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Solder Paste Printing Inspection – An Inside Look

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Industry cost control pressures and technology drivers demand more powerful 3D AOI machines for control of solder paste printing. Here is an inside look at the factors potential purchasers of these systems should take into consideration.

The Process

As the surface mount assembly technology continues to evolve, it becomes increasingly clear that real in-line automated inspection is essential to ensuring reliable and cost-effective production. Driven by shrinking component size, reduced lead pitch, BGA density, shortened tact-times and ever-growing board complexity, traditional use of human inspection can no longer sustain world-class production performance.

In addition, tough competition in the EMS segment intensified by significant restructuring of operations during the recent economic downturn and the resultant need to lower cost-per-board, propel the industry toward higher yields and lower scrap and repair costs. This necessitates that inspection be an integrated part of the process from its earliest stages.

Indeed, the use of early stage inspection is becoming an industry standard. As the use of BGA components becomes prevalent and density increases, inspection after the solder process leaves too many joints hidden from view. Problems in BGA components are undetectable on a standard post-reflow inspection system and x-rays are complicated, slow and costly. Repair costs increase dramatically after the assembly process is complete and closed loop feedback for process control is less effective. Board repair is not always possible and entire boards may end up on the scrap heap.

Estimates link from 60 to 80 percent of end-of-the-line defects to problems in the printing process. Experts consider solder volume to be the best predictor of finished board quality.[1]

Some of the problems in the later stage of the process can be reduced by improving the printing process. A good printing process can prevent small shifts and twists of components from becoming defects.

For all of these reasons, more and more companies are seeking optimal options for inspecting SMT boards from the very start of the line, especially for BGAs and fine pitch components.

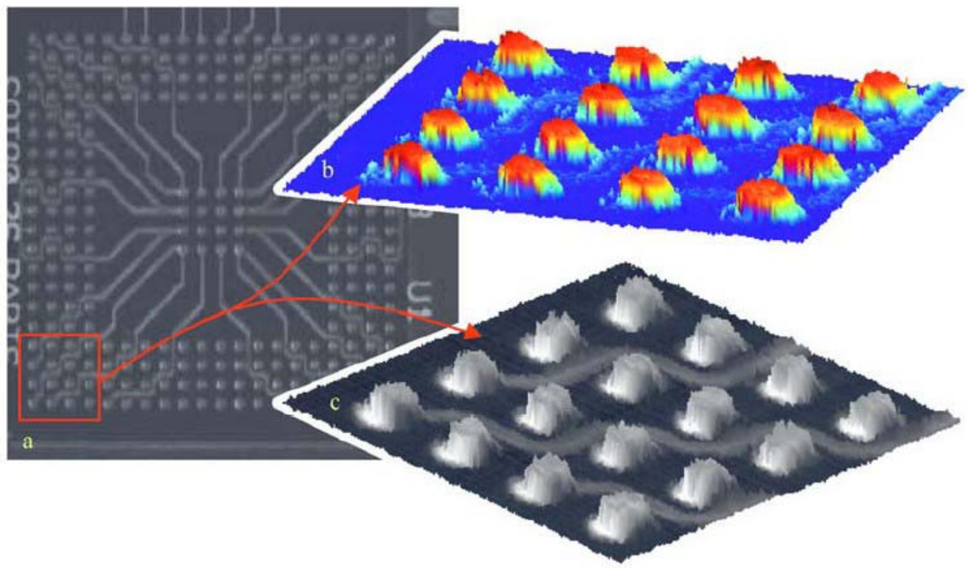
The printing process is dynamic and, therefore, sensitive and defect-prone due to a variety of factors including: cleaning of and, wear and tear on the mask, aging of the solder paste, sensitivity to environmental conditions and handling and frequent refilling of the paste. Problems in the printing phase will typically affect areas and components all over the board. Detecting such problems just after printing helps reduce reworking and “bone pile” costs.

How Should Paste Printing Be Inspected?

