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A Case Study of In-Process Inspection Methods to Improve First Pass Yields

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Abstract
The electronics content of many consumer products has increased substantially over the past decade. Several of the electronics added to the automobile control vehicle functions that have a direct bearing on the well being and safety of the passengers being transported. Automotive electronics are also subjected to very harsh environments. For these reasons, the reliability and quality of electronics components is of utmost concern. Many products are built with a "no touch-up rule" that prohibits rework if the product does not pass end of line test. For the electronics assembler this places a heavy burden on a high first pass yield process. The purpose of this paper is to discuss and present results from a test and inspection strategy adopted by an SMT assembler that includes in-line 3D solder paste and component inspection to improve first pass yields.

Introduction

In-line inspection or imaging test in the SMT manufacturing process is becoming more popular as component sizes continue to shrink, boards become smaller and more complex, and more attention is focused on cost reduction and yield improvement. Errors such as missing, misaligned, rotate, or components with bent leads, can cause over half of all defects during PCB assembly. Advantages of imaging test before reflow include lower rework costs, better process control, and the capability for improvement of the placement process to further reduce defect rates.

This paper describes the implementation of in-line component placement inspection in a manufacturing environment. Several aspects of the project are described, including the imaging test technique and issues related to the installation. Results from the implementation of 3-D laser imaging test for component placement inspection show a significant improvement in first-pass yields.

Situation Before Implementing Imaging Test

The manufacturer described in this study is a leading global contract electronics manufacturer. The facility where the implementation of imaging test took place provides manufacturing services and products for the transportation and industrial market segments. The company's strategy is to improve and expand existing capabilities through effective use of tools and processes such as Creative Problem Solving, Six Sigma, and Technology Road Mapping. The target product for the introduction of 3-D component placement inspection is a safety-related device where no rework could be performed after reflow. Achieving high first-pass yields was critical to meeting cost and productivity targets for this product.

Benefits of 3-D Component Imaging Test

3-D laser scanning provides a high-speed, high-density, high-resolution image of the PCB surface. Component placement inspection (CPI) is performed using the same 3-D scanning laser used in highly successful solder paste measurement systems. This technology has been used for years in the SMT manufacturing environment. The only difference between the system used for solder paste inspection and CPI is additional software, which includes component algorithms, a programmable Z resolution, and enhanced image processing capability. The 3-D image is based on the height of the components above the PCB surface and is much less sensitive to changes in board finish or component color. The 3-D technique provides a robust and accurate method to measure the position of components on the PCB. Device presence, rotation, and polarity can also be verified using 3-D image technology.

The 3-D data is collected by a laser triangulation method that uses solid-state scanning and detecting devices in conjunction with signal processing electronics. The system collects accurate, high-speed data of both height and position. A separate channel collects light intensity data, used to create a 2-D image that resembles the image from a CCD camera. The 2-D image is used to locate board fiducials and other features that may not have height above the PCB surface. A laser diode is used to project a spot of light onto the PCB surface, and the spot is scanned across the board using a solid-state optical device. (See Figure 1.) The position of the reflected light is focused onto a position-sensitive photo detector that determines the height of the reflecting surface at the point of the laser spot. The laser beam is raster scanned to create a line of height measurements, and the entire scanner is moved over the PCB to collect successive lines of data. The image resolution of the scanner can be selected to optimize the application. In this case the resolution of the scanner is approximately 25 microns in X and Y, and 12 microns in Z.

