Controlling the Process: Post-Reflow AOI (Automated Optical Inspection) to Ascertain Machine and Process Capability

Titus T. Suck, International Product Manager and European Marketing Manager, Orbotech S.A.

In the past two years, the use of AOI to inspect assembled boards has found industry-wide acceptance worldwide. However, the assembly process is complex and many real defects are not related to process issues as such. They are related to the nature of the substrate, the environment, the components, SMT equipment etc.

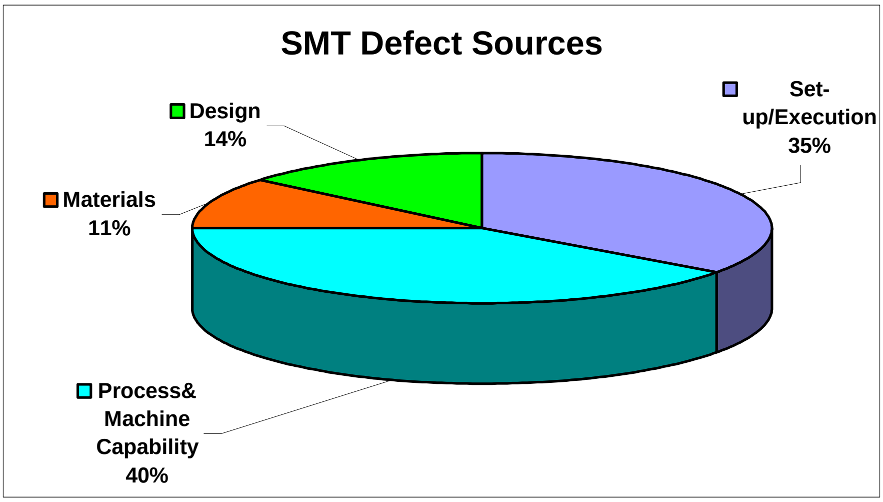

Figure 1 SMT Defect Source Distribution

Today AOI systems deal with defects resulting from those factors as well as those resulting from actual process issues. Given that every fraction of a line's process yield counts in today's heavily competitive world, it is key that the AOI not only serve as a gatekeeper. Instead of merely preventing defects from being incorporated into an assembly that will only be found, if at all, in the last and most expensive stages of testing, the AOI system must allow to trace back and identify root-causes of defects. In this way, AOI can become the corner stone of an effective quality management process.

For a forward-looking quality management approach, it is key to have a critical look at today's inspection and test strategies. Fact is that the opportunities for errors increase dramatically at more than 18,000 solder joints. At that stage, yields tend to drop into the single digits even for world class (<100ppm) manufacturing operations. Fact is that ICT today does no longer have access. Fact also is that 70% to 80% of all defects are not electrical but structural. The question is what kind of approach is needed to address this set of problems? Clearly, it cannot be the goal to simply add yet another complementary test to the existing test sequence. The goal should be to reduce and possibly even make testing redundant. The issue is ***NOT to FIX*** a problem by increasing the test resolution but ***NOT TO TEST AT ALL*** by taking the entire manufacturing operation to a higher quality level from the outset.

The cost of fixing problems is simply prohibitive. . The real business difference between fixing problems and preventing them through rigorous quality management is highlighted in the following graph:

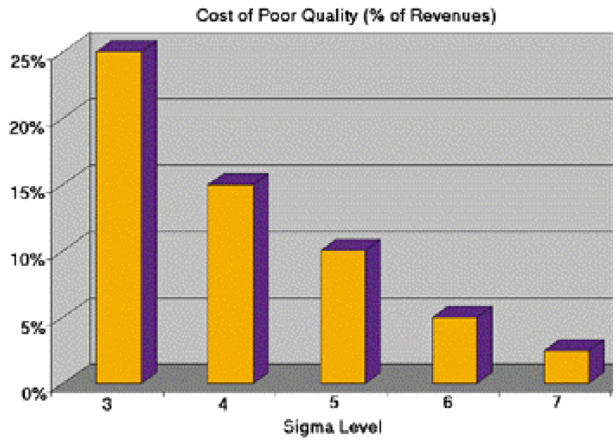

Figure 3: Cost of Quality (Courtesy of Speedline GmbH)

It shows that the loss of revenue due to low quality processes has a real and overwhelming impact on a business. A 3-sigma business would thus spend around 25% of revenue on fixing quality issues.