Simpler applications with relatively large pads and components can be adequately managed with standard 2D inspection. Such processes are more stable; small changes in solder height are of little significance. However, in applications that involve small components like 0402, 0201, CSP and fine pitch components (0.4mm), 3D inspection is essential. The dimensions of each solder deposit are of the same magnitude in all directions. Therefore, the height of the deposit (a result of the stencil thickness) is about the same as its width and length., As a result, small changes in the height of the deposit are as important as small changes in is area, and might reduce solder quality.

Moreover, when components have a large number of pins (IC or BGA), it is important to verify that the height variation between the deposits of each of the components is small enough to ensure that all joints will be soldered properly. If one of the component legs or balls is not touching its deposit, an opening might occur or the joint might lose reliability over time.

The 3D inspection should cover the entire board, not just the intended locations of solder, in order to detect solder inadvertently deposited outside the designated printing area, also known as “unexpected paste”. Unexpected paste can result in solder balls that might cause severe and unpredictable damage. (See Figure 1.)



The image in the back (a) is 2D image of a BGA.
The color image (b) shows pads in the BGA corner in 3D. Colors represent the height (blue – low, red – high)
The b/w 3D (c) picture shows the same place from a difference angle. The gray levels are Taken from the top image. Bright reflective pads can be detected at the base of each deposit.

Figure 1 – BGA: 3D Image

The challenge

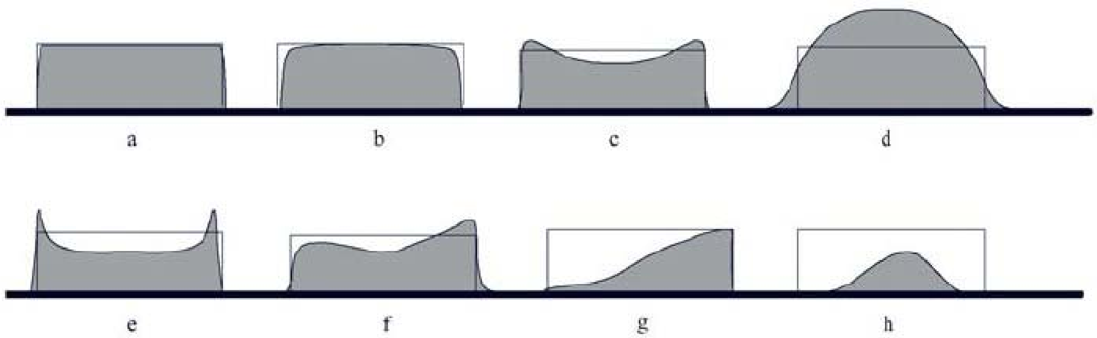
Now that we have established the need to inspect the printing process and to do so in a way that takes heights into account, we come to the next important issue: how to ensure that the inspection is effective.
To do so, we have to meet several challenges:

- **Accuracy**
  Inspection must provide very accurate measurements of paste deposit volume, area, shape and location relative to the plane of the contact pads.
- **Closed loop process control**
  The measurements should be accurate enough, not just for defect detection or gate keeping, but for real process control. The data should enable closing the system-printer loop and data exchange between the system and later stages of inspection.
- **Speed**
  The inspection should not affect line speed. Full inspection must be performed no matter what the tact time of each board. The machine should be able to perform 100% inspection of the whole board even at the fastest line speeds.
- **Boards**
  The system should be able to cope with a range of boards despite differences in color, thickness and type of pads and solder paste. It is also vital that the machine handle the entire range of board warpages.
- **Simplicity**
  The machine should be simple to use and simple to program. It should require neither long setup time nor highly=trained operators.

Each of these aspects can impact tremendously on the quality, usability and benefits gained by introducing such a system into the production line.

Height, Volume and the Concept of 3D Inspection

Since deposits are not necessarily uniform on top, attempts to extrapolate the volume of a deposit from just a few samplings, do not necessarily yield accurate results. For some typical deposit profiles, see Figure 2.



a. Good
b. Good
c. Good, result of soft squeegee.
d. Bad. might be result of snap-off, PCB support or printing pressure problem.
e. Borderline ,'dog-ears'. possible problem in lifting the mask from the board, paste rheology
f. Borderline . result of non-balanced squeegee.
g. Bad. typically result of operating the squeegee to fast or lack of paste.
h. Bad. clogged stencil

Figure 2 – Typical Deposit Profiles

This method becomes increasingly problematic as the number and distribution of measurements per deposit decrease. An alternative approach is to measure many points per deposit in the required tact time, but to inspect only a small number of deposits - only critical points or only a small sample– and hope to gather enough information to predict printing problems.