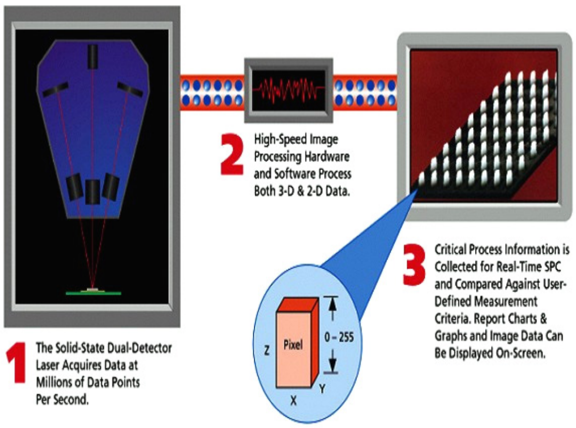

Figure 1 – Basic Principle of 3-D Laser Scanning

Poor performance of many 2-D AOI systems is caused by variations in the board finish or variations in component finish or color. A system that relies on special lighting techniques may have problems when the board finish or component color changes, or if the lighting changes. Many 2-D systems can require frequent algorithm adjustments when slightly different parts or PCBs are introduced to the system. This continual adjustment can have the effect of widening the range of what will be accepted by the system, sometimes to the extent that false accepts can occur. Inspecting a bare board and evaluating the defects found can be an enlightening experience after a 2-D inspection system has been in use for some time and many algorithm adjustments have been made.

In some AOI systems, defects are identified by comparing the images of board with data from a "golden board." The best systems provide real measurement data that can provide for defect detection and process control required for component placement. In addition, it's easier to verify the performance of these machines to measurement standards. Imaging test systems offering accurate, repeatable measurement data provide not only the best results, but also data that can be used for statistical process control (SPC) and process improvement.

Solder Paste Imaging Test

In-line solder paste inspection (SPI) has been in place at the site for some time, using the same 3-D laser scanning technology. By inspecting solder paste after printing, solder paste defects can be identified before components are placed on the board and potential solder joint defects occur. Implementation of in-line SPI allows the identification of defects as they occur. It also provides measurement data for SPC and process development, contributing to the reduction of paste-related defects during manufacturing. (See Figure 2.)

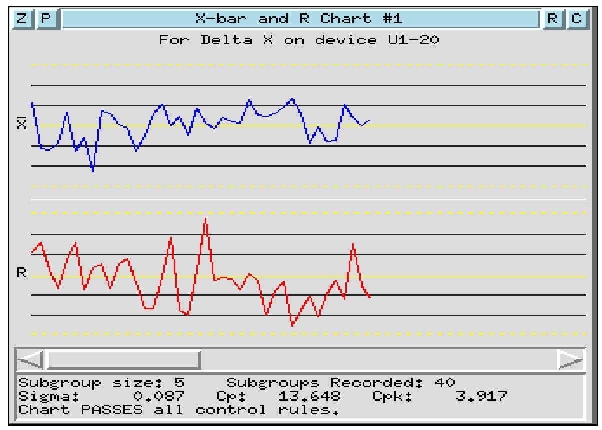

Figure 2 – An Example of SPC Data Created Automatically using 3-D Imaging Test

For the application considered, the cost of rejects found at solder paste imaging test was calculated to be just over $2 per unit. For the same product, a defect found at in-circuit test, functional test, or during final test prior to shipment was estimated to cost between $23 and $35 per unit. The cost of field returns was approximately $150 per unit. Annual failure rates were calculated, based on the total number of defects detected with in-line SPI over a twp month run. Depending on the efficiency of various test scenarios, the annual cost savings from in-line solder paste inspection for this single product was estimated to be between $80,000 and $500,000 per year. If in-line SPI were not used at all, the number of scrap boards would have been much higher. This is due to the fact that the operators would not know when a process problem was occurring until the product reached in-circuit test or manual inspection down line. By this time up to forty subsequent panels (160 boards on a 4-up panel) would have been populated.

The precision measurements from in-line 3-D solder paste inspection also enable engineers to identify and remove the root causes of process variation. In one example, variation in paste volume was found to correlate with a difference in squeegee direction during front-to-back versus back-to-front printing. For this particular setup the squeegee speed was fixed at 10mm per second, and the pressure for both the front and rear squeegees was set to 5 kilograms. Theoretical solder paste volume for these deposits, based on aperture size and stencil thickness, was 8236 cubic mils. Figure 3 shows that the original process variation ranged significantly from the expected value when the squeegee was moving back-to-front.

Optimization of the process was accomplished by adjusting the rear squeegee pressure. Figure 1 shows that the variation in solder paste volume due to print direction was significantly reduced. The actual solder paste volumes of the optimized process were slightly lower than the theoretical volume, which is expected in a stable print process.