In the attempt to systematically improve the manufacturing process in an SMT line, post-reflow AOI plays an ever-increasing role. In fact, in conjunction with a TQM strategy, it can become the corner stone of managing, monitoring and improving quality.

As mentioned above, all manner of defects are currently thrown together which makes it difficult to assess one's process. By focusing on equipment capability, however, we can eliminate a significant number of considerations from the equation. Practical experience has shown that machine capability analysis can reduce the placement related defect frequency by 50% and more. The point is that placement equipment is very stable and highly reliable, and, if the equipment is functioning within specification and if it is process capable, then a major source of defects is under control.[i] The fact is that post-placement AOI is largely unnecessary, and that the monitoring of process quality is best performed from the post-reflow position, i.e. the end of the process. Not every off-set or angled shift of a component after placement actually turns into a real defect nor does every 'optimally' placed component remain in an acceptable position throughout the reflow process.

It clearly makes little sense to use an expensive post-placement AOI to measure errors and to feedback correction factors to the placement machine, if the error is an easily corrected and controllable problem. The measurements really compensate only for a condition instead of providing a meaningful analysis and remedy of the problem. In any case, defects which are related to materials, design, execution and the environment in general actually are not correctible through the use of a post-placement AOI.

In short, if there is a problem with the equipment – and hence the process – it is not discovered by post-placement AOI, and quality overall is not improved. The challenge is to create an approach with a simple tool, which allows isolating the underlying machine issue, to measure machine performance in a repeatable and consistent manner, and to translate such data into an indicator of the process capability.

Orbotech Ltd. together with CyberTRon GmbH as a partner have developed a process and tool which

- Is implemented on the post-reflow AOI
- Allows to separate equipment related defects from process related defects,
- To minimize the influence of the measurement approach on the measurement results,
- Can be implemented at factory floor level by quality management
- Is easy to use, quick and inexpensive
- Provides a quick analysis of machine and process capability at any point in time (daily, weekly, monthly analyses are easily integrated into production)

Initially this tool will be implemented in an off-line situation though full integration into a dedicated SPC software for SMT production will be not long behind. The measurement approach can be used to evaluate both the accuracy of the printing of paste deposits and of the placement of components.

Adding Value to Post-Reflow AOI:

In essence, normal placement equipment (chip shooter or pick and place machines) populates a highly accurate glass plate, which is covered with adhesive, with dummy ceramic components. Subsequently, this test vehicle is inserted into a post-reflow AOI system where images are taken. Those data are then sent to a separate off-line workstation where special image analysis software is used so as to analyze the ΔX, ΔY and Δ Theta factors so as to determine the equipment's capability at this specific point in time.

