Inline Component Placement Inspection:
Lowering PCB Assembly Costs with Continuous Quality Improvement

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In-line inspection during SMT assembly is becoming a requirement to assure the quality of today's electronic products and to reduce the manufacturer's costs of scrap and rework. It is important to simultaneously meet the goals of producing a cost competitive product while continuing to meet or exceed customers' quality expectations. An effective way to work towards this goal is to implement Continuous Quality Improvement (CQI). Two of the basic principals in implementing CQI are to "continuously improve all processes" and to "mobilize data and team knowledge to improve decision making". [REF 1] In-line inspection during SMT assembly provides the data and knowledge needed for this effort.

There are three major applications for inspection during SMT assembly: solder paste inspection before component placement, component placement inspection before reflow, and post-reflow inspection, which often includes some type of solder joint checking. This article focuses on the uses of automated inspection technology for component placement before reflow. (See the Sidebar "Choose the Right Place for In-Line Inspection" for a summary of in-line inspection applications.)

In-line inspection for component placement is becoming more popular as component sizes continue to shrink, boards become smaller and more densely populated, placement rates become faster, and cycle times become shorter. Errors such as missing, misaligned, or incorrectly rotated components can cause over one-half of all defects that are found after reflow. Advantages of pre-reflow in-line inspection for component placement include lower rework costs, better process control, and the capability for improvement of the placement process to further reduce defect rates.

Inspection cycle time is critical for in-line applications. As manufacturing cycle times become shorter, it becomes more difficult to manually check each board for proper assembly. In-line automated systems must be fast enough to do the job within the allowed cycle time. Most people are not willing to increase overall manufacturing cycle time to do inspection. Because product life cycles are getting shorter, and many different products are often run on a single SMT line, short programming times and product changeover times are also important.

COMPONENT INSPECTION CAPABILITY

When choosing a component inspection system, it is important to first define and understand your process needs. The system you choose should help to identify defects in your process and improve product quality. Begin with a survey of your current process. What are the most common types of component placement defects in your process? For some manufacturing sites, the most common problem may be misplaced or missing resistors or capacitors. For another site, the most common problems may be the accuracy of QFP placement or device polarity. Next, be sure that the system you choose has the imaging technology and features best suited to your manufacturing process.

Inspection accuracy and repeatability must be suited to your process. Inspection accuracy for resistor and capacitor chips is usually not as critical as for leaded devices, and different systems offer very different capabilities. Some systems attempt to identify defects based upon the use of a "golden board." In these systems, defects are identified by comparing differences between the "golden board" and the board that is being inspected, regardless of whether the differences are defects or are just harmless variations. In general, systems that provide real measurement data are better able to provide the defect detection and process control required for component placement. In addition, it's easier to verify the performance of these machines to measurement standards.

A critical aspect of any inspection system is the robustness of the inspection. Today's circuits often have one thousand or more components per board. If the inspection results in too many false calls, line operators will have to check the system results too often and they will quickly lose confidence in the inspection results. Poor robustness for component placement inspection is often caused by variations in the board or in the components. A system that is sensitive to changes in the color or finish of the PCB, or a system that relies too heavily on special lighting techniques may have problems when the board finish or color changes, or if the lighting changes.

At a minimum, an inspection system should measure the position of each component in X, Y, and theta, and also check device polarity. The positions of each device should be compared to CAD data to see if the component position is within tolerances. Devices outside of tolerances should be identified and measurements are used to update SPC charts.

The trend of SMT manufacturers in Asia (including Japan) has been toward solder joint inspection tools for use after the board is soldered. Lately, many manufacturers have realized that it is less expensive to inspect each board and detect defects before reflow. These manufacturers are now using solder paste and component placement inspection systems, proving that "an ounce of prevention is worth a pound of cure!"

INSPECTION TECHNOLOGY

There are two technology types available to perform in-line component placement inspection.

The majority of component placement inspection systems use either grayscale or color CCD cameras. The cameras collect images of the PCB, and the images are analyzed to determine if there are any defects in each area. Camera-based systems can be very fast, but because they rely on the brightness of light reflected from the PCB, they can be sensitive to changes to lighting conditions or changes in materials.   Most systems that rely on cameras for image collection have programmable lighting to create optimal images of each site or component. As board complexity increases, problems with lighting contrast or shadowing may arise. As each image becomes more complex, the image processing becomes more difficult and the cycle times can drop.

Laser-based component inspection systems use a laser scanner to create a 3-dimensional image of the PCB. This 3-D image is based on the height of the PCB surface and of the components and is much less sensitive to changes in component color. Laser scanning systems also can provide a 2-dimensional grayscale image, similar to the image from a CCD camera.   This image can be used to identify objects where there is little height contrast, such as for board fiducials or to identify component leads in solder paste. Laser scanning provides very accurate position measurements of the components. These measurements are important to help reduce the number of false calls, and also to provide the information needed for optimal process control. (See the sidebar: "3-D Laser Scanning for Component Placement Inspection" for more details.)

