Finding the Voids in Production

by Doug McClure, Nicolet Imaging Systems/SRT

This article takes a step-by-step approach to how to select X-ray systems for production process optimization and failure analysis.

Current manufacturing practices heavily integrate surface-mount manufacturing techniques. With an increasing number of solder connections in devices such as ball grid arrays (BGAs), flip chips, µBGAs and other high-density packages, now more than ever production yields must remain high while maintaining process efficiencies, testability and repair.

Issues such as solder-joint quality and noncoplanarity, which directly affect process yields and product reliability, need to be closely monitored. Real-time X-ray technology has emerged as the most effective, and in many cases, the only method for process analysis and data collection for these high-density packages.

X-Ray Inspection

It now is common to see X-ray technology incorporated into an assembly line. Depending on the inspection rate required, these systems may be found in-line for lot sample or 100% inspection or off-line for process ramp-up, prototyping or rework inspection.

Figure 1 shows the process flow of a typical surface mount technology (SMT) line. This monitoring provides key statistics on the process, quickly providing a warning of any potential problems. X-ray technology not only can identify hidden solder joints but also can pinpoint the area in the manufacturing process that created the defect.

Some of our customers now place X-ray inspection systems at the end of the production line completely replacing in-circuit test (ICT). X-ray inspection detects insufficient solder (a paste dispense operation problem), skewed parts (a placement system error), and voids in the solder reflow (an oven profile problem).

More importantly, as the automated X-ray system collects measurement information on each joint, it provides immediate feedback on the performance of the assembly process. For these chip-scale packages (CSPs), the measurements include:

- Insufficient or excess solder.
- Bridging.
- Opens.
- Voids.
- Skewed placement.
- Missing balls.
- Poor or no reflow.
- Lifted leads.

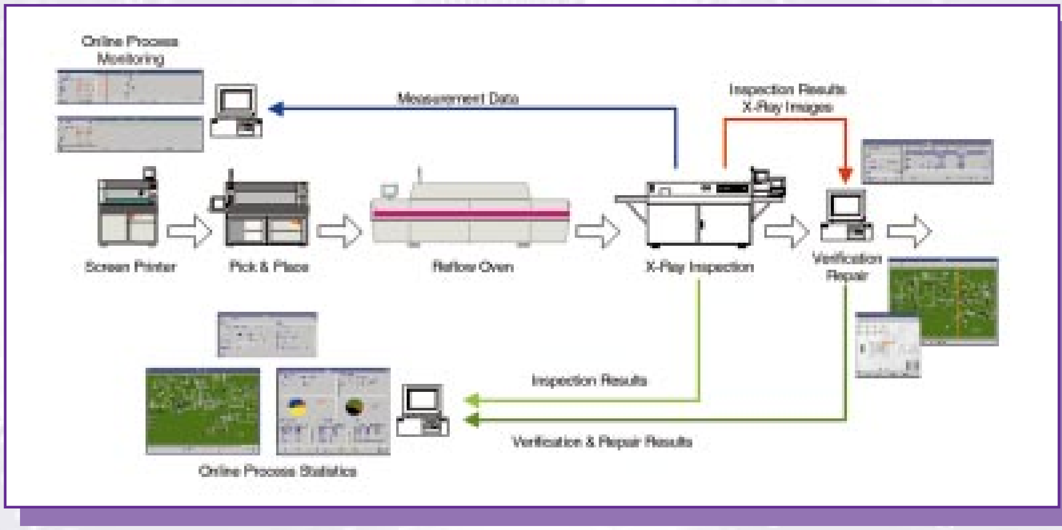

Figure 1. Typical Placement of an X-Ray Inspection System in the Production Flow

X-ray systems make this information available as close to real-time as possible and provide a summary of defect type and location so errors can be quickly corrected. Although more expensive than some ICTs, X-ray inspection systems require little programming, can detect cold solder joints, and do not need test fixtures.

Inspection Criteria

X-ray assessment of solder-joint connections requires knowledge of visual inspection criteria plus an understanding of obscured and internal structural characteristics of solder joints. Through trial and error, our customers have developed the following X-ray inspection criteria as a reference for inspecting component solder connections and understanding voiding and delamination—items not viewable with optical or visual inspection.

BGA Components

Using X-rays to inspect BGA solder joints should start at the center of the BGA. This is most likely to be the last area to reflow and, as a result, the most likely spot to exhibit voiding, nonreflow, solder balls, or component delamination.