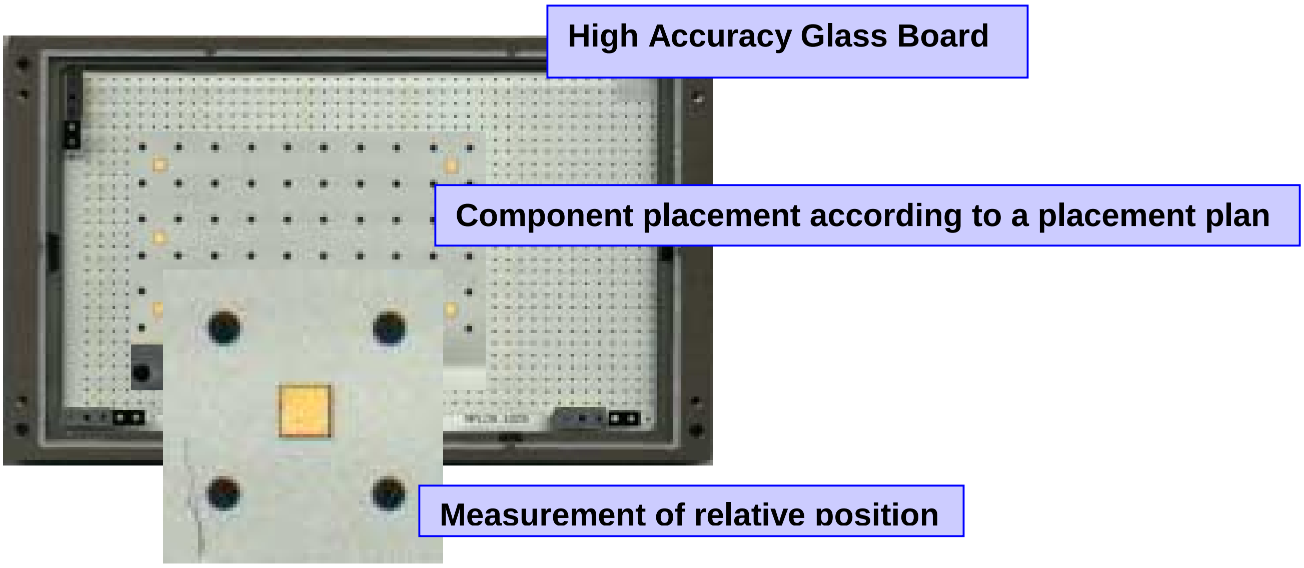

Figure 2 Measurement Process with Glass Plate

This SMT process control procedure contains two sub-procedures:

- A machine capability assessment (short-term capability)
- Process performance (long-term variability evaluation)

Machine Capability Module

In this case, the measurement data are collected from a single board at a single point in time. The input parameters include measurement results for each component and paste deposit as well as date and time of test, placement head information, squeegee direction, component orientation, machine ID etc.

The mean value of the measured offsets and the corresponding standard deviations are calculated, and used to calculate the machine capability or Cp.

$$Cp = \frac{\text{Pick and Place vendor's machine specification}}{6\ (\sigma\Delta x,\ \sigma\Delta y,\ \sigma\Delta\theta).}$$

However, since the Cp value tells us something only about how narrow the distribution is or, in other words, how closely we can repeat a process, but not how far the process average is from a nominal value. To this end, we use specification limits and the mean values for ΔX, ΔY, $\Delta\theta$ to calculate the Cpk value or the centering of the data distribution.

$$Cpk = \frac{\text{Specification limits (USL=LSL=SL)} - \text{Placement offset}}{3\ (\sigma\Delta x,\ \sigma\Delta y,\ \sigma\Delta\theta).}$$

In other words, Cpk evaluates the spread and average of a placement offset in relation to the value of the standard deviation. A Cpk of 1.33 indicates that a 4 Sigma capability has been achieved whereas a Cpk of 2.66 characterizes a 6 Sigma process. In terms of DPMO the difference is between 6210 DPMO and 3.4 DPMO Once the Cpk and Cp values have been determined, they can be compared to the minimum acceptable capability thresholds, and if either Cp or Cpk are lower than the respective threshold value, the machine can be classified as not process capable. A machine calibration would be the next logical step.

All measurements can be output in a plot diagram and a table that summarizes the results for shifts in all linear and angular directions.

