Where does AOI fit in PCB manufacturing?

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It has taken almost a decade for automated optical inspection (AOI) systems to establish their place on PCB production lines. In the same period, the number of AOI vendors and the variety of AOI technologies has grown tremendously. Vendors now supply products that range from simple camera systems to complex three-dimensional (3-D) x-ray systems that can fit into almost any automated manufacturing line.

The performance of solder-paste printers and surface-mount technology (SMT) component-placement machines has improved during the last 10 years. Assembly speeds have multiplied, and the accuracy and reliability of production equipment have improved, enabling high-volume manufacturers to achieve higher yields. Component manufacturers have also helped automate the assembly of PCBs by providing more and more components in SMT packages. The automated placement of SMT packages has almost completely removed error-prone manual assembly from manufacturing lines.

The smaller components and higher component densities on today’s PCBs have driven manufacturers to demand AOI on their production lines. No longer can humans perform reliable, consistent inspection of fine-pitch components and maintain an accurate record of observations and measurements. The benefits of automated inspection lie in its repeatable and accurate measurements, which manufacturers can store and distribute electronically.

In many cases, process engineers can observe automated solder-paste printing and assembly processes and adjust them to keep defects at a few parts-per-million (ppm). Typical figures for defects from a high-volume/low-mix production line range from 20 to 150 ppm. It proves difficult to detect every defect and every type of defect by inspecting only a sample of PCBs. Only 100% inspection of all PCBs ensures full defect coverage for statistical process control (SPC).

Tie defects to equipment

For the most part, you can tie specific production defect types—of which only a few exist—to specific pieces of production equipment and, in many cases, to a single production machine. But some variations, such as component offset (due to self-curing effects during reflow), can't be traced to a specific production step. To find the source of all defects, you would have to provide for 100% in-line inspection after each manufacturing step. Naturally, financial constraints preclude inspecting every PCB after every manufacturing step. So, process-control engineers and quality-control managers must decide how to balance the cost of inspecting PCBs against the profits gained from increasing PCB yields.

The uses of AOI fall into two general categories: prevention and detection. In general, you can use AOI at any of four places on a production line (Figure 1). AOI used after paste printing, after chip placement, and after component placement falls into the prevention category. AOI used after reflow
soldering falls into the detection category, because inspections at this point cannot help prevent future defects. Here's how AOI can help at each of the four steps:

**Figure 1.** Four points along a PCB production line provide places to apply AOI to enhance production quality. Few manufacturers will find it economical to use all four inspection stations, though.

1. **Post paste printing.** To a large extent, solder defects originate from faulty paste printing. After applying solder paste to a PCB, you can easily and inexpensively clean (wash) off defective solder paste. Most 2-D inspection systems can monitor printing-screen offset and skew, insufficient paste area, smearing, and bridging. A 3-D system also can measure solder-paste volumes.
2. **Post chip placement.** Inspection at this point can check for missing or offset chips as well as skewed chips and chip-orientation defects. The inspection system also can check solder paste at the pads used to connect fine-pitch and ball-grid array (BGA) components to the PCB.
3. **Post component placement.** After equipment places components on a PCB, an inspection system can check for missing, offset, or skewed components and incorrect polarity of components.
4. **Post reflow solder.** At the end of the production line, an inspection system should check for missing, offset, and skewed components, and for any polarity defects. The system must also check for proper solder joints and for defects such as insufficient solder, solder bridges, and lifted leads.

Engineers and vendors can discuss the pros and cons of different inspection strategies indefinitely, but your main selection criteria should focus on your component and process type, fault spectrum, and product-reliability requirements. If you use many BGA, chip-scale packaging (CSP), or flip-chip components, applying inspection systems at location 1 or 2 makes the most sense. Mission-critical PCBs used in aerospace, medical, and safety products (automobile airbags) may require inspection at many places along the production line, specifically at locations 2 and 4. This class of PCB also might benefit from x-ray inspections. On the other hand, for low-end consumer products, performing an inspection only at location 4 may prove sufficient.

**Inspect or measure?**

As you evaluate an approach to using AOI on a production line, keep in mind the differences between systems that simply inspect and those that measure. Inspection systems simply find defects, such as missing or misplaced components. Inspection systems are fast and inexpensive, but they offer no process-control tools, so you can't use them to enhance your PCB production process.
Process engineers still must adjust production processes manually.

Measurement systems provide accurate data for every component and prove vital for measuring process parameters. These systems tend to be more expensive than inspection systems, but when you integrate them with SPC software, they provide the information needed to improve process performance.

In general, customers mistakenly evaluate inspection systems only on their call accuracy—the ratio of the real errors (real calls) to false errors (false calls). You also must evaluate measurement systems on how precisely they make measurements within narrow tolerances.

**Control production processes**

In the end, you'll want to use the data from AOI systems to help you control production processes so your company can obtain higher yields and higher profits. To achieve effective process control, you need accurate measurement data, reproducible and repeatable measurements, measurements made close to the event in space and time, and real-time processing of measurements and all relevant process information.

By placing an AOI system close to a printing or placement process, you can eliminate other process variables that will accumulate during production. Assume you measure the position offset of components after reflow soldering. The data you gather will not reflect the accuracy of the placement process. Instead, you will have measured the effects of placement and reflow soldering. This information proves next to useless for controlling part placement. When it comes to monitoring trends, placing an AOI system close to the process you must monitor can ensure a fast response so you can correct a variable that tends to move out of bounds. A short distance between a process and an AOI monitoring system also reduces the number of out-of-spec (potential scrap) PCBs produced prior to the inspection step.

Although most AOI users in the electronics industry still focus on post solder inspection, future miniaturization of components and PCBs will call for more effective closed-loop process control. AOI systems that provide flexible measurement and inspection capabilities will be more widely used, and engineers will find the costs of such systems easier to justify. By all accounts, AOI will continue to play a significant role in enhancing production-line performance and increasing yields.