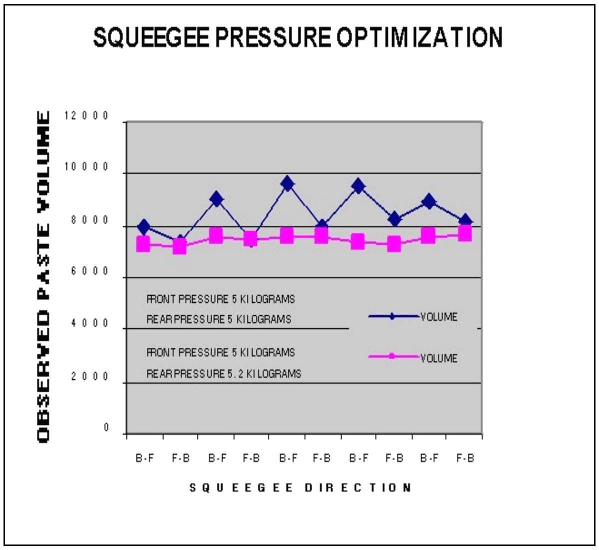

Figure 3 – Measurements of Solder Paste Volume Before and After Squeegee Pressure Optimization

Placement Imaging Test Equipment Qualification for Component

When choosing an imaging test system and strategy for process improvement, it's important to start with an understanding of the current process. The imaging test system chosen should be able to identify defects in the process. The best AOI tools also provide data that can be used for traceability, SPC, process improvement, and product improvement. The ability to accurately measure component positions and perform the imaging test with low levels of false accepts and false rejects is imperative. A good qualification procedure first defines the requirements of an AOI system and then attempts to verify equipment performance.

Inspection accuracy and repeatability must be suited to the process. The accuracy required for component placement can usually be calculated, based on the component dimensions and the dimensions of the pad. Minimum placement accuracy may also depend on post-reflow specifications or the minimum gap spacing between pads. With most components, some self-alignment occurs during the reflow process, where the surface tension of the melted solder tends to center the component on the pads. This same surface tension can be the cause of tombstoning, bridging, and other defects if the solder paste and component placement are not within tolerances.

Another critical aspect of any imaging test system is the robustness of the inspection. If the imaging test results in too many false calls, line operators will have to visually check the system results, causing frustration and lack of confidence in the results. During equipment qualification, tests were performed to quantify the following equipment performance:

- Detection of missing components – components that are supposed to be present, checking for absence
- Polarity – detection of components that are reversed or mis-mounted from their proper mounting scheme
- Co-planarity – detection of leads that are bent side to side and also bent upwards
- Wrong package detection – system ability to detect incorrect package sizes
- Skewing – checking of the components that are out of position, not meeting IPC Class III requirements

In addition, tests were performed to verify that the equipment met requirements for imaging test robustness:

- Component change tolerant – checking to be sure that the system is tolerant to changes in package style for the same component
- Bare board test – verifying that the system behaves properly when there are no components on the board

Test matrices were created to record the results of each test. Cycle times were also recorded for reach test. The test results for detection of missing components were straightforward. The system passed all tests to detect missing components with a perfect score. There were no issues that came up during this test.

For polarity detection, the 3-D imaging test equipment also passed all tests. Different polarity marks impacted cycle time slightly, depending on whether the polarity mark could be detected with 3-D data or if 2-D image processing was required. It was determined that there was not enough contrast ratio for one type of diode whose 2-D polarity mark could not be clearly imaged, but after rigorous trials it was determined that the machine was capable of detecting all but one part number for polarity. This part was covered by the ICT and functional test, and in the past the line had not experienced any polarity issues with that particular component.

The co-planarity test was determined to be successful even for leads that were bent as little as .0065”. It was decided that the time required to test the skew of every lead would increase the cycle time to the point where the line would be too slow.

The bare board test passed on all conditions. To test wrong package detection, a 1206 resistor was put in place for components that are larger than 1206, and as small as 0805. The system passed all tests, detecting the wrong size packages as defects.

When testing for skewed components, initially there were two components that passed even though they appeared to be skewed beyond IPC standards. Once it was determined that that limits of +/- 50% of the body size was too wide for these components, the limits were reduced and the components were correctly detected as skewed. Two other components exhibited a problem because of occlusion, or shadowing, caused by adjacent taller capacitors. Once a different algorithm was used for these components, the errors went away. After these adjustments, the system could detect all skewed components.