All BGA solder joints should be relatively uniform in size and circular in shape. Measurement of the center ball location and four outer row positions will provide a quick reference for confirmation of complete reflow.

The maximum permissible void size should be less than 10% of the minimum joint dimension. In the case of multiple voids, the maximum cumulative area should be less than 10% of the maximum joint dimension. This is only a rule-of-thumb since each manufacturer is customer driven by unique quality and product-reliability requirements.

If the component has been reworked, an X-ray scan of the entire region below the component should be performed to verify that rework has been successfully accomplished.

PLCCs

Inspection of plastic leaded chip carrier (PLCC) solder joints should begin in one corner of the PLCC component, then scan around all four sides. Pay attention to the presence or absence of heel, toe and side fillets on gullwing leads.

The heel fillets should have consistently sized, well-formed castellation regions. The heel fillet is the region subjected to the majority of all mechanical and thermal stresses. Toe fillets will not always be visible due to the lack of wettable area at the lead tip.

As with BGAs, the maximum permissible void size should be less than 10% of the minimum joint dimension. In the case of multiple voids, the maximum cumulative area should be less than 10% of the maximum joint dimension.

Passive Components

X-ray inspection of passive components (chip components such as resistors) should be performed last since they normally will be acceptable if all other component connections are acceptable. Because passive components are comparatively smaller in mass, they are more likely to reflow before other components and less likely to contain voids. However, they may exhibit voiding during second-side reflow operations.

When a chip component has been reflowed successfully, it will have a fillet at the end terminations and side terminations if there is sufficient wettable pad area on the sides of the component end metallization.

The best manufacturing practices include process monitoring, process optimization, quality assessment, and rework of failed products.

Small Active Components

Small active components such as small outline transistors (SOTs) and small outline ICs (SOICs) are less likely to exhibit poor reflow characteristics because of their low mass. For small active and passive components, the maximum permissible void size should be less than 10% of the minimum joint dimension. In the case of multiple voids, the maximum cumulative area should be less than 10% of the maximum joint dimension.

Selecting a System

When selecting an X-ray system to test large CSPs, BGAs, flip chips, µBGAs and other high-density packages, a high-resolution source is required. Tube resolution primarily is determined by spot size, which is measured in microns. The lower the micron number, the higher the resolution.

Most systems have at least an 8-micron X-ray tube, but as the package density increases, higher resolutions are required. Nicolet now offers machines with 1-micron sources.

In addition to the source, the X-ray system should have a high magnification capability to inspect for subtle defects. For example, a 0.05-mil to 0.250-mil field-of-view generally is required to detect opens. Lower magnification is needed for improved throughput and quick detection of bridging, missing balls, excessive solder, and poor reflow.

A manual X-ray system also should have the capability to rotate a sample. This enhances the capability to view and separate solder artifacts in the X-ray image. While most systems offer 360° rotation, our customers have found ±45° board travel to be optimum for both throughput and inspection quality.

Magnification

Whether the X-ray system is manual, semi-automated or fully automated, there always will be trade-offs. A larger field-of-view provides higher throughputs because more joints are inspected simultaneously.

At a magnification of 5x or 10x, the cross-sectional viewing area is about the size of a BGA component. At this level, it is easy to see bridging, missing balls, excessive solder, and poor reflow.

It is at these low magnification levels that most manufacturers of X-ray inspection systems specify the throughput. Yet, to detect voids, misshapen balls, or unreflowed solder, these manufacturers emphasize that higher magnification and board rotation or 3-D imaging must be used. Each of these processes takes time and reduces throughput.

Defect	Algorithm	Measurement
Excess Solder	Diameter	Bump Diameter
Insufficient Solder	Moment	Ball Diameter
Lifted Component	Solder Amount	Joint Circularity
Solder Bridge	Bridge	Percent Void
Off Position	Void	Maximum Void Size
Skew	Skew	Skew Angle

Table 1. AIP Defect Measurements

Intensity

If in-depth failure or process analysis is the objective, you may want to vary the X-ray intensity. Increasing the intensity allows penetration to lower levels and is required to analyze solder balls under chip packages. However, lower X-ray intensity is required to view traces and lead carriers.

Manual and semi-automated systems typically have a dial to select intensity; fully automated systems usually are set for a particular Z-height measurement. Something to remember: As intensity increases, the distance to the focal point decreases.

