Boosting First-Pass Yield

Laser-based inspection of solder paste deposits and component placement can dramatically improve first-pass yield.

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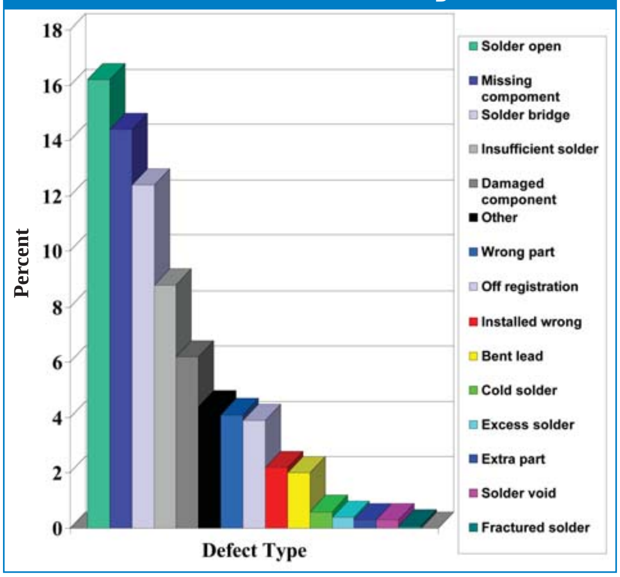
In-line inspection during surface mount assembly has become increasingly necessary as components shrink, boards get smaller and more complex, and profit margins narrow. Nearly 40 percent of all printed circuit board (PCB) defects are component-related, such as bent leads, missing components and misaligned components. By inspecting boards before reflow, assemblers can lower rework costs and improve process control.

Typical Defects in PCB Assembly



Nearly 40 percent of all printed circuit board defects are component-related, such as bent leads and misaligned components.

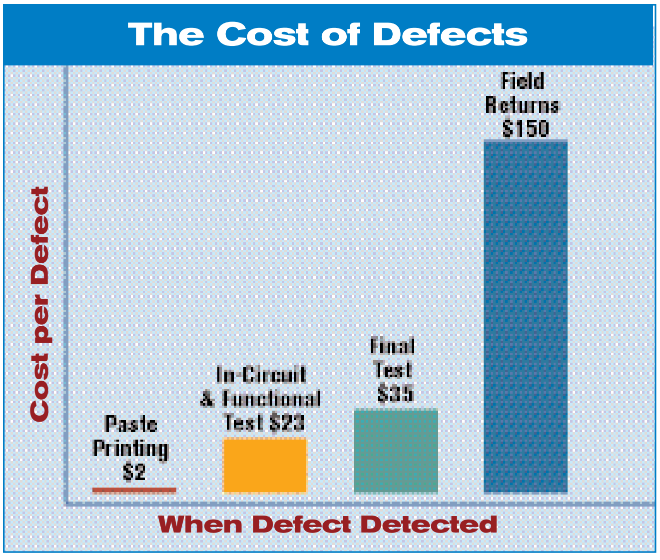
Kimball Electronics learned the importance of in-line inspection last year. The contract manufacturer received an order to assemble a safety-related device with a critical stipulation: No rework could be performed after reflow. Achieving high first-pass yields would thus be critical to meeting cost and productivity targets for this product.

Kimball had to catch defects early, so the company decided to try laser scanning to inspect the assembled boards before reflow. Laser scanning produces a high-speed, high-resolution 3D image of the PCB's surface. The technology has been used for years to inspect solder paste deposits, but only recently has it been used to inspect component placement. The only difference between laser systems for solder paste inspection and those for component inspection is the software, which includes component algorithms, a programmable Z-axis resolution, and enhanced image processing.

