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AOI IN AN 01005 WORLD

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ABSTRACT
Since its infancy the SMT industry has been driving toward the use of smaller and smaller components. Each resulting reduction in size leads to new challenges.

The latest development in this saga of miniaturization is, of course, the 01005 package. Progressively smaller and more portable electric devices have now pushed these components from the test lab into active mass production. With 01005 packages, every stage of surface mount assembly is faced with obstacles: from board design to component placement to paste reflow. All of these processes can introduce specific types of defects which are considered virtually impossible to rework due to the small size of the device. AOI has become an essential tool to ensure a superior yield in the assembly of 01005s.

This paper discusses the unique hurdles associated with each of the various processes. It also introduces new tools which are available now to overcome those hurdles and assist in the successful manufacture of devices using these components. These tools address the potential problems from multiple points in the production line: the paste print, component placement, and inspection review processes. Details will be presented about developments that provide recognition of tilted components via the selective implementation of 3D technology, more precise determination of component position by utilizing super-resolution algorithms, and that give quality control personnel the means to better assess the attributes of the resulting product with higher quality reference images.

Key words: 01005, AOI, super-resolution, quality

INTRODUCTION
Over the past ten years, we have seen tremendous changes in our lives with the introduction of a range of various portable devices for consumers such as cellular phones, PDAs, MP3 players and GPS', as well as the integration of more electronics in medical devices like pacemakers and hearing aids. These devices integrate more and more functions into smaller packages to satisfy our increasing demand for performance, comfort, and mobility.

In this environment, the electronics industry had to adapt to develop new PCBs (Printed Circuit Boards) which could be integrated into these products. The race to build smaller and smaller PCBs is long running, demanding the smallest component. The smallest of these, 01005 component packages, are now enabling further dramatic savings of space and weight on the PCBs.

Upon introduction in 2004, 01005 components were predicted to be restricted principally to medical applications where the key driver is size, not cost. Now, on reaching the production stage, their cost has dramatically decreased and they are now widely integrated into many consumer devices. Compared to their closest relative, the 0201 component package, which is 2.25 times bigger, 1005s are currently only 12 times more expensive. This makes them of more interest as their price has dropped eightfold since introduction.

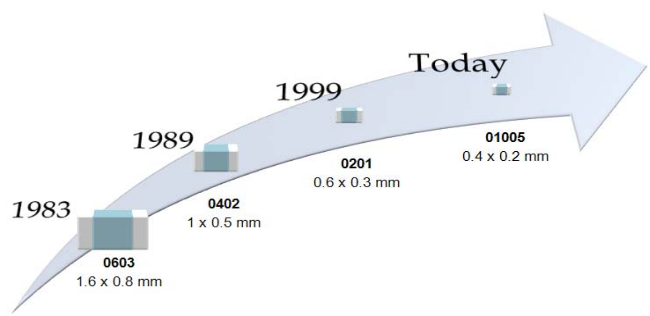

Figure 1. Evolution of Passive Package Size over the Years

Almost invisible to the naked eye (0.2 mm x 0.4 mm) and extremely lightweight (0.004 mg), 01005s represent a real challenge for assembly. Qualified production facilities are capable of manufacturing PCBs with 01005 passive components, but they all face increased difficulties. The assembly process becomes arduous due to their extremely small size making rework nearly impossible.

01005 ASSEMBLY PROCESS CHALLENGES
Since their introduction in the early 2000s, 01005 packages have been the focus of many studies requested by PCB manufacturers to determine appropriate standards and

parameters for the design of the PCB, deposition of the solder paste, necessary qualifications of the P&P (Pick and Place) machines, and reflow process. These components impose new or more stringent demands on every segment of the production line. If these demands are not met, quality will suffer.

PCB Design

The board design is the first parameter to be optimized with the objective of reducing the populated area on the PCB without sacrificing yield. Reducing populated area is a key driver in the implementation of 01005s.

Special attention has to be paid to the pad type, dimensions, and gap as well as the minimum spacing between components. The use of improper pad dimensions or insufficient spacing between components can contribute to solder bridging after reflow. Improper pad dimensions also cause billboard, floating and skewed components, tombstones, and numerous solder joint issues.