COST SAVINGS

There are several ways that an in-line component placement inspection system can pay for itself. Defects detected immediately after component placement are much less difficult and expensive to repair than the same defects if they are found after solder reflow.

In-line process control is an important aspect of CQI and arguably offers the greatest potential for cost savings. Many of the component inspection systems available offer a variety of built in SPC tools. (See the sidebar: "SPC Tools for Improving Quality in the SMT Process" for more details.) It is important to be able to correctly identify defects on each PCB, but process control capability can help to eliminate the causes of component placement defects and to reduce the number of defects actually produced. Very few defects are created in the reflow oven if the solder paste deposits and component placements are within specification. A study by one manufacturer found that component placement accuracy faults accounted for 73% of their total component faults on 0402 packages. [REF 2] SPC methods can be used to trace problems back directly to their source so preventative action can be taken. Real-time SPC charting can show the positions of components as they are placed to indicate when a system is drifting or the placements are becoming less precise. A consistent shift in one direction may indicate a problem with a motion system or a damaged placement mechanism. SPC tools such as Pareto charts can show the most common types of defects as well as identify the components on which they occur. Several defects occurring with a particular device may indicate a problem with a feeder.

Process characterization is another valuable service provided by component placement inspection systems. Testing the capability of a machine for its intended application is an important part of any new product introduction. Data from a proven, automated system assures that you have both the accuracy and the amount of data required to make valid engineering decisions about equipment and processes. Some manufacturers use their automated inspection systems to verify the correct operation of each placement machine after it has been serviced.

Many of today's SMT boards require high-speed, high-accuracy component placement. In-line component placement inspection systems are needed to identify the defects as they occur and to reduce expensive rework after soldering. In-line inspection tools provide understanding of the placement process and the opportunity to improve SMT manufacturing yields. Detection of solder paste and component placement defects can help eliminate the need for expensive post-reflow inspection systems.

As a final note, regardless of the type of inspection equipment utilized, it is still only a tool. Inspection equipment should not be placed in-line with the expectation that process improvement will then occur automatically and without effort. In order to achieve the highest quality as well as cost savings, a company must commit to the effort, staff, and training that will allow them to utilize their data and build a knowledge base to improve production quality. Placing inspection equipment in-line provides important defect detection capability to eliminate costly scrap and rework. Even more importantly, in-line inspection equipment provides the right data and tools for SPC analysis and hence supports Continuous Quality Improvement for your organization.

SIDEBAR: SPC TOOLS FOR IMPROVING QUALITY IN THE SMT PROCESS

The two SPC tools presented here are the Pareto chart and the X-Bar and R chart. When using control charts to monitor your process it is important to understand that they do not determine whether your *product* is good or bad, but rather whether your *process* is performing consistently or not. Your inspection equipment should be able to both make pass-fail judgements on each board using specification limits, as well as provide SPC tools to help prevent defects because of process variation. SPC charts (and in-line inspection equipment for that matter) should do more than simply indicate that the process is changing, they should also help point to the source of the change. Real-time SPC charts should be flexible enough to allow you to look at individual devices, package types, or package classes such as BGAs or QFPs. X-Bar and R and Pareto charts can be used together to know *when* your process changing. More importantly they can also help you understand *why* your process is changing.

X-Bar and R charts are a means to graphically monitor your process and to determine if it is in control (experiencing only normal random variation within an acceptable range) or out of control (changing due to some external influence). The X-Bar and R chart pictured in figure (1) automatically tests several control rules which are traditionally used to determine when a process is out of control. For example, one of the rules tests whether 9 or more consecutive points have occurred on one side of the process mean, which can indicate a shift is occurring in the process. The chart pictured in figure (1) also tests an important statistic called Process Capability (CpK). Cpk indicates whether your process, given its natural variation, is capable of producing product within your desired specification limits.

When an X-Bar and R chart fails, it may be difficult to understand why the variation in your process is occurring. Your inspection equipment should be supplying measurement data which can help. Pareto charts such as the ones pictured in figures (2) and (3) provide more concrete analysis of inspection data. These charts can provide the information you need in a nicely distilled format. A Pareto chart sorts and counts problem occurrences and presents them graphically to help isolate the most frequent or worst problems. In order to be most useful for SPC analysis, a Pareto chart should allow counting of measurements which fall outside SPC control limits, not just measurements which fall outside your specification limits.

