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AOI: A Strategy for Closing the Loop

AOI has been a process-monitoring tool within the SMT industry for several years. Often used to catch defects, the AOI system has become nothing more than a gate on the process. This article details a set of defect-prevention solutions centered on the availability of high-quality inspection and measurement data from an AOI system and a few carefully engineered software applications.

By Peter Conlon

Automated optical inspection (AOI) has been available to the SMT industry as a process-monitoring tool for several years. Typically, this tool is used to catch defects, making the AOI system a gate on the process. In this role, the AOI system generally is placed post-reflow to help ensure that defects created while the board is being manufactured are discovered before the product is shipped to the final customer.

Defect detection tells the process engineer what is happening at that moment. Post-reflow AOI indicates that defects have occurred, and that the PCB should be scrapped or repaired depending on the number and severity of defects. Delivery pressures mean that this manufacturing decision is taken, and it may be some time before a process engineer reviews the production-defect data. If the defects are random, the process engineer may not take action. If, on the other hand, the defects are systematic, the process engineer may need to engage in a long, experimental process to discover the root cause of the defect, and prevent it in the future. AOI can be more useful than that.

Defect prevention is a combination of statistical process control (SPC) and six sigma. Both of these concepts have been around for a number of years. The notion of being able to continually improve the paste printing and placement processes is something every process engineer aspires to implement, but may never have the opportunity due to time and resource constraints, as well as internal policy pressures. AOI-centric defect prevention is a methodology that uses the inspection and measurement data produced by a number of today's AOI machines. This methodology uses many SPC/six sigma principles, but shelters the user from the details, allowing them to continue with the task of acting on the outputs of a real-time root cause and predictive analysis.

By being flexible with AOI deployment on the line, defect prevention can shorten

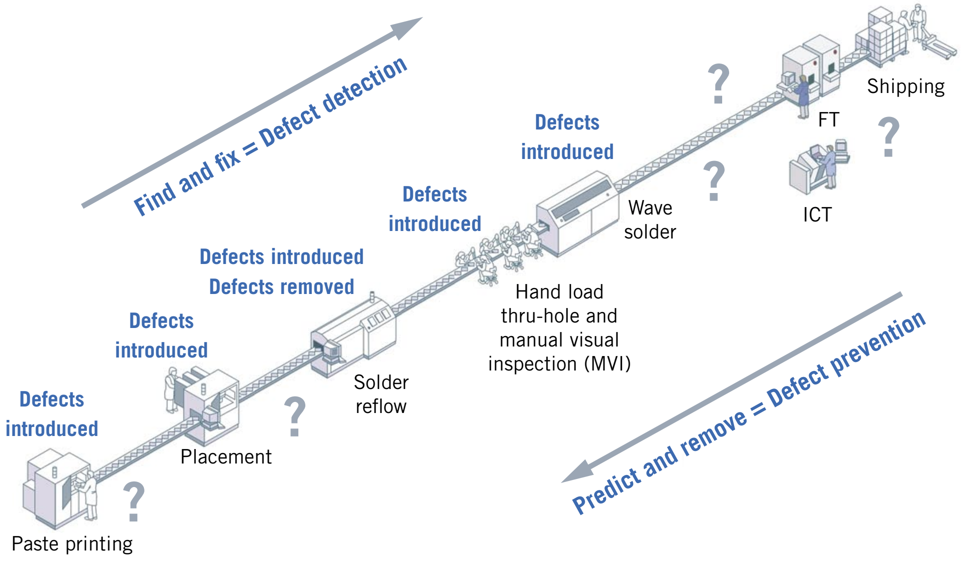

Figure 1. Testing at the end of the line ensures quality is shipped, but does not address defect causes.

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time-to-feedback for the current line status. Print and placement errors can be resolved more quickly, and end-of-line defects per million opportunities (DPMO) can be reduced and maintained at a low level. A detailed set of defect-prevention solutions center on the availability of high-quality inspection and measurement data from an AOI system, and a small number of carefully engineered software applications. These solutions have been deployed successfully in a number of high-volume SMT facilities worldwide.