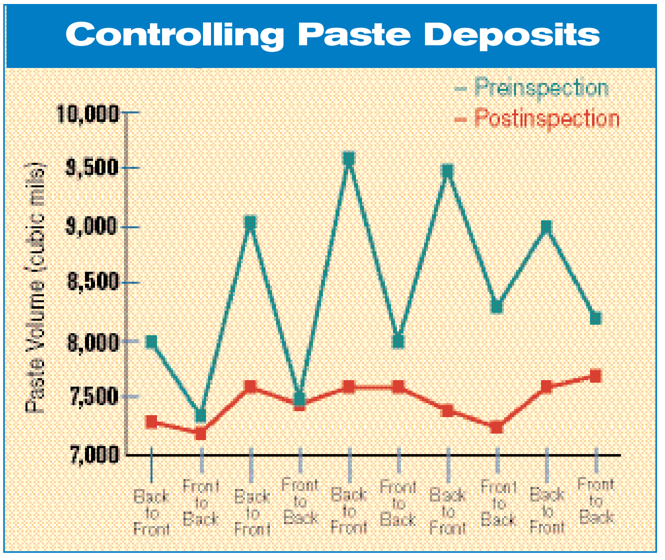
The 3D technique is a robust and accurate method for measuring the position of components on the PCB. Component presence, rotation and polarity can also be verified using 3D imaging technology. The technique is less sensitive than automated optical inspection (AOI) to changes in board finish or component color.

The 3D image is based on the height of the components above the PCB surface. Height and position data are collected by a laser triangulation method that uses solid-state scanning and detecting devices in conjunction with signal processing electronics. A separate channel collects light intensity data, which is used to create a 2D image that resembles the image from a CCD camera. The system uses the 2D image to locate board fiducials and other features that may not have height above the PCB surface.

A laser diode projects a spot of light onto the PCB, and the spot is scanned across the board using a solid-state optical device. The reflected light is focused onto a position-sensitive photodetector 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 resolution of the



Why is in-line inspection of PCBs important? Kimball Electronics calculated the cost of rejects found at solder paste inspection to be just over $2 per unit. For the same product, a defect found at in-circuit test, functional test or final test prior to shipment was estimated at $23 to $35 per unit. The cost of field returns was approximately $150 per unit.



Solder paste inspection enables engineers to identify the root causes of process variation. At Kimball Electronics, inspection data revealed that variation in paste volume correlated with a difference in squeegee direction. The problem was solved by increasing the pressure of the rear squeegee.

scanner can be selected to optimize the application. In Kimball's case, the resolution of the scanner was approximately 25 microns in the X and Y axes, and 12 microns in the Z axis.

Poor performance of many 2D 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 2D systems require frequent algorithm adjustments when slightly different parts or PCBs are introduced. This continual adjustment can widen 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 can be an enlightening experience after a 2D 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 images of a production board with data from a "golden board." A better method is to obtain real measurement data that can be used to detect defects and control subsequent placement operations. In addition, it's easier to verify the performance of laser scanning systems against measurement standards.

Solder Paste Inspection

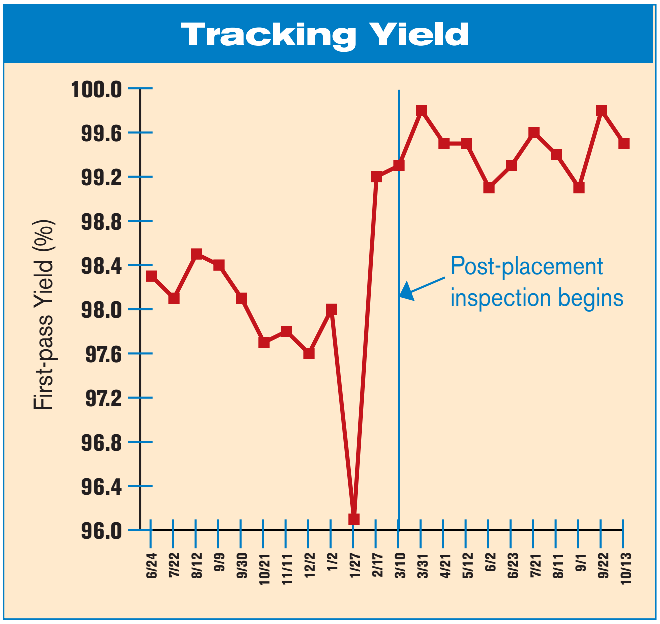
Kimball has been using 3D laser scanning to inspect solder paste for some time. By inspecting solder paste after printing, solder paste defects can be identified as they occur, before components are placed on the board. This prevents solder joint defects during reflow. It also provides data for statistical process control (SPC) and process development, which further reduces paste-related defects.