For today’s complex PCB assemblies, these solutions are simply not good enough. To derive maximum benefit from paste printing inspection, manufacturers need to inspect the entire board using accurate 3D volumetric measurement.

3D By Triangulation

There are several techniques that can be used for acquiring height measurements for 3D mapping. Among them are Moiré interferometers, phase shift interferometers, triangulation, time of flight, focusing and confocal methods. The most commonly used and suitable technique for height measurement of solder paste printing is triangulation. With a simple adaptation, this method can measure a large number of points simultaneously.

The basic triangulation method is demonstrated in Figure 3a. Two lines can intersect at only one point. One of the lines is a projection of a laser dot. The second line is the line between the camera and reflection point at the angle the optics define. This method requires a single line camera and yields a single measurement point.

The same technique is employed to measure a line of points simultaneously. Rather than projecting a single dot, the laser projects a line or “laser screen”. The intersection between the laser screen and its reflection on the camera results in a line of height measurements (see Figure 3b.).

The angle between the two lines is important for the accuracy of the measurement. When the laser is projected from the top, each pixel has a predefined X-Y location. Thus, the pixels are spread evenly throughout the resulting image. When the laser is projected on an angle, only the Y of the pixel is known in advance. Since triangulation deals with both the X and the Z of the target, the pixels recorded by this method are not regularly spaced. As a result, difficulties might arise in calculating volume accurately. See Figure 4.