PCB Fabrication

01005 production can be particularly demanding on the PCB fabrication process. Copper and solder mask registration must be accurate. Board stretch must be minimized. If attention is not paid to these details, bridging, missing components, and poor component alignment may be present after reflow.

Solder Paste Process

It has been shown that the printing process creates 49% of 01005 defects overall, including the majority of solder bridges and insufficient or excessive solder issues [1]. A multitude of crucial factors interact during this stage requiring particular attention to avoid defect creation.

The foremost of these factors include: stencil type, stencil thickness, the solder paste type and chemistry, the stencil cleaning program, squeegee parameters, and paste replacement scheduling. If mistakes are made in the specification of any one of these or the print process falls out of control for any reason, first-pass yields can plummet. Even worse, poor performance at the print stage may not become apparent until the product is in the hands of the end user.

Due to the complexities of the printing process, its susceptibility to change over time and the minute size of the printed solder brick, the value of controlling and validating the printing process using an automated inspection system can be realized even at this early stage. Solder Paste Inspection (SPI) provides information, leading to solutions that stabilize the printing process and ensure correct solder paste application on the PCB. The SPI machine, alerting the user to potential defects, is an essential process control element for these components.

Component Placement Process

Modern Pick & Place machines generally do a remarkably good job of reliably populating 01005s. Studies have shown that only 6% of 01005 defects are linked to the placement process. However, it is still essential to control package placement conditions.

An efficient pick-up can be obtained only if the package quality and size are under control, tapes are optimal and feeder units have proper fiducials. Poorly adjusted component pickup positions contribute to the risk of billboard and face-down defects.

While some Pick & Place machines have the capability to ensure that components stay on the nozzles all the way through placement, others only verify their presence and position on the nozzle before placement. The danger here is that components may be lost before actual placement. An even less appealing scenario is that a lost 01005 may fall onto the panel and then have another component placed on top of it.

Because of the very small size and light weight of the 01005 package (only 0.004 mg), the placement force also needs to be carefully controlled to avoid component cracking [2].

Figure 2. 01005 Termination Damage due to Excessive Force Applied during Placement

Of course, the small size of the 01005 package necessitates that placement systems be well maintained and very accurate. Even when taking the self-centering reflow effect into account, testing has shown that placing 01005s with an offset larger than 0.050 mm will result in skewed / misaligned component defects after reflow [3].

Figure 3. Skewed 01005 Component due to Inaccurate Placement

The potential placement issues illustrated here, as well as the extreme difficulty in manually inspecting 01005s before the oven, make a strong case for pre-reflow AOI. Not only can the AOI machine verify and control the placement of the component over the pad and solder paste, but it will also analyze trends and prevent the formation of defects. Providing real time SPC analysis, AOI is able to generate proactive alarms and bring the process under control.

Reflow Process

The reflow process comprises approximately 43% of the total 01005 defects observed at the end of the line. The challenge of this process is in establishing and maintaining the best heating profile which can accommodate small and large packages at the same time. Failure to do so is likely to cause tombstone and floating components which make up the majority of the reflow induced defects.

These defects can be easily identified by a post-reflow AOI system which provides a precise analysis of the solder joint as well as that of component presence and final position. As previously mentioned, the self-centering effect often observed during reflow has a beneficial impact on 01005 packages even when lead free solder is used. Unfortunately, it has its limitations and will not eliminate all misalignment errors.

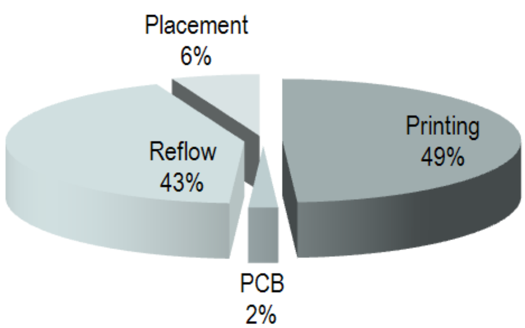

Figure 4. Breakdown of 01005 Defect Root Causes

Rework

Due to their extremely small size, it is unfeasible to consider making adjustments to the positioning of 01005s at the pre-reflow stage of the assembly line. Post-reflow rework is also problematic and very expensive to attempt. Solder tips are too large in comparison to the package being soldered and it is difficult to get a safe mechanical contact to transfer the necessary heat. Any manipulation must be performed under a microscope and involves risks to the pad and/or the other components.