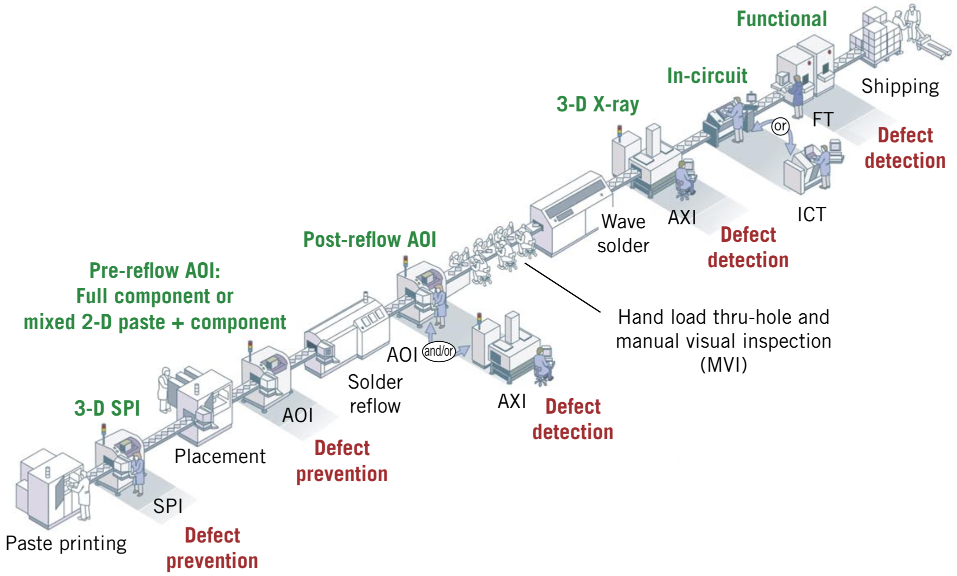

Figure 2. Developing an inspection and test strategy: Combining inspection and testing improves shipped quality by improving the SMT process through the use of a defect-prevention strategy.

Every company involved in electronics manufacturing faces a constant concern over ever-shrinking profit margins. For contract manufacturers (CMs), this means they may not win their next contract if the quality of the current contract is not on target. Therefore, CMs must improve quality or absorb the costs of manufacturing failures. The need to maintain market leadership and quality, reduce internal costs, and lower warranty costs drive OEMs. To maintain profit margins using AOI has become a standard part of manufacturing; and it is deployed on many lines post-reflow to detect manufacturing defects prior to shipping.

Another less-common approach is using AOI earlier in the manufacturing flow for defect prevention. Many companies have not considered applying the strengths of AOI for process feedback as a way to continually improve the manufacturing process. This article discusses how defect detection can be migrated to defect prevention, and the benefits of deploying a defect-prevention strategy.

Defect Detection Defined

AOI is found most often post-reflow. Depending on the type of defect identified, it might be possible to repair the boards to maintain a high end-of-line yield. However, this limits the benefits of AOI to overall line performance. In the long run, good post-repair statistics can create false impressions of actual line performance. Figure 1 illustrates that the deployment of test and inspection depends on product complexity, and how much money a user will spend.

Another Approach: Defect Prevention

By applying AOI in the pre-reflow stage, manufacturers can reduce or eliminate future defects. The production-defect data that the AOI system collects can be used immediately to fix line problems, or analyzed to predict future defects. Ideally, measurement/inspection would be placed at each production stage on the line. However, this is neither practical nor necessary.

To successfully apply AOI as a defect-prevention tool, a manufacturer must have a capable measurement tool with compatible data analysis software, and a review station to estimate the effectiveness of the inspection/measurement process. Perhaps the most important prerequisite is the user's willingness to trust the data from the AOI, and believe that if this measurement is used to feedback into the process, it can be improved (Figure 2).