For assembly of the safety-related device, Kimball calculated the cost of rejects found at solder paste inspection to be just over $2 per unit. For the same product, a defect found at in-circuit test, functional test or 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.

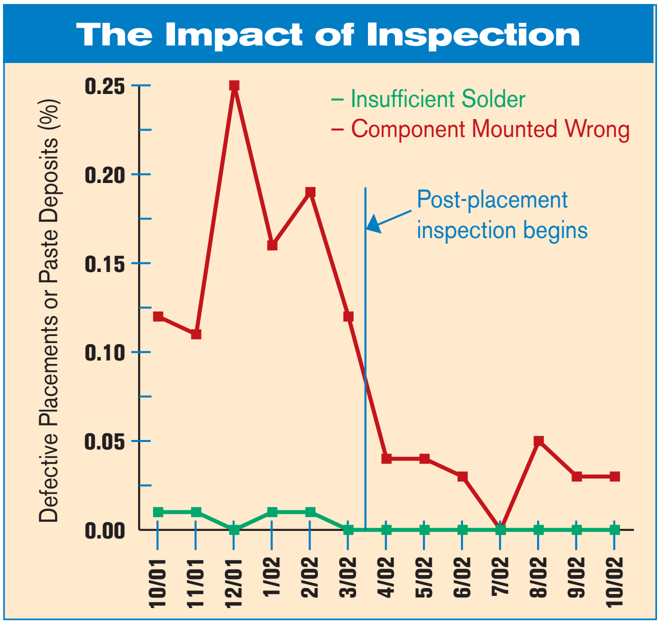
In addition, we calculated the annual failure rate, based on the total number of defects detected with in-line solder paste inspection over a 2 month run. Depending on the efficiency of various test scenarios, the annual cost savings from in-line solder paste inspection for this product was estimated to be between $80,000 and $500,000 per year.

If in-line solder paste inspection were not used at all, the number of scrap boards would have been much higher. This is because operators would not know when a process problem was occurring until the product reached in-circuit test or manual inspection down the line. By this time, up to 160 subsequent boards would have been populated (40 panels with four boards per panel).

Solder paste inspection also enables 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 (front-to-back printing vs. back-to-front printing). For this particular setup, the squeegee speed was fixed at l0 millimeters per second, and the pressure for both the front and rear squeegees was set to 5 kilograms. Based on aperture size and stencil thickness, the theoretical solder paste volume for these deposits was 8,236 cubic mils. However, this volume varied significantly when the squeegee was



Since Kimball Electronics began inspecting populated boards prior to reflow, first-pass yields have consistently exceeded 99 percent.



Component placement inspection dramatically reduced the number of mismounted components at Kimball Electronics.

moving back-to-front.

The problem was solved by adjusting the pressure of the rear squeegee. After adjustment, the actual solder paste volumes were slightly lower than the theoretical volume, which is expected in a stable print process.

Inspecting Components

Before choosing an inspection system for PCB assembly, it's important to understand your current process. The inspection system must be able to identify all the possible defects in the process. The best inspection systems also provide data that can be used for traceability, SPC, process improvement and product improvement. It's imperative that the system be able to accurately measure component positions and perform inspections with few false accepts and false rejects. A good qualification procedure is to first define the requirements of an inspection system and then verify that the equipment meets those requirements.