The narrow process windows, the inability to perform manual inspection, and the difficulty and expense of rework necessitate a more tightly controlled process when implementing 01005 production. Only when AOI is in place can these process parameters be optimized. In addition to a final check of the quality of the product, it assures that these myriad of potential issues are never visible to the customer.

AOI STRAGEGY FOR THE 01005 PROCESS

Today, AOI is a mature technology that has proven beneficial to the SMT line. The Return On Investment (ROI) of the systems has been well established and the majority of electronics assemblers have adopted some form of automated inspection system. Bringing real added value to the final product, AOI becomes indispensible in the 01005 assembly process as human inspection is extremely difficult and rework is impractical.

In the past, the conventional thinking was that AOI usage was best optimized by placing the machine at the earliest possible stage of the process. The sooner a defect is detected, the lower the repair costs.

AOI placement options need to be reassessed when considering 01005 production because the repair/rework options have also changed; pre-reflow 01005 touch-up is not possible and post-reflow 01005 rework is extremely troublesome. Preventing, not finding and fixing, the defect as early as possible is the new objective. The locations of the inspection systems in the line may not change, but their purpose does. Post print SPI and pre-reflow AOI are now placed early in order to enable quick, precise process control: controlling the process, not simply inspecting it. However, as 01005s are more sensitive to reflow settings, post-reflow AOI is also needed to realize the best possible line performance in terms of quality and cost. If 43% of 01005 defects are created during reflow, it would be foolhardy not to perform additional inspection afterward.

A Closer Look: SPI, Pre-Reflow And Post-Reflow AOI

As most defects are caused, either directly or indirectly, by paste printing, the need to employ post-print AOI (SPI) is clear. It is important to identify print defects as early in the process as possible, before additional investment is made in the panel. At this stage, any PCBs which are to be populated with 01005s would not be touched up but can be cleaned, the print parameters adjusted, and the panel printed again.

Two different categories of automated paste inspection are available; 2D or 3D inspection.

2D provides useful information about the pad surface coverage as well as the position of the solder paste. 3D adds height, volume, and shape measurement capability, providing more precise data for the 01005 process. 3D speed and accuracy have improved greatly in the last few years; it is becoming the inspection tool of choice.

3D SPI is used for process monitoring purposes in volume production, controlling, for example, stencil cleaning frequency and, in the NPI (New Product Introduction) stage, it can dramatically aid in the optimization of stencil printing parameters.

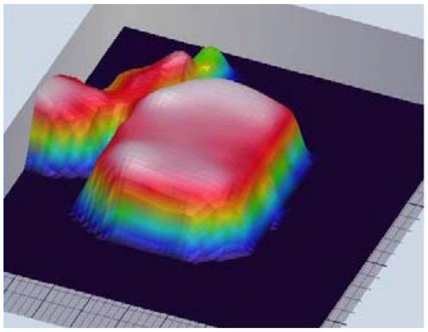

Figure 5. 3D View of an 01005 Paste Deposit with a Bridge Defect

Use of pre-reflow AOI is also important even though, here again, rework is not immediately possible. If 01005 defects are found, the choice is either to clean the panel and start again or to wait to fix the issue post-reflow. In either case, receiving prompt notification of placement faults is a priority so that immediate measures can be taken to find the root cause and prevent future imperfections.

Verification of and reporting on component positioning are two of the chief drivers for the use of pre-reflow AOI. Some studies have demonstrated that 01005 components using small solder powder exhibit a self-alignment effect during the reflow process. Capacitors or resistors that were placed with a deviation of up to 0.045 mm were properly positioned and soldered at the end of the assembly line [4]. Even when this phenomenon is observed, it cannot be assumed to be a constant in the process. For a process to be in control, the placement machine must accurately place the 01005s on their pads.