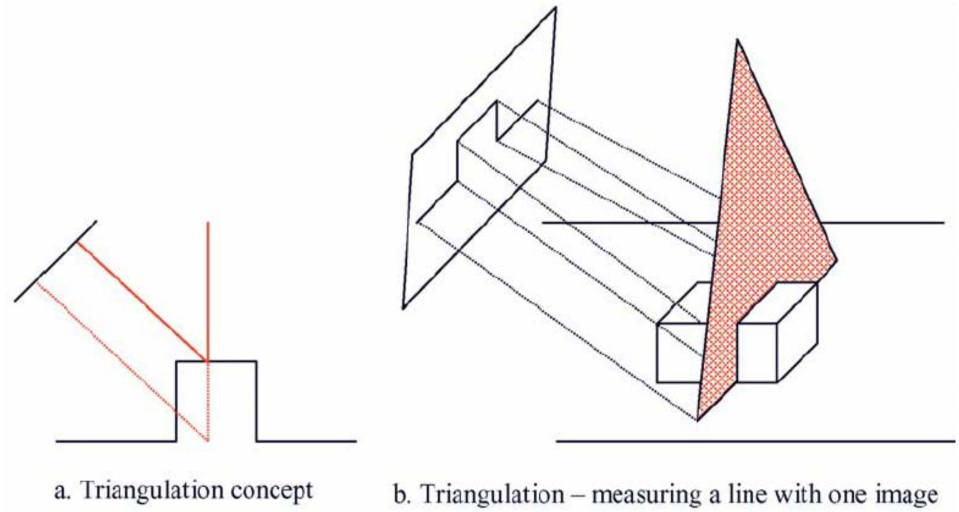


Figure 3 – Triangulation of a Point and of a Line

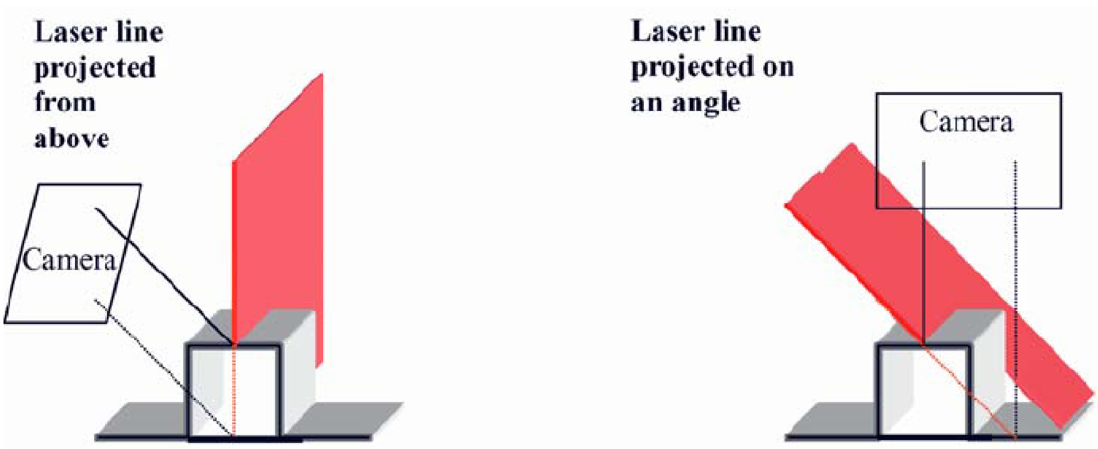


Figure 4 – Different Laser Line Projection

Note: Note the difference between triangulation when the laser line is projected from the top, to triangulation when the laser line is projected in an angle. The dotted line represents the laser line and the reflection line, assuming there were no deposits in the laser's path. Note that, in the case of the angled laser line, the x location of the measurement changes as a function of the measured height.

Changes in the laser spot present another problem with projecting the laser at an angle to the target. This spot (or line) will vary in width and can lose symmetry, which makes it difficult to find its exact center. The advantage of projecting the laser on an angle is the simplicity of the optical configuration scheme needed to achieve the same resolution. This is why this configuration has been chosen by many of today's inspection system manufacturers.

Nonetheless, to achieve better accuracy and reliability of the data, placing the laser directly above the target is clearly the superior method.

Is Height Mapping Enough? Adding a True 2D Channel

Does knowing the height of each point on the board enable a real understanding of the printing results? Not really. It is not possible to be certain that the printing is good enough without distinguishing between the paste and the rest of the board, and measuring paste height relative to the height of the pads.

Conductors, pads, silk screens, etc. are not necessarily of uniform height and smears of paste can be very thin. Therefore, knowing the height of each point is not enough to clearly identify the paste. Only knowing the height (from a 3D image) and having a gray-level (a 2D image) of each point on the board enables the detection of true defects (Figure 5). The 2D image is also essential for finding fiducial marks.

