Using AOI in the 01005 Components Assembly Process

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ABSTRACT

There are many quality assurance challenges for printed circuit board assembly using 01005 chip components. The need for post reflow inspection is no longer an optional step in the process. Due to the small geometry human inspection is all but impossible, and AOI inspection is the only way to guarantee high quality output. In this paper we will discuss the challenges faced by AOI equipment manufacturers and YESTech’s design innovations to best facilitate the inspection of 01005 components.

Introduction

The continuing demand for smaller and lighter portable products has been driving the miniaturization of components from 0402 in the early 90s to the 01005-chip component packaging of today. The use of such miniature components presents significant challenges to the SMT (Surface Mount Technology) manufacturing process. SMT equipment manufacturers are scrambling to upgrade their system offerings to handle 01005 components. For AOI equipment manufacturers the 01005 components present opportunities as well as challenges. On one hand the utilization of the 01005 components promote the wide spread if not mandatory use of AOI, and on the other hand, it demands high precision and advanced inspection capability that is needed for assuring quality assemblies.

01005 In Perspective

Let’s try to visualize the size of a 01005 chip. A household ant is about 2 millimeters (78 mils) by 1 millimeter (39 mils). A 0402 is ¼ the size of a household ant. A 01005 chip component measures 0.4 millimeter (10 mils) long and 0.2 millimeter (5 mils) wide, and 0.13 millimeter (3 mils) thick. Sixteen 01005s can fit inside a 0402. Since it is at a size that the naked eye can hardly see, manipulating it with any kind of hand tool is all but impossible. The 01005 is also very expensive. When compared to a 0402 component, a 01005 can cost up to 100 times more. As of 2007, 01005 capacitors can cost as much as 50 cents each.

Figure 1
The price of the 01005 component is expected to decline over time when the volume increases. At its current high price point they are only being used on assemblies that really need the space saving advantage it offers.

**Challenges in the SMT Processes**

Assembling these tiny, expensive resistors and capacitors present many design and assembly challenges. Engineers must pay close attention to board design, component selection, stencil design, solder paste composition, solder paste printing, component placement, reflow and inspection.

Let examine stencil design in more detail, to achieve high transfer efficiency very thin 76 um (3 mils) stencil must be used. This will ensure that the solder paste doesn’t stay in the stencil apertures after printing. However, using such a thin stencil may not provide enough solder for soldering larger components. One solution for this problem is the use of a costly two-stencil, two printer process. To avoid the high cost, the designer may try to find the “happy medium” stencil thinness for all components sizes on the board. Such compromise will unavoidably increase defect rate on the assembly.

**Types of Defects**

Inexperience, equipment limitations and design compromises could all lead to defects on the PCB, amongst the manufacturing defects bridging and tombstones are the most common for 01005 assemblies. Bridging can occur due to overly aggressive pad spacing (less than 150um or 6 mils) or stencil miss alignment. Stencil alignment becomes more critical as the pad geometry shrinks; for 01005 circuits it is absolutely critical to have perfect alignment. Tombstoning is the result of solder surface tension imbalance during the reflow process. Lead free solder that requires a higher temperature to achieve wetting will only increase the chance of having surface tension imbalance and therefore lead to tombstoning.

**AOI Strategy**

Traditionally, AOI can be deployed in three areas of the SMT process, post-paste print, pre-reflow and post-reflow. The rationale of putting AOI early in the process is the belief of early defect detection and repair; the earlier in the process a defect is detected the lower the repair cost. Fixing a solder paste defect is a lot easier and therefore less costly before reflow than after reflow. The problem with this line of thinking is that defects are produced throughout the assembly process, not just in the beginning. Component defects can only be detected after the components are placed, defects such as bridging and tombstone can only be detected after reflow. If the AOI is only
used upstream it will miss many of the defects. Since the majority of the 01005 defects are bridging and tombstoning, post-reflow AOI is essential for assuring product quality.