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

Another critical aspect of any inspection system is robustness. If the inspection produces too many false calls, line operators will have to visually check the results, causing frustration and lack of confidence in the results.

To see if a laser imaging system would meet Kimball's needs for post-placement inspection, the company tested the ability of the equipment to detect the following defects:

- Missing components.
- Polarity. Could the system detect reversed or mismounted components?
- Co-planarity. Could the system detect bent leads?
- Wrong package. Could the system detect incorrect package sizes?
- Skewing. Could the system detect components that are out of position?

In addition, Kimball tested the system to see if it would:

- Tolerate changes in package style for the same component.
- Operate correctly when there were no components on the board.

Test matrices were created to record the results of each test. Cycle times were also recorded for each test.

The system passed all tests to detect missing components and changes in polarity. However, different polarity marks affected cycle time slightly, depending on whether the polarity mark could be detected with 3D data or if 2D image processing was required. Overall, Kimball found that the machine could check the polarity of all but one type of part. The part, a type of diode, did not produce enough contrast for the system to clearly identify the 2D polarity mark. Fortunately, this part was covered by in-circuit and functional testing, and in the past the line had not experienced any polarity issues with that component.

The co-planarity test was successful even for leads that were bent as little as 0.0065 inch. However, the company 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 system passed the bare board test on all conditions. To test the ability of the machine to detect wrong components, Kimball substituted 1206 resistors for components that are larger than 1206s and components that are as small as 0805s. The system found all the wrong sized packages.

When the company tested the system's ability to detect skewed components, it passed two components even though they appeared to be skewed beyond IPC standards. However, Kimball determined that the skewing limit of ±50 percent of the body size was too wide for these components. When the limit was reduced, the system correctly detected the components 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.

Inspection Parameters and Cycle Time

Inspection Routine	*Cycle Times seconds*
Missing component	42.65
Polarity	44.65
Co-planarity	44.65
Bare board	41.03
Wrong component	43.23
Skewing	42.35

When programming inspection equipment for PCBs, engineers should carefully consider which checks they want the machine to perform. Some inspections, such as checking the co-planarity of leads, take more time than others.

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, even when additional measurement algorithms were added to the inspection routine.

Kimball's evaluation proved the accuracy and robustness of 3D laser scanning for component placement inspection. Actual measurement data showed that the C_p and C_{pk} of the inspection equipment were well-suited for the application. In 19 out of 20 cases, the equivalent gauge repeatability and reproduceability (GRR) result exceeded 10 percent, with one case of 9.6 percent. In many of the cases measured, the GRR results were significantly better than 10 percent. With all of the variables tested during the trial run, Kimball determined that the machine would pay for itself in the first 6 to 9 months of use.

Implementing Inspection

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

Further optimization of machine performance was done to improve cycle time. Kimball 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, "rescans," which can be required if the processor slows the inspection time, can be eliminated. With optimization, the inspection cycle time was improved by several seconds.

After the machine was installed and programmed, there was a marked reduction in defects caused during component placement. Kimball's first-pass yield increased from 97.5 percent to 99.5 percent within several weeks.

Pareto charts taken from production data show that paste- and component-related defects are reduced. In recent months, these defects have accounted for only a small percentage of the total defects found during manufacturing. Mismounted and missing components regularly showed up in the Pareto charts created before the use of in-line component placement inspection. In fact, from January to August 2002, not only did the number of defects related to component inspection decrease, but overall defect levels dropped.

The immediate improvement in yield resulted from the ability of the inspection system to detect defects at their source. Inspection 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 with a certain component were traced back to the placement machine. Kimball found that a feeder cover plate was causing drag on a particular feeder, resulting in mispicks. Realignment of the feeder cover resolved the problem.
- Shifts in X, Y and Ø 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 mismount of components that were not held in place. Once the problem was identified, the solder paste was replaced.
- Several worn feeders causing mismounts were identified and repaired or replaced.
- 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. **A**