Thus, pre-reflow AOI plays a fundamental role in accurate placement positioning as it can feed back relevant X, Y, and angular deviation data to the placement machine. Integration of a powerful real time SPC engine in the SPI and AOI systems is a necessity to implement such a process control strategy. This SPC engine has to record accurate placement deviations and analyze trends to predict potential future defects.

Ideally, AOI will automatically generate and report alarms to the placement machine enabling real time interaction and modification of the placement settings. This closed loop between the two machines provides maximum benefit when placing packages with small windows for position error, such as 01005s.

Post-reflow AOI is also essential to verify final product quality in 01005 lines and to ensure that defects created during the reflow process, typically solder joint related, are properly identified. As visual inspection is so difficult, AOI at this stage ensures that these defects will not escape. Some defects, such as floating components or pillows, may be missed at ICT (In Circuit Test) or functional test because electrical continuity can still exist. Optical inspection is the most effective means available to detect these issues.

To address the many difficulties that 01005 production presents, the optimum AOI strategy is to position multiple machines throughout the line: post-print for paste verification and control, pre-reflow as a process and placement monitoring tool, and post-reflow to guarantee final product quality.

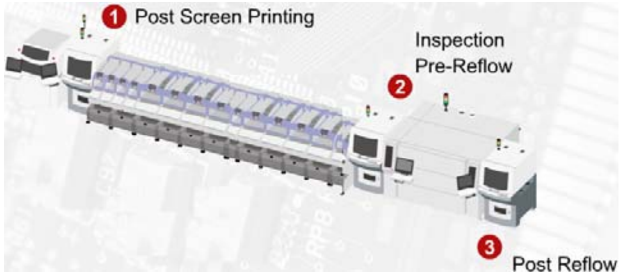

Figure 6. Multiple AOI Strategy for the 01005 Process

01005 repair is difficult, intricate, and expensive. In order to keep production costs low, defect rates must be kept to a minimum by continually analyzing the production process so that it can be improved and optimized. Combining SPC data from the upstream SPI and/or AOI with post-reflow AOI can be useful for identification of relationships between final defects and the earlier processes. The data is also beneficial to improving the process, itself. Therefore, with multiple AOI systems, each equipped with powerful SPC tools, it is possible to trace defects back through the process at a component level. This allows the user to determine which aspect of the process created the defect and where to initiate the corrective action.

As an example, if the post-reflow AOI machine were to detect a shifted component, it would be possible with the use of SPC data from the various machines to conclude that this defect was due to a poor solder print, an inaccurately placed component, or even by some combination of these factors. By quickly identifying the problematic process, corrective action can be taken to bring the process back under control before it adversely affects additional product.

Once defect inducing patterns have been identified, real time SPC alarms can be tuned to be even more effective. This sequence can continue in a cycle of self-perpetuating improvements. This continuous improvement strategy is valid whether 01005s are being placed or not, but the tight process windows and rework challenges associated with 01005 production make it especially valuable.

01005 CHALLENGES FOR AOI

AOI systems have not been immune to the hurdles posed by the extremely small package size of 01005 components. They've had to adapt and advance in order to accurately locate the components and identify any defects. Innovative solutions are being applied to improve existing capabilities and new features have been added to remove previous AOI limitations.

Magnification / Speed

01005 inspection, generally, demands greater resolution from the AOI system. The competitive nature of the electronics assembly market requires reduced costs and high line speeds, necessitating faster AOI machines that will not bottleneck the production line. These two requirements are conflicting and create a dilemma for AOI vendors.

Many vendors are employing state-of-the-art image detectors with a native pixel size near 7 microns. The size of the viewed pixel at PCB level will be determined by the magnification of the chosen objective lens. For a given detector, smaller pixel size yields a reduced FOV (Field Of View) which, in turn, leads to a longer inspection time.

In other words, magnification is usually a trade-off for machine throughput. If pixel size is reduced to enable more accurate inspection of 01005 components, the user can expect decreased machine throughput due to a smaller FOV. Additionally, pixel size reduction decreases the available amount of light to each pixel. This creates shot noise that degrades image quality. Large components do not require the increased pixel resolution so the sacrificed inspection time and image quality are wasted on these.