The AOI placed upstream tends to serve more as a process monitoring tool, the AOI placed post-reflow serves more as a gate keeper to prevent defects from getting to the customers.

For assemblies using 01005 chip components the post-paste print AOI serves mostly as a process monitoring tool because other than scraping a badly printed bare board there is really no effective inline repair mechanism for random paste defect. Any manual manipulation tends to introduce more problem than it can fix. Pre-reflow inspection is a good process monitoring tool for verifying component placement but again it is not feasible to try to repair misplaced 01005 components inline. In addition, like other surface mount devices, 01005s will self-align during reflow. Study shows that the placement of 01005s could be off by as much as 45 um and still be well aligned after reflow. Study also found that 01005s will self-align despite a theta offset as large as 25 degrees. The tendency to self-align and the difficulty and risk of pre-reflow repair render pre-reflow AOI inspection nothing more than a process monitoring tool.

Offline repair and rework equipment for 01005 assemblies are available today. They can repair most types of defects that can occur on a 01005 assembly. However, offline repair is an expensive step.

The best inspection strategy for 01005 assemblies involves the use of multiple AOIs in multiple points of the SMT process to monitor the process and detect defects. Since repair is not always feasible, the upstream AOI needs to be able to pass defect data to the downstream (post-reflow) AOI so that additional verification can be performed on the suspected components. This will increase detection without increasing the false call rate.

## Essential AOI Capacities

There are various characteristics of AOI machines that are essential for 01005 inspection. Let’s look at a few of them in detail.

1. High Magnification

Comparing and evaluating AOI equipment from different vendors can be a confusing process. Some of the specifications that are of interest are analogous to those that are considered when shopping for a handheld digital camera. The imaging sensor type and pixel count (megapixels) as well as the optical and digital magnification (zoom) are important features that can help determine the ultimate capabilities of the system. To accurately inspect a 01005 device it is important that the combined optical and digital magnification is
sufficient to provide the necessary amount of resolution and information to the AOI software inspection algorithms. However, it is important to understand that more is not necessarily better. Higher magnification leads to a smaller field of view (FOV) and therefore longer image acquisition times and more data to process. With the ever increasing cycle times of today’s manufacturing process it is important for an AOI system to be able to balance both magnification and image acquisition speed.

One of the most popular AOI specifications to determine 01005 inspection capabilities is the “pixel size.” The pixel size is determined by the properties of the imaging sensor and the optics of the AOI system. Let’s take for example a typical 1.3 Mega-pixel CMOS sensor with an array size of 1280 x 1024. When fitted with a lens at a focal distance that produces a field of view of 32mm x 25.6mm you would achieve a pixel size of 25um. If you consider that a 01005 chip resistor is 200um x 400um then the projected image of the component would be 8 pixels x 16 pixels in size. This may not be enough information for the inspection algorithms to provide sufficient defect detection. However, by utilizing the same sensor with a lens that provides a field of view of 16mm x 12.8mm, the resulting pixel size of 12.5um would display the component at 16 pixels x 32 pixels. This 4x increase in area may now be enough information for the inspection algorithms to accurately detect the defect conditions.

When selecting an AOI system for 01005 inspection it is important to find the balance between resolution and inspection speed. Some of the leading vendors provide systems with multiple cameras at different magnifications that allow the high magnification necessary for accurate 01005 inspection while keeping a fast cycle time by utilizing the lower magnification camera for other larger components. In this way the system is flexible enough to handle a wide range of product types without any hardware modification.