To maintain throughput, users typically employ a fast overview technique, optimizing both magnification and X-ray intensity to look at sections of the boards for opens and shorts. Only with potential problem areas, such as large components, a dense cluster of large ICs, or uncovered errors, do they increase X-ray intensity and adjust magnification to detect voids, misshapen balls or unreflowed solder.

Process Measurements

The types of measurements, the desired defect detection, and the corrective action to take once errors are found depend on the types of production equipment and processes used. Developing an understanding of how the SMT process works in each company defines the intensity level for the X-ray, the field-of-view, and the measurements that will be taken.

You must decide which measurements are being used to qualify what is a good or a bad solder joint. Trade-offs in throughput, cost of equipment, and repeatability of measurement data are decisions you must make to determine the placement of the X-ray equipment as well as the selection of manual, semi-automated, or fully-automated systems.

Automated inspection processing (AIP) provides fast, accurate area-array solder-joint measurements. With built-in algorithms automated linear and volume measurements, an operator no longer has to guess at a pass or fail condition. **Table 1** shows common measurement techniques and the defects.

Which System Is Best

There are three types of X-ray systems: manual, semi-automated, and automated. Each has advantages and disadvantages.

Manual systems are used off-line and typically have enough manipulator flexibility to handle different-sized assemblies. Performance is mid-range with the emphasis on ease-of-use by production personnel. These systems typically are found in the high-mix contract-manufacturing environment. But manual systems rely on the operator to determine errors.

To reduce human error and increase throughput, some manual systems have incorporated semi-automated positioning and image processors to provide analysis and measurement capabilities. With the capability to quickly feed back data for design verification, failure analysis, and process monitoring, these semi-automated inspection systems are becoming very popular.

Many times, the operator may want to electronically enhance the image or take a measurement. All manual and semi-automated systems include some sort of image enhancement hardware. Since the operator is making the defect decision, these tools greatly aid the human eye and reduce the chance of a false call.

A common technique uses image averaging which provides a smoothing effect to the image, helping to define the edges and aiding in defect detection. In addition, by calibrating the number of pixels for a known distance, the operator can quantify measurements of void areas and diameters of solder bumps and balls.

Automated systems, especially for in-line use, are best suited for low-mix, high-volume production. This more quantitative approach assesses the SMT process capabilities to verify its capabilities for fast and continual process optimization. The systems typically incorporate component or assembly handling duties using a conveyor feed to route defective units to a rework or reject area.

More importantly, the system's image-processing software will make the defect call and not rely on the operator's visual interpretive abilities. With the X-ray images routed to and analyzed by a computer running image-analysis algorithms, the X-ray images can be examined pixel by pixel to determine, locate and log the defective connections.

With the emphasis on the machine processor making the defect call, visual enhancement tools are not needed. The image, having been digitized, now is examined at speeds determined by the CPU and the numbers of processors used. The resulting measurement data, when compared to a set of measurement rules, is used to make the out-of-tolerance call.

Taking it one step further, if the measurement data is accumulated over a period of time, you can determine drifts in the manufacturing process before faults are generated. To be more useful, this information is available at near real-time once an initial inspection routine has been fine-tuned.

A manual system offers more variables in the analytical examination but at the expense of throughput. The automated system provides throughput and repeatability at the expense of the initial setup plus the measurement details that need to be defined.

There also is the expense differential. An automated system will cost more because of the additional mechanical assembly and processing power required to automate manual tasks, such as board handling.

Conclusion

When considering the use of advanced high-density component technologies such as BGAs, a new set of manufacturing considerations comes into play, including X-ray inspection for failure analysis and process optimization and advanced rework systems for thermal control and automation of the rework process. Although X-ray inspection is not suitable for 100% in-line inspection because of the time required to perform testing, it is required to test PCB assemblies with BGA, µBGA, and flip-chip components because:

- Visual inspection has no visual access.
- ICT cannot identify voids or verify solder quality and, without test points, has no or limited physical access to the component.
- Functional test only identifies that a board is defective. It cannot identify the specific location or cause of the failure.

Inspection is just one part of the new production methods for surface-mount assemblies. Automating the rework process now has become economically practical and even necessary. Automated rework stations provide better, faster, and repeatable repairs to damaged boards. From site preparation to the thermal dynamics of the reflow profile, today's automated rework stations are helping to achieve profitable yields.

The best manufacturing practices also include some means of process monitoring, process optimization, quality assessment and rework of failed products. Many companies are realizing the benefits of these practices and combining X-ray inspection with reflow and rework technology to provide cost-saving solutions.

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