System repeatability was evaluated by measuring the same features many times. The repeatability of the measurements proved to be excellent, including measurement of bent lead height.

Cycle times showed little difference as additional measurement algorithms were added to the imaging test. (See Table 1.)

Table 1 – Cycle Time Variations for Different Tests

Test	Cycle Time (seconds)
Missing Component	42.65 sec
Polarity	44.65 sec
Co-planarity	44.65 sec
Bare-board test	41.03 sec
Wrong package	43.23 sec
Skewing	42.35 sec

The evaluation proved once again the accuracy and robustness of 3-D laser scanning for component placement inspection. Actual measurement data showed that the Cp and CpK of the imaging test equipment was well suited for the application. In 19 cases out of 20, the equivalent GR&R result exceeded 10%, with one case of 9.6%. In many of the cases measured, the GRR results were significantly better than 10%. With all of the variables tested during the trial run, it was determined that the machine could become a great asset and pay for itself in the first six to nine months of use, based on the line rates at the time of the evaluation.

Implementation of In-line CPI

The machine for component placement inspection was placed in-line in March of 2002. During the first several weeks after the installation, a significant part of the implementation effort was devoted to developing tolerances for the imaging test programs. Tolerances must be set to that all defects are captured, without capturing less severely mis-mounted components that would not affect the final assembly yield. These tolerances for pass/fail determination can depend on other process parameters, such as pad sizes or paste volumes deposited. The initial work took several weeks, but once the proper tolerances were determined, they were stored with the imaging test template developed for each package type. These templates can be copied and re-used for subsequent imaging test programs. Programming and start-up time are not an issue today, now that the proper tolerances have been established.

Further optimization of the machine performance was done to improve cycle time. This optimization balanced the speed at which the scanning laser head moves over the PCB to match the speed of the processor. By optimizing the scan parameters, “re-scans,” which can be required if the processor slows the imaging test time, can be eliminated. With optimization the imaging test cycle time was improved by several seconds.

Results of In-line CPI

After the machine was installed and programmed, there was a marked reduction in defects caused during the component placement process. Figure 5 shows the percent yield from the SMT process for the line before and after the in-line imaging test was implemented in March. The implementation of in-line CPI can be credited with an improvement in first-pass yield from 97.5% before implementation to 99.5% within several weeks after the CPI system was put in place.

Figure 4 shows significant improvement in first-pass yield immediately after implementation of in-line CPI. Figure 5 shows significant reduction in mis-mounted components following implementation of in-line 3-D CPI equipment.

Results from Pareto charts taken from production data show solder paste- and component-related defects are much reduced. In recent months these types of defects have accounted for only a small percentage of the total defects found during manufacturing. Mis-mounted and missing components regularly showed up in the Pareto charts created before the use of in-line CPI. The charts shown in Figures 6 and 7 include all of the top failure categories for the complete product manufacturing process, and include all assembly steps (not just the SMT process). Similar data from recent months following the start-up of in-line CPI shows that the number of defects related to component placement are significantly reduced. (See Figuire 8.)

Close examination of the charts in Figures 6 and 7 reveal that in the eight months from January through August of 2002, not only did the number of defects related to component imaging test decrease, but overall defect levels dropped. This is best illustrated by the change in scales on the left-hand side of each chart.

Figure 6 shows the effect of mis-mounted and missing devices. Figure 7 shows that the occurrence of mis-mounted and missing devices declined significantly.

The immediate improvement in yield resulted from the ability of in-line 3-D CPI to detect defects at their source. Since the implementation of in-line CPI, imaging test data has been used for root-cause analysis to eliminate the source of several component placement defects, further improving yield and reducing costs. Some examples include:

- Defects of a certain component were traced back the placement machine. It was identified that a feeder cover plate was causing drag on a particular feeder, resulting in mis-picks. Re-alignment of the feeder cover resolved the problem.
- Shifts in X, Y, and theta were traced back to a camera that was starting to fail on a placement machine.
- Low paste tack, caused by dry paste, was discovered when it caused the mis-mount of components which where not held in place. Once the problem was identified, the solder paste was replaced.
- Several worn feeders causing mis-mounts were identified and repaired or replaced.
- It was discovered that a particular component was having co-planarity issues. The problem was traced to a nub protruding from the molded part that would not allow the component to sit flat.