A capable measurement tool typically is defined as:

- Capable = <10% gauge repeatability and reproducibility performance (GR&R).
- Measurement = ability to gather X, Y, and Theta offset for every component inspected.

In addition to these requirements, it also is important to review the line and ensure it meets certain criteria before moving from detection to prevention.

First, the line must be in control, or at least capable of being brought under control. This statistical term describes a process in which the total variation is within tolerance, and any variation is from the process mean, and is random in nature. To bring the line in control, it is necessary to detect the defects, assign a cause to those defects, and implement a strategy to prevent those defects from happening again — or minimize their reoccurrence.

Second, it is essential to have accurate production-machine data for all elements of the placement machine — printers, gantries, heads, nozzles, and feeders. Each of these can contribute to the overall defect performance of the production line. Therefore, to communicate process corrections, the actual placement setup must be known and tracked. Most placement machines can adjust their placement set up dynamically, and any prevention solution must be aware of these changes.

Next, manufacturers must decide on the correct inspection strategy for the types of components being manufactured, and the most critical variables for the product being produced. The three most common inspection scenarios are: 2- and 3-D solder paste measurement to measure all printed paste deposits; mixed-mode measurement in which a selection of components and critical paste deposits are inspected (2-D only); and full component-placement measurement.

Implementing Defect Prevention

Implementing defect prevention can reduce total defective parts per million (DPPM) post- and pre-reflow. Following is a four-step implementation process.

The Step-by-Step Process

Step 1: Identify principle defects using defect Paretos from one of the defect detection or validation sensors, namely post-reflow AOI, 3-D X-ray, or in-circuit test (ICT). Using 3-D X-ray is preferred because it gives the best coverage. Using this information, defects can be analyzed and categorized into two major defect categories: paste-related defects and placement-related defects.

Step 2: Depending on the outcome of Step 1, manufacturers determine the most suitable early defect-detection strategy to reduce post-reflow DPPM — most likely 3-D paste inspection and/or post-placement inspection. By implementing an early defect-detection strategy, there should be a significant reduction in post-reflow DPPM. However, at the same time, the pre-reflow DPPM may spike as the defect detection sensor is moved up in the SMT process. This is early defect detection; however, this still does not address the root cause of the defect. To do that, we must progress to the next step.

Step 3: By implementing a feedback strategy with the paste printer or placement machine (automatically or manually) systemic defects could then be reduced. This, in turn, would reduce pre-reflow DPPM and bring the process into a stable environment to examine defect prevention.

Step 4: To sustain an overall reduction in process DPPM, the user must implement a monitoring process that includes:

- Early warning alarms so that random defects are caught and analyzed;
- Trending tools such as real-time C_{pk} monitoring of SMT lines. Paste printer and placement machines should be deployed to alert early deviations in process capability.

Improving the Chances of Success

Defect prevention is not SPC, nor is it statistical quality control (SQC). The analysis of measurements (SPC) alone does not provide all the answers; neither does the analysis of defects (SQC). Instead, a combination of both techniques is required. Defect prevention means finding solutions to problems and fixing those problems. Test-equipment manufacturers can help increase the success of this approach by providing tools that give data in simple messages that can be applied to solve complex problems.

Traditionally, process and production engineers have been responsible for defects on the line. Increasingly however, line technicians and line supervisors are responsible for maintaining line yield. Companies want their engineers to be responsible for new product introductions (NPIs) and equipment validation. The process of implementing defect prevention requires an engineering sponsor, but typically a competent line technician completes this.

The presentation of defect-prevention data must be simplified so a non-engineer can interpret and apply the information. Complex SPC/SQC charts requiring interpretation will not be useful. Users should be told exactly what has gone wrong and what corrective action should be taken to eliminate the defect.