Various methods have been adopted by AOI manufacturers to remedy this dilemma. Each has some drawbacks.

Some vendors allow the pixel size to be modified / scaled. This approach may require that the pixel size remain constant throughout the inspection process, requiring physical intervention in order to change the pixel size once the machine has come to a halt. This is inelegant and any resolution changes will be global; affecting all components, large and small.

Other vendors have taken this concept a step further. The pixel size can be changed within a single inspection pass. This has an advantage over the previous method as the pixel size can be varied by component size even within the same panel. However, cycle time will be negatively impacted especially when small components such as 01005s are dispersed widely throughout the panel. In addition, this form of pixel scaling often relies upon a mechanical switching system that can degrade system repeatability.

Some manufacturers utilize multiple cameras with varying magnification or pixel sizes. These can be programmed to use a specific resolution for specific components within the same inspection pass. The advantages and drawbacks are as above: the negative impact on inspection time will be reduced, but the degree to which it will be reduced depends upon the distribution of the components on the panel. And, again, switching between multiple optical paths can negatively affect accuracy and repeatability.

Finally, a fourth option is to use a multi-megapixel camera. This can be a single camera maintaining a constant field of view, but allowing selectable resolutions. In high resolution mode all of the pixels can be utilized while low resolution mode uses fewer pixels across the same FOV. Although processing time in low resolution mode will be decreased, this still does not address the root problem: slower inspection due to the high resolutions required by 01005s limits the FOV.

A common trait of all of the systems described is that they increase the cost and complexity of the hardware. This eventually does impact the end-user.

A new approach, based on proven technology, is now available for component inspection that does not involve the introduction of expensive new hardware or increased complexity to either the system or the user. A large FOV can be maintained and the quantity of light obtained by each pixel need not decrease. This new method uses super-resolution technology to combine multiple lower resolution images into a single image of higher resolution. The higher resolution image can then be utilized to better identify the presence, or lack thereof, of an 01005; to more accurately establish the location of that component; and to display a clearer, more user-friendly picture to quality personnel of any potential issues.

Super-resolution is not merely marketing jargon. It is a mathematical term that has been used for 20 years [5]. The first work on the topic was published in 1984 [6]. Super-resolution has previously been applied to satellite imaging, video surveillance, microscopy, medical computed tomographic imaging, and video restoration. Its use in automated component inspection is a new development.

Multiple-frame super-resolution, which provides more benefit in our application than would a single-frame variant, uses a subpixel shift between multiple images of the same field of view. In practice, two images can be mathematically combined to yield a pixel that is one half the length and width (one quarter of the area) of the original images' pixel size.

The concept is simple, though mathematically complex. The initial image is captured and then, after moving the camera and lens a known distance that is some fraction of a pixel, another image is captured of the scene. This provides more information about the subject than would a single image at that same resolution. The two (or more) images can then be interpolated to a high-resolution grid. If the camera gantry were to be moved some whole multiple of a pixel length between captures, no new/novel information would be obtained.

Automated inspection in the electronics industry lends itself quite naturally to super-resolution techniques for two main reasons. First, we have the ability to control the scene. The objective can be held stationary, the preferred lighting or lightings can be duplicated, and any changes to the environment or optical path are so small as to be of no consequence. Second, the ability to accurately control the camera position is integral to the machine design. Locating the imaging system with subpixel precision should be easily achievable for any reputable AOI system.

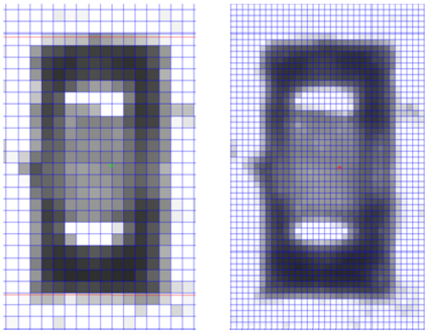

Figure 7. Identical 01005 Capacitor in Standard Resolution and in Super-Resolution (With Associated Pixel Grid for Reference)

The advantages of super-resolution are not just theoretical. Testing bares them out. ANOVA Gauge Repeatability and Reproducibility (GRR) trials on 01005 components show an improvement of 38%, at minimum, over the same tests performed without super-resolution. Some GRR figures have improved by as much as 65%.