Figures and Captions:

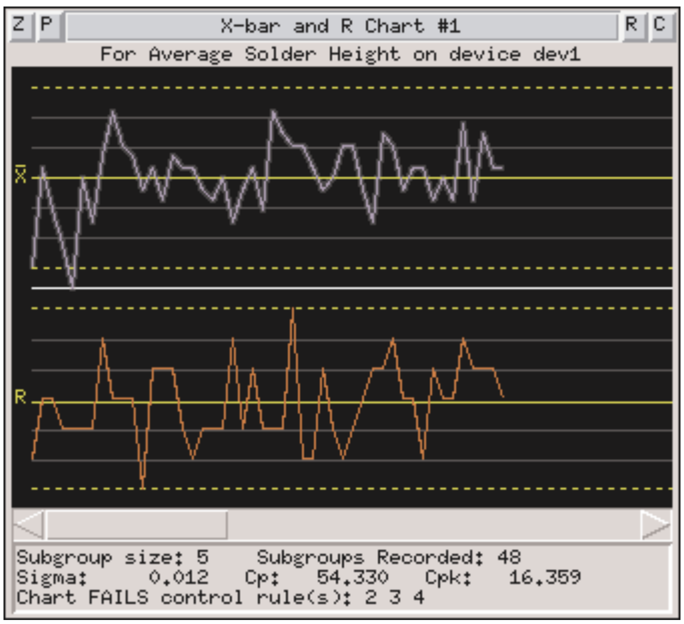


Figure 1. (supplied as attachment xbar screen.tif) shows an X-Bar and R chart used to track the measured height of solder paste deposits on a particular device. This same type of chart can be used to analyze measurements such as X and Y centroid location or Theta which are critical to component placement quality.

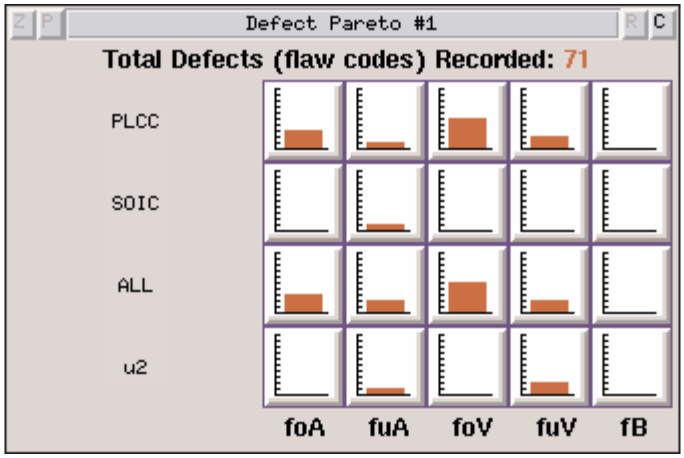
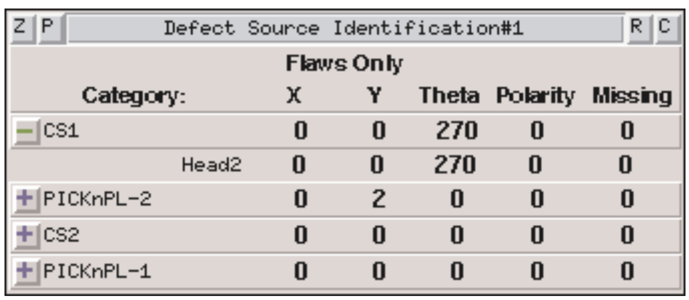


Figure 2. (supplied as attachment pareto screen.tif) analysis chart. This chart allows an operator to click on an individual Pareto bar to reveal details on when the counted items occurred to help correlation with events such as shift changes.



Category:	Flaws Only X	Y	Theta	Polarity	Missing
− CS1	0	0	270	0	0
Head2	0	0	270	0	0
+ PICKnPL-2	0	2	0	0	0
+ CS2	0	0	0	0	0
+ PICKnPL-1	0	0	0	0	0

Figure 3. (supplied as attachment defect source.tif) shows an implementation of a Pareto chart which is particularly suited to component placement inspection before reflow. In addition to providing data about measurement performance, this chart uses cross-reference information to relate measurement data directly back to the performance of the placement equipment.

SIDEBAR: CHOOSE THE RIGHT PLACE FOR IN-LINE INSPECTION

Virtually all of the defects that occur during SMT manufacturing can be traced to poor solder paste screen printing or poor component placement.$_{\text{REF 4}}$ Many people have found that the key to getting the best payback is to do inspection as soon as possible after the potential source of the defect. If the majority of solder joint problems on a PCB are caused by poor solder paste printing, then solder paste inspection can help identify defects as they occur and eliminate rework costs later in the process. If component placement defects such as missing or misplaced components are causing problems, then an in-line system after your component placement machines and before the reflow oven will find these types of defects when they are easy to fix.

