pad, and Area Pad. The principle behind the Solder Thickness N algorithm is that grey level values represent solder thickness. The algorithm uses background as reference and calculates relative percentage. Average intensity of each pin is calculated and compared with standard value. If the inspected value is larger than the upper limit or smaller than the lower limit, solder fail is indicated. AXI4 captures solder shape by setting different criteria [group count]. As above this algorithm calculates average grey level value in each pin, and compares it with standard value. If the inspected value is larger than upper limit or smaller than lower limit, the result is a fail. Figure 24 shows examples images of good and bad pins.

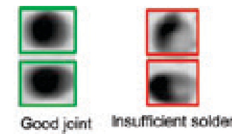

Figure 24. AXI 4 Images for Package 03015

The main algorithm measurement data is shown in Figures 25, 26 and 27 for boards #1 and #2. The three lines in the figures represent upper limit, standard, and low limit settings for Grey Level, and Solder Area. Board #1 has 5 bad pins - R79, R80, R84, R96, R206, and board #2 has 2 bad pins - R48, R208 (Figure 26-27). It is noted that R48 exhibits solder defects on both pads.

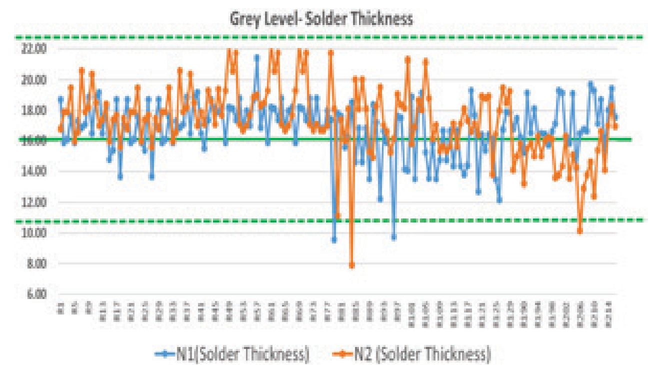

Figure 25. AXI 4 Grey Level Data for Board #1

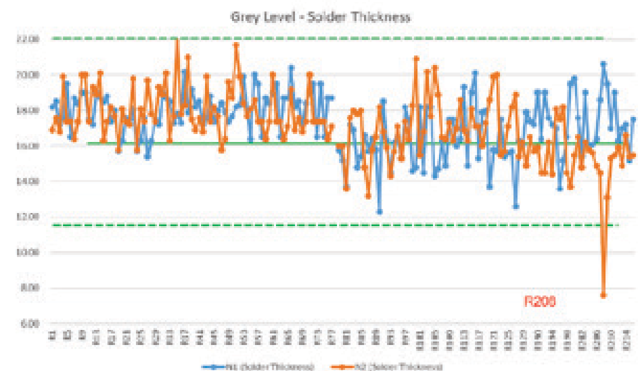

Figure 26. AXI 4 Grey Level Data for Board #2

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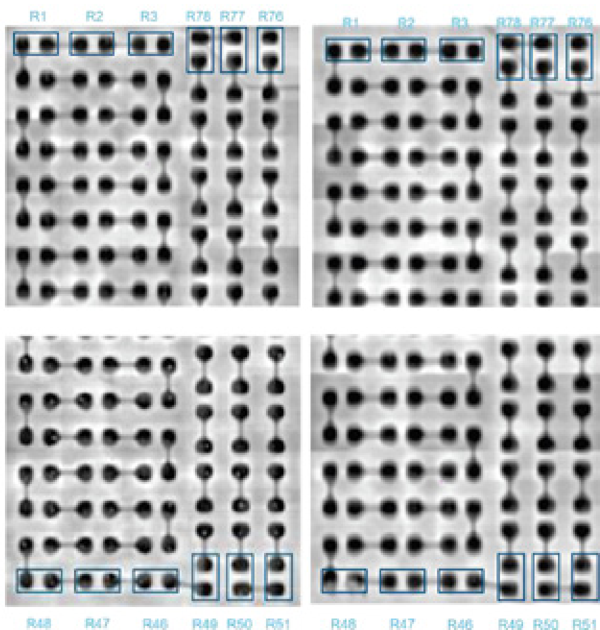
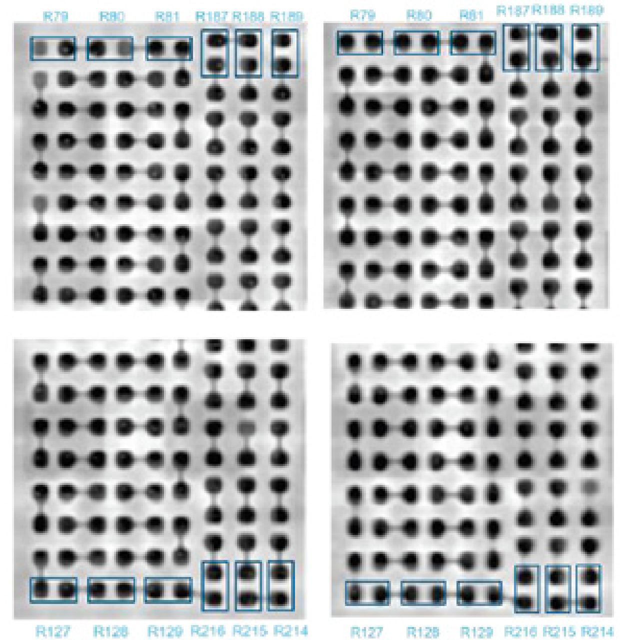
Figure 27. AXI 4 Solder Area Data for Board #2

AXI4 detected all seven solder insufficient locations for boards with 200 µm and 150 µm spacing. This is indicated by the blue rectangles on figures 28 and 29. AXI4 has already pCT capability.