Detection to Prevention in Action

One company* has been working with customers on AOI trials pre-reflow for defect prevention. The following examples are based on two of these trials. The first example is a CM that previously used a mixed-mode inspection strategy in a high-volume manufacturing line to inspect the quantity of chip components placed on a board, and paste deposits for BGAs and chip-scale packages (CSPs). Before implementing pre-reflow AOI, the manufacturer's post-reflow defect PPM was about 30+ DPPM. Four weeks after implementing pre-reflow AOI on the line, post-reflow DDPM was cut by about half. With root-cause analysis of defects found in mixed-mode and short-feedback loops, it is possible to reduce DPPM at pre-reflow, and further improve post-reflow DPPM to below 10 (Figure 3).

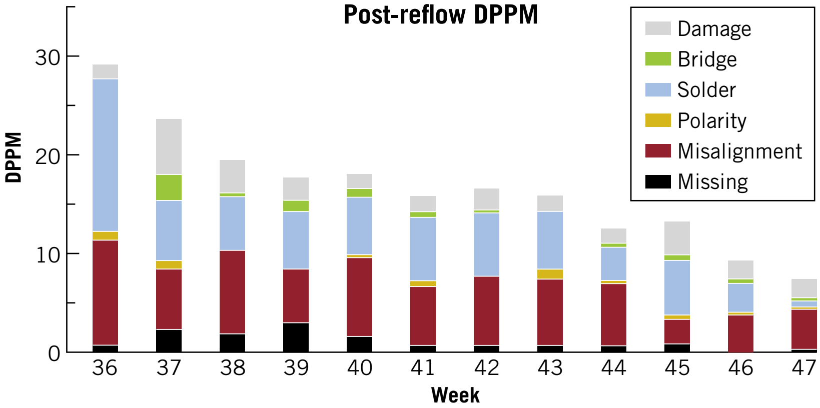

Figure 3. The effect of a well-implemented defect-prevention strategy: End-of-line defects are reduced, improving end-of-line test and repair efficiency. This improves quality and throughput. In this case, the AOI machine was placed between a chip shooter and a fine-pitch placement machine performing "mixed-mode inspection" (2-D paste and components).

To illustrate the effect this type of improvement can have on a manufacturer's profit margins, let's use some numbers for the reduction in post-reflow DPPM, as in the case of high-volume cell phone production. If there were 300 components on each board and four boards per panel, the daily volume would be 3,000 boards. If we assume only one defect per board, repair and component scrap costs will be $8/board. By merely bringing the DPPM from 36 to 8, we could achieve an annual savings of $72,000.

Typical industry post-reflow DPPM is around 100–300, depending on board complexity. If 100 DPPM were lowered to 8 DPPM for the same board, that would result in a savings of more than $200,000. With detect prevention, the typical DPPM target is to reach a sustained level at 50 ppm or below pre-reflow DPMO, and 10 ppm or below post-reflow DPMO for an improved end-of-line yield.

The second example is from a trial with an OEM customer that was only using mixed-mode inspection. The manufacturer was repairing defects post-reflow without any pre-reflow review or repair. This OEM opted to implement defect prevention to reduce production scrap and warranty returns. The pre-reflow inspection, in this case 3-D solder paste inspection, focused on the most critical parameters for the design — chip component and paste deposits for BGAs and CSPs. Chip components account for 80–90% of board placement, so accurate print-process measurement is critical. Print quality of paste deposits is the most critical parameter for BGAs and CSPs because the joints are no longer visible after reflow. Insufficient paste could lead to 50% higher rework costs, and more losses in scrap. Previously, repair and component-scrap costs for this line were $100/board, with a monthly production of 8,000 boards. A 1% improvement would result in 80 fewer defective boards, and a savings of $8,000/month in board repair and component scrap costs.

Conclusion

By applying AOI at paste inspection or pre-reflow component inspection for defect prevention, manufacturers can improve their processes for better overall products and lower warranty costs to maintain profit margins. As demonstrated in examples from specific OEMs, deploying a defect-prevention strategy can result in significant reductions in repair, scrap, and warranty costs. SMT

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