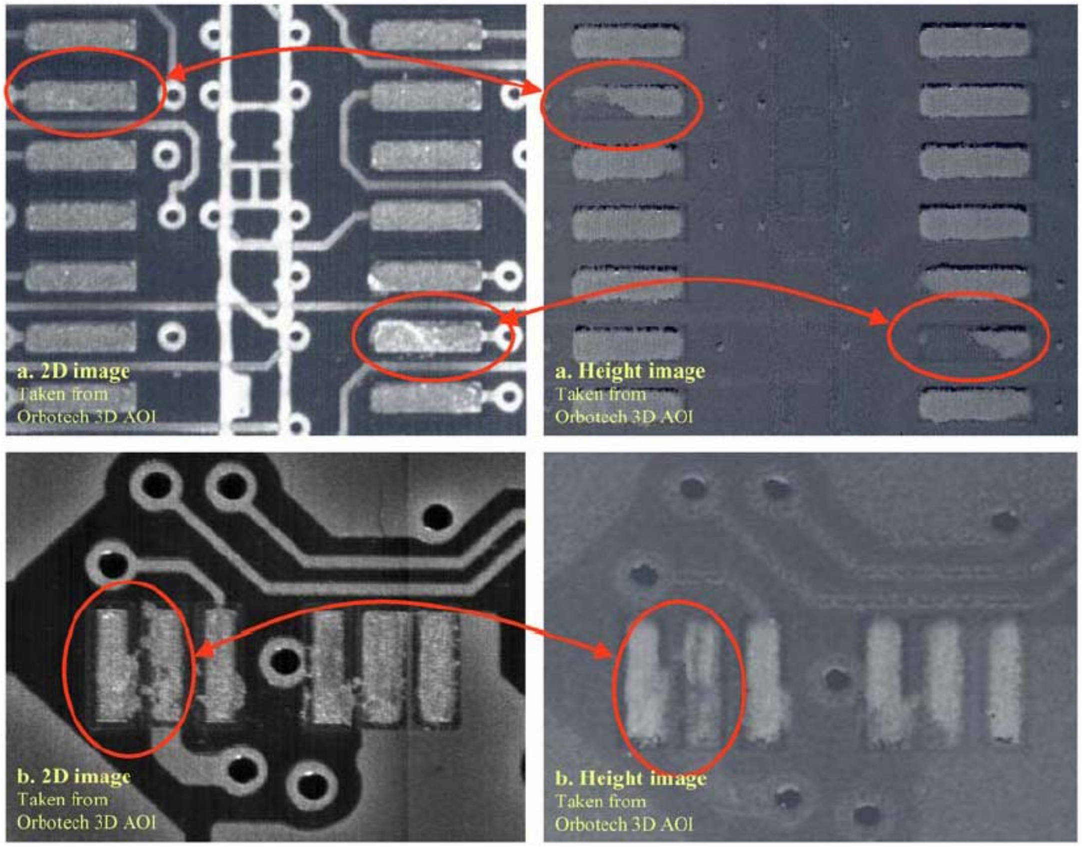


Figure 5 – Insufficient Solder Deposits Visible only on a Height Map Image (a) and a Short Verified only by a Gray-Level Image taken from Above (b)

One simple option would be to use the laser illumination reflected in the triangulation process to create a gray-level image. Unfortunately, this would result in a poor-quality image due to the limitations of such lighting. Also, problems like shadows or poor reflection will appear at the same points in both the 2D and height mapping images. To improve image quality, another channel must be added so that the 2D image uses a different optical path and a different light source than the height mapping image.

The addition of this optical channel also creates the option of making the illumination scheme adjustable to different board types, for example, one configuration for boards with tin air-leveled coating on the pads and, another, for board with golden pads. See Figure 6.