The increased resolution that is obtained via the use of super-resolution may be free in monetary terms, but it does, like most all of its alternatives, have some cost in the form of longer inspection times. Because multiple images are combined to create each super-resolution frame, it is necessary to capture more images than would otherwise be required.

However, measures have been employed that minimize the impact which super-resolution has on inspection time when implemented. Faster image capture components (cameras, frame grabbers, etc.) can be utilized, but the biggest and most cost effective measure is the intelligent application of software. By using super-resolution selectively on the components and in the areas of the inspected panel where it is needed, its negative influence on inspection time can be kept to a minimum.

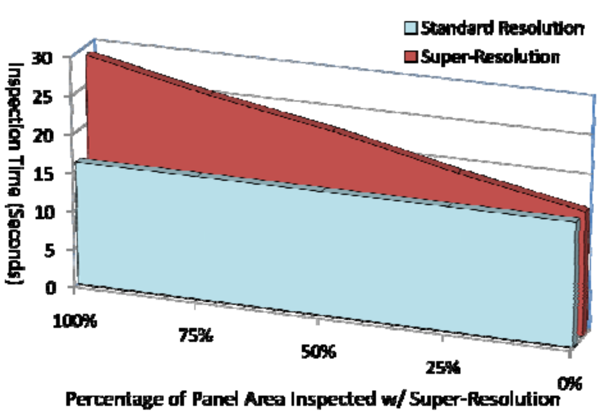

Figure 8. A Comparison of Super-Resolution Versus Standard Resolution Inspection Times on the Same Product

Additional value can be gained from super-resolution by combining it with other technologies that maximize the use of pixel information. Subpixel capability does not increase cycle time substantially, but uses powerful algorithms to determine the location of lines, edges, and points to less than pixel accuracy. These techniques can be applied to more exactly determine the position of components as well as to inspect solder joints more precisely.

When searching for an edge or area of contrast, the subpixel algorithm will examine the gray levels of adjacent pixels and interpolate the actual location of the edge to a fraction of a pixel. Due to the minimal impact subpixel calculations have on inspection times, they can be applied to all components across the panel without fear of making the AOI system the bottleneck in the production line.

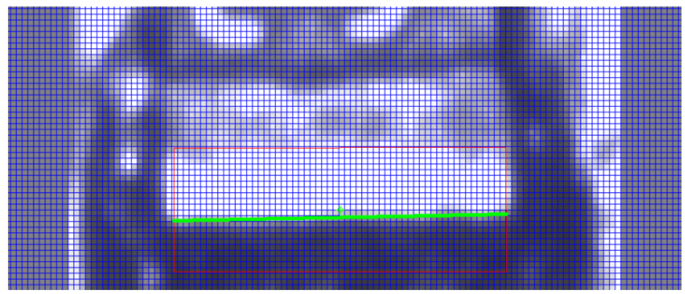

Figure 9. The Edge of a Resistor Defined with Subpixel Precision at Super-Resolution

By simultaneously employing super-resolution and subpixel technology, a machine with an optical pixel size of 26 microns at board level can inspect with an accuracy approximating that of a camera with a 3 or 4 micron pixel size. Both the machine and the repair station operator benefit from the higher resolution working image. And, this level of precision can be reached without reducing FOV, introducing costly new hardware, diminishing the light quantity available to the sensor, or inducing crippling inspection times.

Accuracy

The accuracy of AOI systems certainly becomes more critical when inspecting 01005 packages. To minimize false calls and correctly flag defects, the AOI machine must be able to precisely determine component positions. Additionally, in order to be capable of checking solder joint validity, the system must have the ability to realign the solder joint inspection window in concert with the actual component location.

Linear motors with high resolution optical encoders provide the accuracy necessary to move the center of the camera's FOC to a precise location then measure component position deviation. The axes themselves must be mounted within a stable framework to ensure consistent performance.

Even when the FOV center is positioned in the proper location, poor quality optics can create a discrepancy between the image observed at the camera and the physical object. As 01005 packages have highlighted the need for AOI accuracy combined with a substantial FOV, most vendors have moved toward the use of low distortion lenses.