Board #1 Board #2

Figure 28. AXI 4 Images for spacing 200µm with 78parts



Board #1 Board #2

Figure 29. AXI 4 Images for Spacing 150µm with 81parts

AXI 5 uses Density Profile (Peak Value and Area) as its main algorithm for this project. Figure 30 shows its good and bad density profiling graph. Peak Value range is from 0 to 255, and its tolerances are set to 255 (upper limit|) and 30 (lower limit). Upper limit and lower limit for Area is set to 26,000 µm2 and 12,740 µm2, respectively.

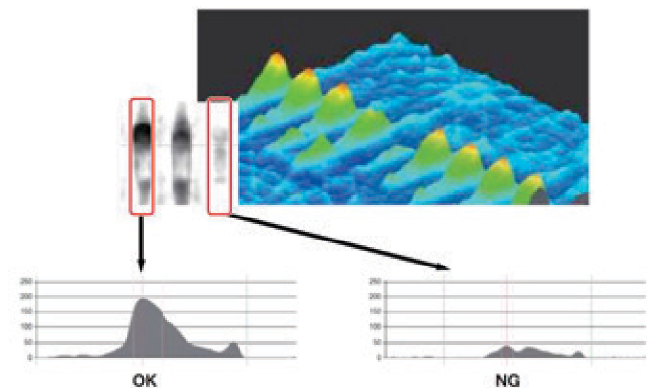


Figure 30. AXI 5 Algorithm – Peak Value

The AXI5 machine also has planer CT capabilities, and its AXI/pCT images are shown in Figures 31 and Figure 32 for board #1 and board #2. It is easy to see clear difference between good and bad pin based on these 3D X-ray images. The defective pin number is

listed below on the images. The AXI5 detected all defects without false call based on its pCT images.

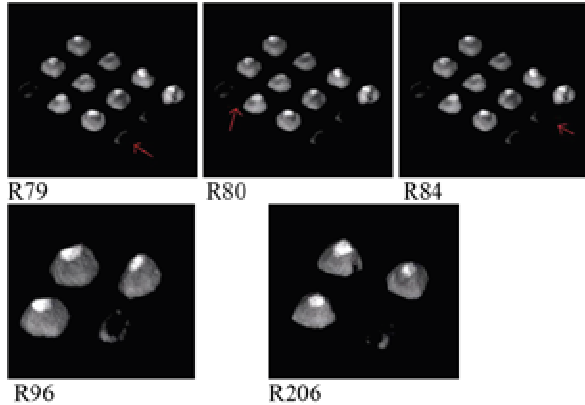


Figure 31. AXI 5 AXI/pCT Images for Board #1 Defects

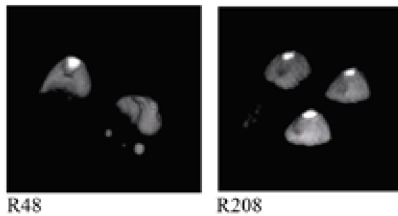


Figure 32. AXI 5 AXI/pCT Images for Board #2 Defects

The main AXI5 algorithm is Peak Value which is used to defect insufficient as explained in Figure 30. The measurement data of Peak Value are shown in Figure 33, and Figure 34 for the two boards. The AXI 5 detected five pins based on Peak Value algorithm for board #1. For board #2 AXI5 detected one pin as defect per the Peak Value algorithm, and one more pin failed per the Area algorithm (Area is less than 12,740 µm2), see Figure 35. For this project, AXI 5 shows very good results, and its non-destructive e-cross-sections techniques play important role for the clear distinction between good and defective pins.