2. High positional accuracy

As component size gets smaller, the accuracy of equipment in the manufacturing process becomes increasingly critical. If a placement machine is inaccurate, then 01005 component defects will be unavoidable. However, whereas a placement machine is an essential part of the assembly process, the AOI machine is a supplement. Having an inaccurate AOI system would not prevent the product from being assembled, but if it cannot identify positional defects then the inspection data may be useless. As a rule-of-thumb the AOI system should have sub-pixel accuracy. This will ensure the system is accurate enough to detect the small deviations in position that can lead to a 01005 defect.
3. Programmable lighting to highlight defect

In any machine vision application lighting is one of the most important features. Magnification of the object under test is only half of the equation. The second half is whether the defect condition can be identified under the current lighting condition. Trying to find one light source that will enable detection of all defect conditions is nearly impossible, given the ever-changing environment of electronics manufacturing. To ensure the widest defect coverage for today’s component and PCB configurations as well as those to come, it is crucial to have a dynamic light source. With the reduction in cost of light-emitting diodes (LED) AOI equipment manufacturers are able to configure light arrays that are highly customizable within the inspection software. With multiple colors at various angles the AOI programmer has the flexibility to enhance the contrast of the image to easily identify a multitude of defect conditions. Even within the 01005 component family there are many variations of color and surface properties. Combine this with the variations of paste composition, pad size and material, and PCB color and texture and the possibilities are endless. Programmable lighting is an invaluable tool for ensuring the widest range of defect detection.

4. Tele-centric lens\(^1\) to reduce false calls.

For increased accuracy and repeatability and extremely low false call rates, the use of tele-centric optics has become increasingly popular in AOI equipment. Normal lenses exhibit varying magnification for objects at different distances from the lens. This causes

several problems for machine vision and other applications:

- the apparent size of objects changes with distance from the camera
- some features or objects may be hidden by objects that are closer to the lens
- the apparent shape of objects varies with distance from the center of the field of view (FOV). Objects appearing close to the edges are viewed from an angle, while objects near the centre of the FOV are viewed frontally (circles near the centre of the FOV become ellipses when moved towards the periphery).

Tele-centric lenses, on the other hand, have the same magnification at all distances. An object-space tele-centric lens creates images of the same size for objects at any distance and has constant angle of view across the entire field of view. An object that is too close or too far from the lens may still be out of focus, but the resulting blurry image will be the same size as the correctly-focused image would be.

Because their images have constant magnification and geometry, tele-centric lenses are used for metrology applications, when an AOI system must determine the precise size of objects independently from their position within the FOV and even when their distance is affected by some degree of unknown variations.

5. Network capable software to share defect information.

One of the most important functions of an inline AOI system is data collection and retrieval. This data can be in the form of a text output, database, image collection, or combination of several formats. Collecting the data is a basic function of most AOI systems and can be as simple as enabling a checkbox in the software. However, retrieving the information can be a little more complex and depends on the configuration of the manufacturing line.

In a networked environment the AOI can simultaneously inspect a PCB while transmitting results from the previous assembly to a “downstream” review/rework station. The downstream station is then not only communicating with the AOI system but also storing inspection results and review operations into a SPC database. Operators have the ability to review the inspection results real-time or archive the data to be reviewed at a later time.

Repair station, offline programming, and SPC software are common network tools often sold as options by AOI vendors. One new feature that has been recently introduced takes even greater advantage of the network environment of the manufacturing line. By placing multiple AOI systems in a single line, inspection results can be shared to actively effect the inspection and/or review at each stage. This new feature introduces a more dynamic inspection technique to ensure the highest possible defect detection.

Since the 01005 assembly line lacks a feasible inline repair mechanism, the post reflow AOI needs to be able to utilize the inspection data from the upstream AOI (or AOIs) to enhance its defect detect-ability. In other words, they need to be able to
collaborate to achieve the best possible inspection. For example, a defect such as insufficient solder is most effectively detected by the post paste AOI. It is more difficult for the post reflow AOI to detect this defect without generating some false calls. By combing the defect reports from the upstream AOIs, the post-reflow AOI can ensure the defect will not escape detection. In an ideal situation there are three AOI machines on the line. The post paste AOI should be tuned to detect stencil miss-alignment, and insufficient solder, the pre-reflow AOI should be tuned to detect component defects such as missing or polarity, the post reflow AOI should be tuned to detect bridging and tombstone defects. By dividing the tasks and combining results optimal detection can be achieved.