However, it is important to understand that the quality of commercially available telecentric lenses is not high enough for 01005 inspection. Telecentricity is an essential property in metrology to determine the precise size of objects independently of their position within the FOV, even when their distance from the camera is affected by some unknown variable, such as PCB warpage or dilatation.

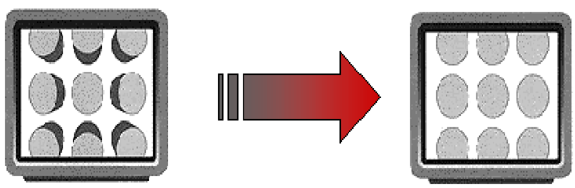

Figure 10. Telecentric Lenses Eliminate Perspective Distortion

If we take as an example a system with a 60 mm x 45 mm FOV and 2% telecentric distortion, which is typical of a good photographic-quality optic, the error in positioning can be as much as 0.74 mm. With 01005s having a width of only 0.2 mm, it is immediately apparent that this is unacceptable. Customized, state-of-the-art lens are available that offer less than 0.05% distortion. This would equate to a maximum position error of 0.014 mm. Lenses such as these are obviously more expensive than a mass-produced alternative, but they are absolutely necessary when inspecting such small components.

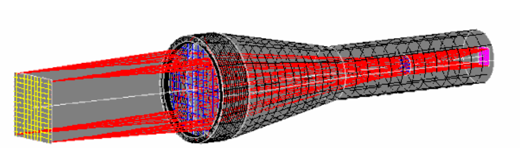

Figure 11. Example of a High Quality Customized Telecentric Lens

The accuracy that can be obtained with the use of a high-quality axis system and telecentric lens become even more critical once advanced software solutions such as those presented above are utilized. Super-resolution algorithms are based on the premise that multiple images are available with known subpixel offsets from one another. The accuracy with which the initial images are obtained is the key to the ability to produce sharp super-resolution images. If lens distortion or axes positioning error is present, these unknowns must be accounted for when performing super-resolution computations and the result will be a less than optimal super-resolution result.

Super-resolution algorithms exist that can make use of estimated motion and approximated initial image positions, but these would require additional low resolution images to create the same caliber of super-resolution image which can be created with just a pair of accurate captures from a well established location. Obtaining those additional images is not encouraged as it unnecessarily prolongs inspection time. The quality of the initial, lower resolution images used for super-resolution is the most important factor; more so, even, than the number of images acquired [7].

Additional Capability

One previously mentioned dilemma regarding component placement is the long-standing issue of dropped parts. AOI systems typically are programmed to determine the presence (or absence) of components in pre-defined locations on the panel. If the Pick and Place machine drops a component in an area of the board which is not inspected, the error is unlikely to be flagged by the inspection system. This issue is particularly dire when 01005s are introduced due to both the inherent difficulty in reliably placing so small an object and to the low probability that the dropped component will be noticed by a machine operator or quality assurance personnel.

By combining elements of 3D inspection with traditional 2D component inspection hardware, the most problematic dropped component situation, small passive packages lodged beneath larger devices, can be alleviated. It is now possible for an AOI system to check the tilt angle, maximum, and minimum heights of QFPs, BGAs, PLCCs, etc.

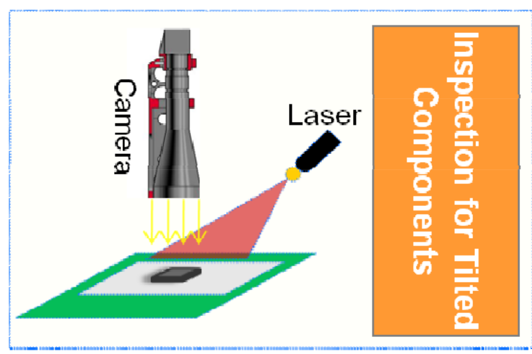

Figure 12. Relationship of Hardware for Tilted Component Inspection

The methodology employed is very similar to that long used in some 3D SPI systems: laser triangulation. During the AOI machine's normal inspection routine, an angled laser projects a calibrated pattern of lines across the FOV as shown in figure 13. While capturing images of the inspected components at normal light levels, the camera system also records one image of the laser lines from directly above. Software algorithms then analyze the laser line spacing, angles, and deviation in order to calculate two planes: one for the component and one for the panel around that component. From these two planes, component tilt as well as minimum and maximum component heights can be obtained. If the package height is greater than specified or tilt is beyond a set tolerance then that location will be flagged as it is likely that another component is trapped beneath the inspected device. These calculations are performed and results are available for each component that is programmed to use this three dimensional algorithm.