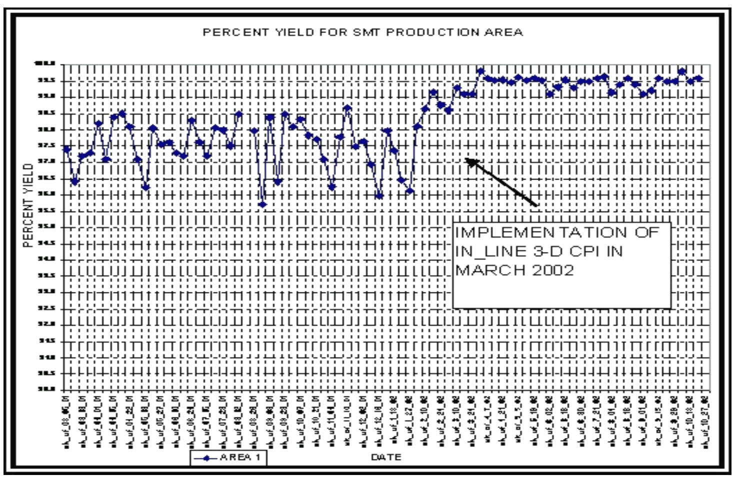

Figure 4 – Weekly Yield Chart

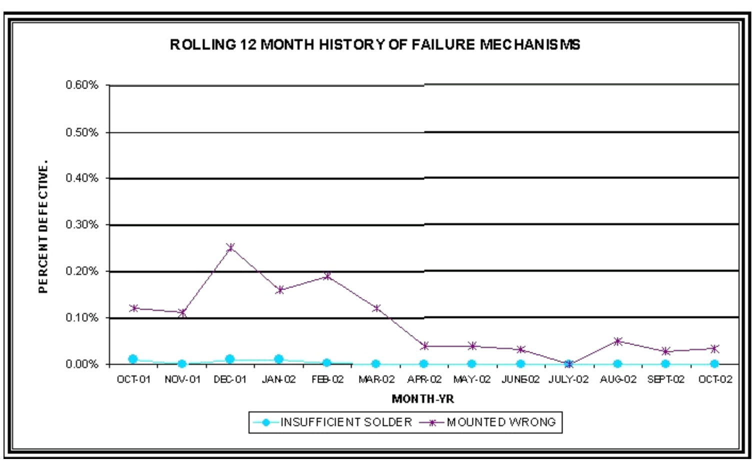

Figure 5 – History of Failure Mechanisms

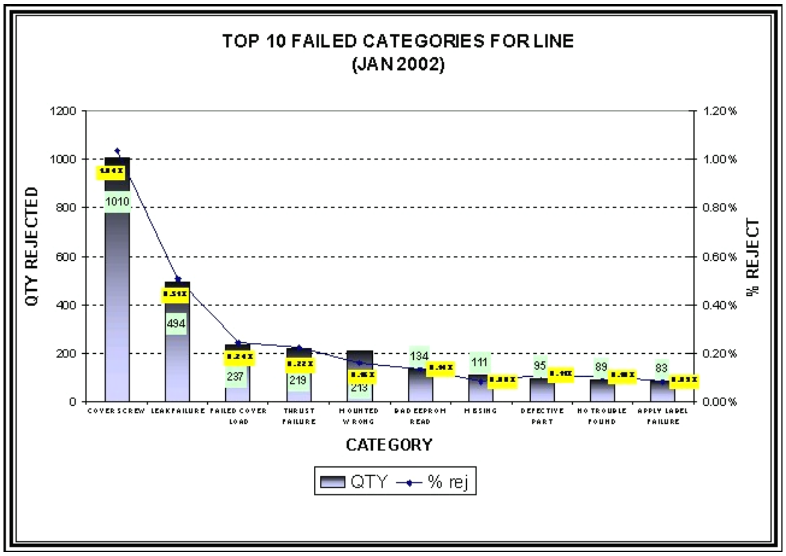

Figure 6 – Pareto Chart of Defects Produced before Implementation of In-line CPI

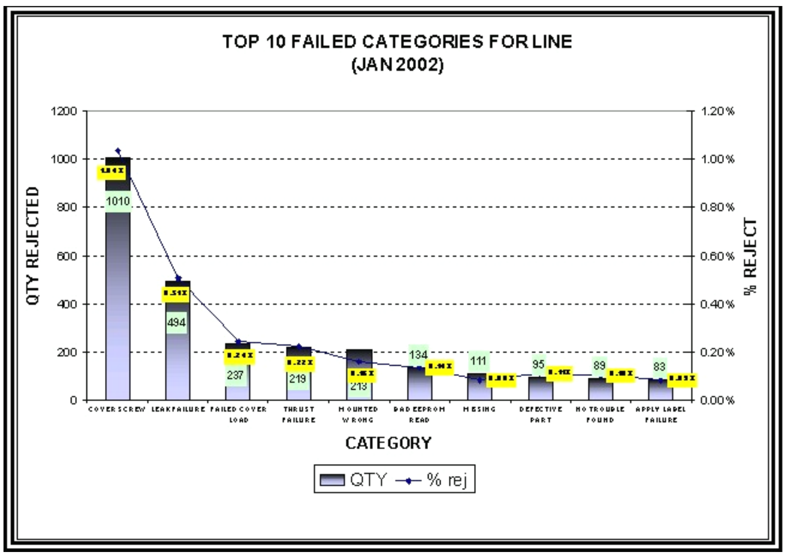

Figure 7 – A Pareto Chart Produced after Implementation of In-line CPI

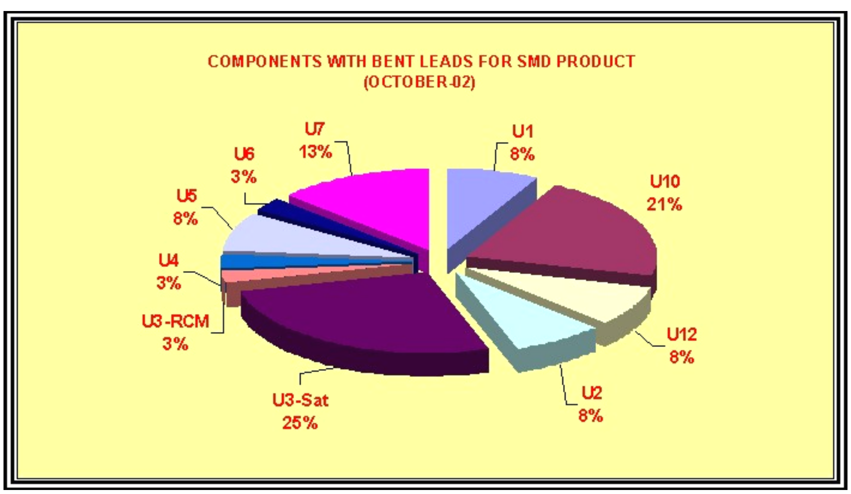

Figure 8 – Data Showing the Frequency of Bent-lead Failures of Different Components

Conclusion

This case study clearly shows the capability and benefits of using in-line 3-D imaging test for solder paste and component placement inspection.

In this particular case, the implementation of in-line 3-D CPI was motivated by the requirement that the products be built in a "no-repair" process, so rework could not be performed. For the safety-related product, an additional motivation was to achieve the highest quality levels possible. Results of the qualification and implementation of in-line 3-D imaging test show that the equipment capability and performance may be applicable to a variety of processes and product types.

Implementation of 3-D imaging test has allowed this manufacturer to meet their goal of improving and expanding their capabilities.

References

1. Houston, Paul and Robert Kelley, "Process Capability Case Study on 0201 Processing Utilizing 3D Automated Optical Inspection", *Proceedings of the Technical Program*, *SMTA 2002*.
2. Pollard, Carl, *Pre-Reflow Placement Inspection using 3-D Laser Technology.*