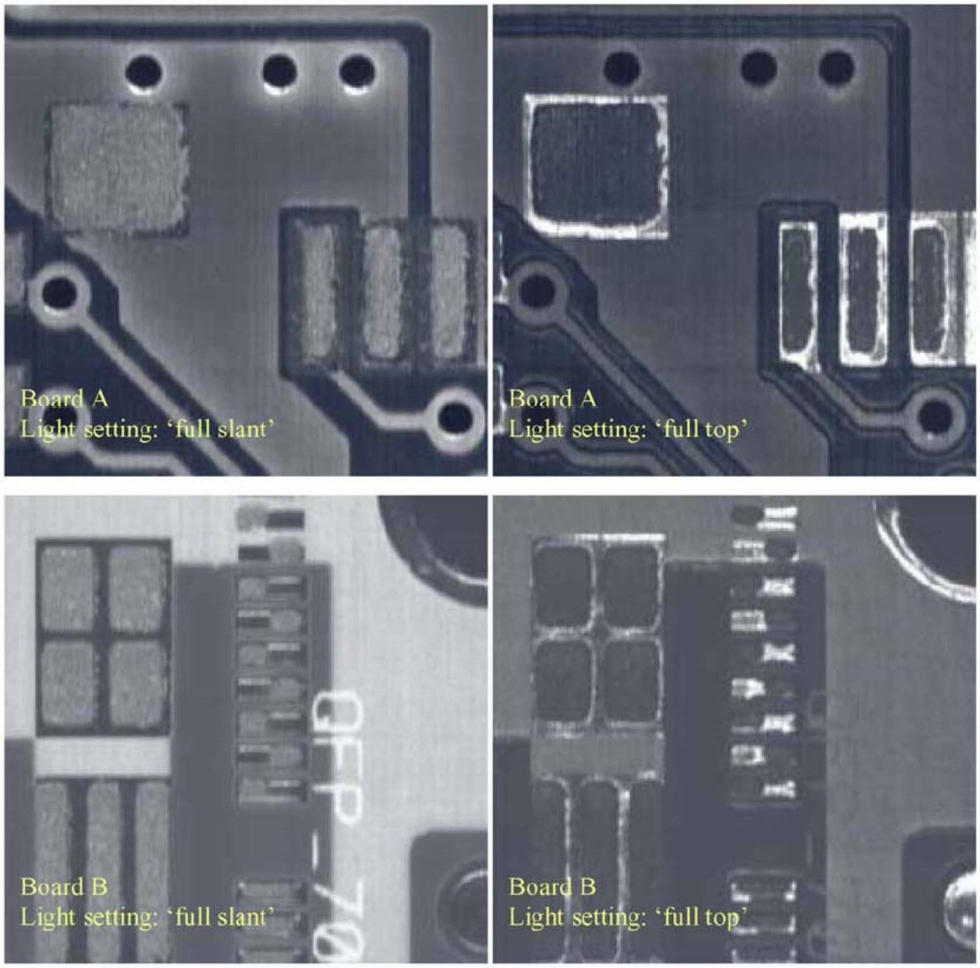


Figure 6 – Two Different boards, each need a Different Type of Light Setting for the 2D Setting

Note: Board A has dark green solder mask and air-leveled pads coating. Viewed better in "top mode"
Board B has red solder mask and flat tin pads. Viewed better in "slant mode"

To maximize the ability to distinguish between pads and paste, illumination should adapt itself automatically in the learning phase for each board type.

Accurate 2D information, as an adjunct to height mapping, can help the system significantly reduce false calls. For example, it can detect that an area identified as "too high" is not really paste, but noise generated from reflective surfaces, very bright silkscreen or holes. It can find thin smears that extend beyond the designated pad area and threaten other pads. It can help identify elements, such as testing points and fiducial marks that are the same height as the pads. Once they are identified, they can be found in the height mapping image to accurately determine paste volume. See Figure 7. It is, therefore, clearly worthwhile to invest in illumination that uses both the top and 3D image to ensure a clear and obvious separation between the key features on the board.

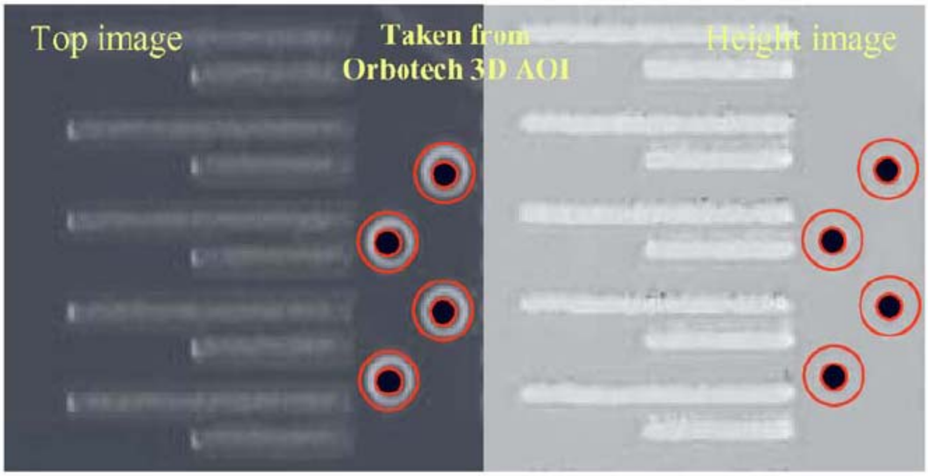


Figure 7 – Detecting Elements of the Same Height as the Covered pads (in this case, vias) Helps in Setting the Reference for Paste Measurement

Measurement Accuracy and Process Control
Paste printing inspection systems should not merely detect defects, but also help the user improve the overall paste printing process. They should help detect trends that might lead to defective boards and allow the user to correct the process before significant damage is done. They should also accurately measure paste deposit on the board to help calculate registration transformation between the board and the printing mask, a problem that, unchecked, can result in massive across-the-board defects.