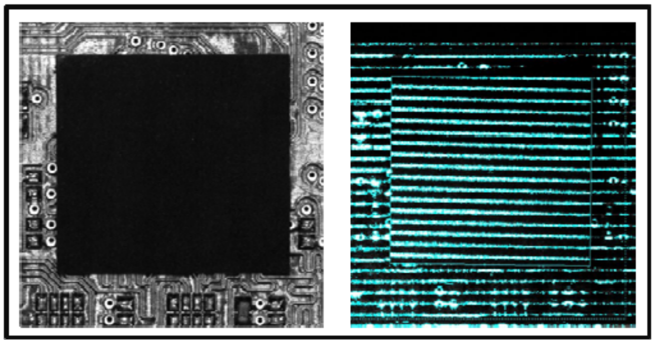

Figure 13. A Typical 2D Image of a Tilted BGA; the Same BGA During Application of Laser Triangulation

While this new capability may not be able to locate every dropped component, it can detect even 01005s if they alter the position of the inspected device. The hardware necessary to implement this 3D laser inspection is not expensive and the increase in cycle time is minimized as no additional head or axes movement is necessary. This technology can be used in both a pre-reflow AOI and post-reflow AOI environment, but, in order to minimize rework and scrap, pre-reflow inspection is the most logical choice.

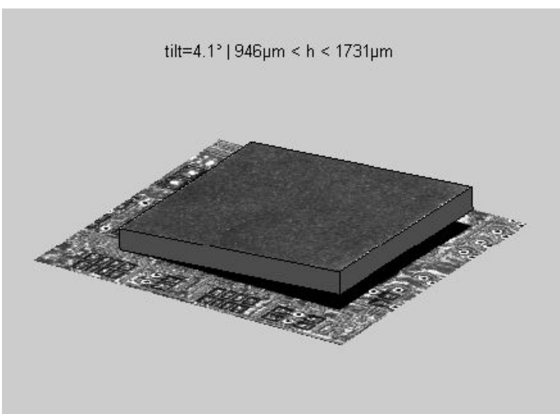

Figure 14. 3D View of BGA with an 01005 Beneath it as Computed with 3D Laser Triangulation Techniques

CONCLUSION

The use of 01005 components in the production environment is steadily increasing. All aspects of the assembly process must be optimized in order to achieve good results for these tiny packages: from board design, to component placement, through the reflow process.

AOI systems are also challenged by the use of 01005s, but the technology is equipped to deal with these challenges and fully capable of providing the customer with accurate component locations and reliable defect detection.

As manual inspection and rework are not practical choices, AOI is no longer an option in 01005 SMT lines; it becomes absolutely essential. The ideal scenario is to implement AOI at or following each of the critical stages of the SMT line: post-print and pre-reflow as process control tools and post-reflow for quality assurance.

In order to provide value to the user, an AOI system must be of the highest capability and equipped with powerful solutions to achieve the required resolution accuracy and inspection throughput, as well as having the capability to return reliable and relevant data to control and improve the 01005 process.

Innovative solutions must be considered and applied to overcome the existing limitations of automated inspection. Integrating select elements of 3D technology into a 2D system provides additional value and capability without breaking the bank or imposing unreasonable inspection times.

While new hardware such as image sensors with more pixels, faster cameras, CPUs, and frame-grabbers will continue to be developed and incorporated, maximizing current hardware is vital to meeting today's industry needs at a price the customer is willing to accept. Software solutions like super-resolution and subpixel analysis are cost-effective, yet provide the means to ensure that the demands of the strict 01005 process window are being met.

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