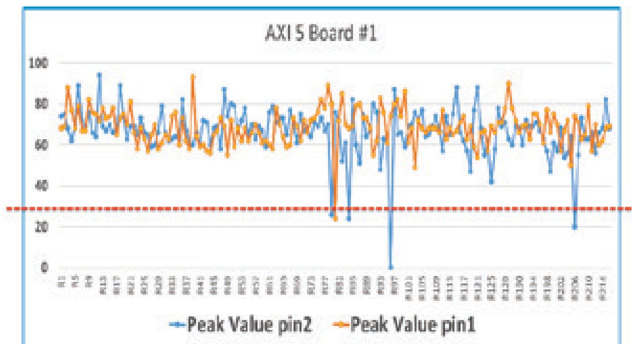


Figure 33. AXI 5 Peak Value Data for Board #1

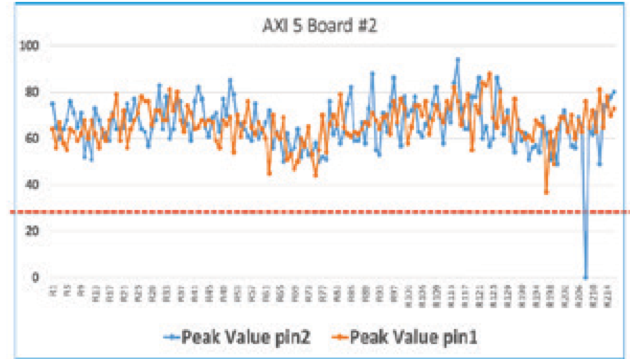


Figure 34. AXI 5 Peak Value Data for Board #2

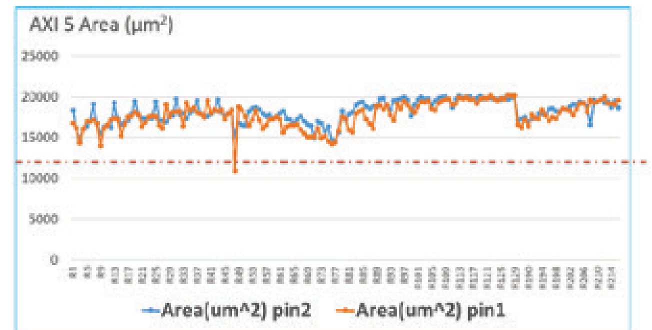


Figure 35. AXI 5 Area Data for Board #2

Table 4. Attribute Gage R&R for three AXI Machines

Machine	Gage R&R 1 board #1	Gage R&R 2 board #1	Gage R&R 1 board #2	Gage R&R 2 board #2
AXI 3	100%	100%	100%	100%
AXI 4	99%	99%	99%	99%
AXI 5	100%	100%	100%	100%

In order to build our GR&R data we used 3 operators to convey the testing (Table 4). We collected pass/fail attribute data and used SPC software to process the data. The Gage R&R data is based on 8586 data points (159 data points with

7 defective pins for one set, and 9 sets for one machine/board). Gage R&R1 stands for Assessment Agreement within Appraisers, and Gage R&R2 stands for Appraiser versus Standard. The Gage R&R results above 90% are considered as excellent, and results above 70% are considered as acceptable. Based on Gage R&R, measurement data, AXI/pCT images, all three machines perfumed with different side excellent progress for the last six months.

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X-ray Capabilities & Conclusions

X-ray inspection is critical for PCBA process development and quality control. Based on our experiences the importance of X-ray inspection will grow even further in coming years. Advanced MXI and AXI machines incorporating 3D Large Board CT and pCT capabilities will be in high demand for inspecting new packages and SMT process.

Demanding applications as BGA HIP, heavy material connectors, micro cracks, package 03015 are a challenge for current AXI equipment, so AXI with pCT capabilities is our expectation X-ray machine for the manufacturing lines. In manufacturing site without AXI/pCT, there is a need of using advanced MXI 2DX and pCT (Large Board CT) for results verification and AXI algorithms tuning. We believe advanced AXI equipment with pCT capabilities needs to be further developed in order to meet the challenges. The AXI 5 has excellent achievements for 03015 package project due to its images and algorithms. AXI with pCT technology is capable to meet our requirements as of now; however, it needs to improve in the areas of testing time, new algorithms development, threshold settings for false call PPM reduction and test coverage.

In near future, we expect for having further advanced developments for both the MXI and AXI equipment in order to be able to meet the constantly growing requirements of the PCBA manufacturing community.

The next generation of AXI equipment should have much improved image quality that permits clear distinction between good and bad pins, zero escape rate and false call PPM < 2000. Easy programming within one hour and including debugging, and both attribute and measurement data available in output. Flexible automated algorithms that are easily adjustable by the machine operator based on the testing results.

For the MXI equipment including 2DX and pCT/Large Board CT, we require further improvements and developments in the automatic inspection functionality both in 2D and 3D.

We believe that “Prevention is better than Detection1”, and “Seeing is believing”. In order to meet these requirements, the X-ray inspection system needs to be able to also provide powerful data output that can be used in real time to tune the SMT process parameters. This includes both attribute data and extensive measurement data with real time feedback to other SMT machines on the production line. This way we will be able to implement powerful prevention models through X-ray inspection on the SMT production line: X-ray machine is a SMART machine in PCBA.

For more information, speak with your Nordson representative or contact your Nordson Test & Inspection regional office

Europe, SEA, Africa
ti-sales-eu@nordson.com

China
ti-sales-cn@nordson.com

Singapore
ti-sales-eu@nordson.com

Korea
ti-sales-korea@nordson.com

Americas
ti-sales-us@nordson.com

Japan
ti-sales-jp@nordson.com

Taiwan
ti-sales-tw@nordson.com

www.nordson.com/TestInspect | +1 760.918.8471
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