In-process inspection and defect detection is the most effective way to provide data which will enable prevention of defects in the SMT assembly process. $_{\text{REF 3}}$ In the case of both solder paste inspection and component placement inspection, having a system in-line finds defects when they are least expensive to repair. Before reflow it is very easy to move components into their correct position, or to add components if any are missing. Rework done after solder paste reflow can require special tools and training, and in some cases there is a danger of damage to the PCB or components. Studies have shown that solder joints formed during rework or "touch-up" are often less reliable than solder joints formed during the original reflow process. In addition, inspection directly after the critical process step shortens the feedback loop and allows engineers and operators to correct any problems sooner. In contrast, post reflow inspection systems at the end of the line or in-circuit test may be used to check final product quality, but any defects found after reflow are difficult and expensive to repair. A component placement error or screen printing problem may create many defective boards before the problem is identified by post reflow inspection. Because there is a time lag between the process step that caused a defect and the detection of the defect, post-reflow inspection is less effective for real-time process control, and isolation of the defect source may also be more difficult.

SIDEBAR: 3-D LASER SCANNING FOR COMPONENT PLACEMENT INSPECTION

Figure 1 is an illustration of a typical in-line system using a laser scanner for component placement inspection. During inspection, the board is held still. The system projects a very low powered laser onto the PCB and measures the position of the reflected beam using position-sensitive detectors. The laser scanner moves over the PCB, collecting height measurements that are used to create each 3-D image.

Figures 2 and 3 are images that were acquired with a laser scanner. Figure 2 is a 3-D image, and figure 3 is a 2-D grayscale representation of the same inspection data. In figure 2, the taller objects appear brighter. The color or reflectivity of the PCB or component has no effect on how it appears in the image. The bodies of components are the brightest objects in the scene because they are the tallest objects. The solder paste and copper pads and traces are less bright, and the PCB material is the darkest of all. The position of components can easily be determined from this 3-D scene.

Captions:

Figure 1: During inspection, a scanning laser system measures a reflected beam to determine the height of a feature. This collected data can be displayed as either 3-D height data or 2-D grayscale data.

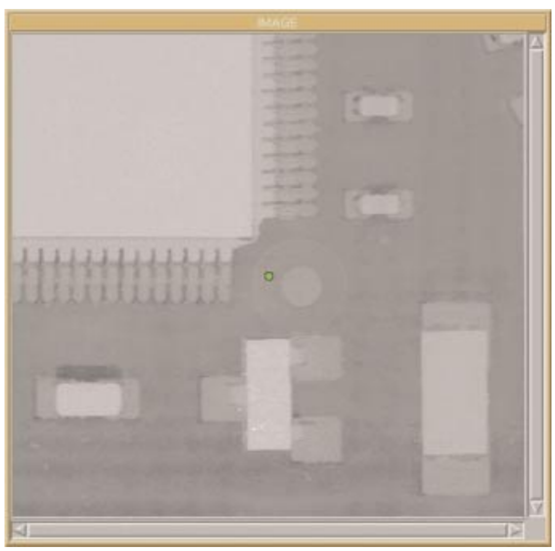


Figure 2: This sample board scene shows features displayed as 3-D height data, where taller features are light and lower features are dark. The use of laser collected height data produces inspection results which do not vary with changes in color or lighting.

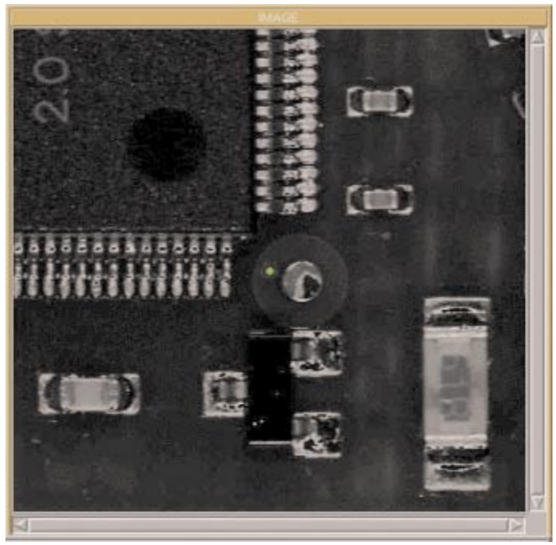


Figure 3: As an operator convenience, the 3-D data shown in figure 2 can also be displayed in 2-D form, which produces a "picture" similar to one obtained by a grayscale camera.

References:

1: Michael Brassard and Diane Ritter, *The Memory Jogger II: A Pocket Guide of Tools for Continuous Improvement and Effective Planning*, Goal/QPC, www.goalqpc.com, ISBN: 1-879364-44-1

2: Jesse Galloway, “Small Component Soldering Process Factors”, *Proceedings of the Technical program: NEPCON West ’99*

3: Ray Prasad, “Step-By-Step SMT: Test/Inspection”, *SMT Magazine*, October 1999.

4: Don Revelino, “Achieving Single Digit DPMO in SMT Processes”, Surface Mount International 1997