Accurate area measurements aid in preventing defects, for instance, by detecting clogging of the mask before defects begin to form. This also enables the improvement of mask washing policies, thus, minimizing both the number of washes and the occurrence of defects.

Precise measurement of height and volume are also important for detecting problems in squeegee speed and pressure, inadequate paste application or paste aging, all of which typically result in uneven paste surfaces. Problems in the separation between the mask and the board should also be detectable by very precise measurement of height profile.

Inspection and measurement systems are usually tested for Gage R&R. It is important that Gage R&R be determined for position area coverage, for volume and for height measurement and that it be less than 10% of the process width on typical components and process tolerances. However, measuring GR&R is not enough; system accuracy on the production line is at least as important.

Warped boards
Another aspect to take into consideration is the shape of the boards. Many of the boards that go through the paste printing process are not flat. Some have small curvatures, while others, mainly boards that already have components on the bottom, and have already undergone a soldering phase, may have quite large variations in height. The IPC standard (IPC-A-610c for SMD boards) requires that boards curve no more than 0.75% of their diagonals. That may not seem like much, but keep in mind that this can be as much as 8mm in large boards. Besides, it is not unheard of to find, in some applications, boards that curve more than 0.75%.

This can pose a big problem for 3D systems. Measuring a 10mm range using a system designed to measure in microns is unreasonable. The system must adjust its measuring range as per the inspection area. This means that either the measuring device (i.e. optical head) must be lowered or the boards must be raised. The necessity to change heights becomes less frequent as the measuring range of the system increases.

The machine should be “smart” enough to find the paste height relative to the pad height in its vicinity to enable correct and accurate measurement of the deposit volume where the board curves.

Speed
Time is an important issue in solder paste printing inspection: Setup time, scanning time, tact time and uptime of the machine.

Setup for new boards, a central issue in high-mix lines, should be simple and straightforward. Setup should be based on standard input files: Gerber, CAD and, eventually, CAM. Setup of a new board should not take more than an hour; changing to an old setup, no more than a few minutes. In addition, setup files should be portable between paste inspection systems ('copy exact').

Scanning speed is an important parameter. Solder paste print inspection systems should be used inline where they can have maximal impact on yield and profit. Therefore, they must be able to keep pace with the production line. If several printers serve one assembly line, inspection can be performed after printer. However, using a single inspection system that can keep up with the paste printers and the chip-shooter is a much more efficient use of resources.

Forward-looking manufacturers looking for new inspection systems should consider, not only the line's current speed, but also the maximal capacity of the line and the effects of potential future improvements. See Table 1.

Table 1 - Near-Future High-End Inspection Times and Scanning Speed for Typical Applications

Typical applications	Cellular	Notebook	Servers
High-end line tact time	10 sec	22 sec	47 sec
Expected time for a fast load/unload	1 sec	2 sec	2 sec
Board size (mm)	120 x 200	300 x 250	400 x 450
Board size (inches) Minimal required	4.7 x 7.9	11.8 x 9.8	15.7 x 17.7
scanning speed	$24\, cm^2/sec$ 3.7 $inch^2$/sec	$40\, cm^2/sec$ 6.5 $inch^2$/sec	$40\, cm^2/sec$ 6.5 $inch^2$/sec

Conclusions

Neither traditional human inspection nor out-of-date inspection systems can adequately meet the challenges presented by today's increasingly complex assemblies.

The earlier in the process inspection is performed, the greater the overall benefit to the manufacturer.
Paste print inspection has the potential, not just to reduce scrap and ease repairs, but to assist in refining the printing process.
In order to meet both today and tomorrow's manufacturing needs, manufacturers should select paste inspection systems that offer:

- 3D inspection at line speed (i.e. at least 40 square cm per second)
- Real 2D and 3D simultaneous inspection for maximal fault coverage
- System accuracy and GR&R to meet the inspection requirements of the finest elements
- Quick, simple setup
- Full board coverage

Manufacturers seeking new inspection systems should consider, not only the line's current speed, but also the maximal capacity of the line and the system's adaptability to changes and improvements.

References

1. AMCOR: Surface Mount Requirements for Advanced Packaging Solutions, 2000.