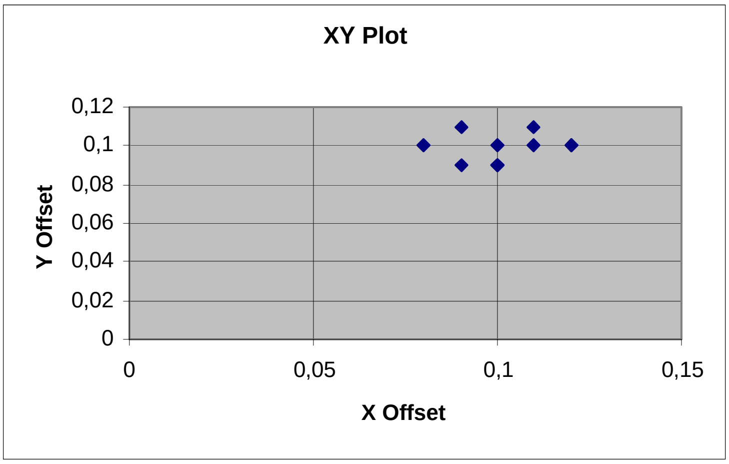

Figure 4 X-Y Plot and The Summary Table. X-Y Plot depicts linear offsets in both directions for each evaluated component.

	$\overline{\Delta X}$	$\sigma_{\Delta X}$	LSL	USL	Cp	Cp$_k$
X	0,10	0,01	-0,15	0,15	4,19	1,35
Y	0,09	0,01	-0,15	0,15	6,63	2,32
Θ	1,01	0,08	-2°	2°	7,99	3,93

Table 1 Summary table contains figures on mean values and standard deviations for shifts in all linear and angular directions

If the machine were found ‘not capable’, line operators or process engineering could be informed of the status of the machine by way of an on-screen message. To close the information/action loop, the receiver of the message would be asked to confirm its receipt and to indicate any actions taken. In this way, the post-reflow AOI assists in eliminating equipment-related errors from the placement process, which can easily represent 50% and more of all placement errors.

Process Capability Module (long-term variations)

In a second step, we can evaluate ***the long-term process variability*** based on measurements taken over a period of time, and where every data point represents one particular *machine capability assessment run* as described earlier. The process performance is described as Pp and Ppk. Once these indices have been calculated, they are again compared to the minimum acceptable thresholds. Control charts $\overline{X}-\sigma$ are then used to determine the long-term process variability, and to separate background noise from abnormal variations. $\overline{X}-\sigma$ Charts consist of a pair of simultaneous graphs for each axis which chart the average single boards shift and the standard deviation of the shift as a function of time.

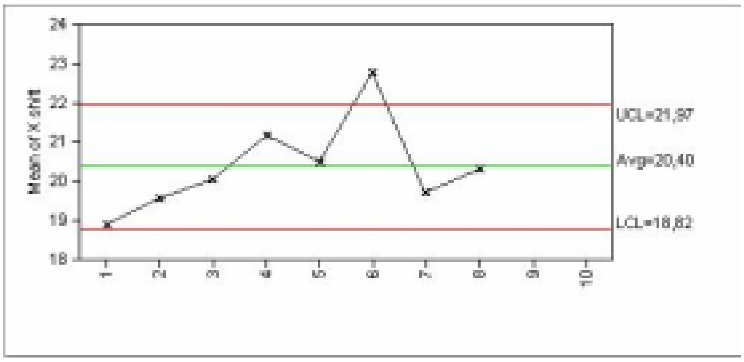

Figure 5 $\overline{X}$ **Chart**

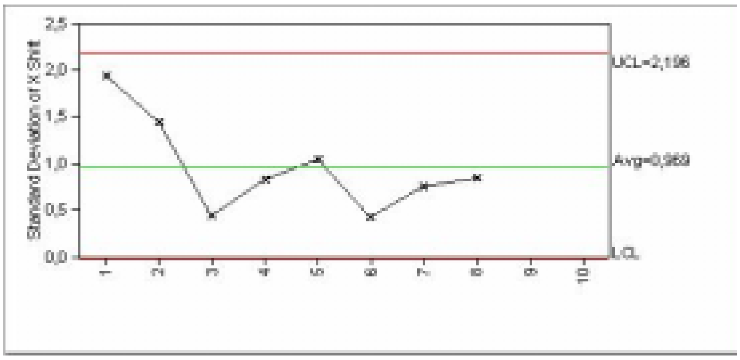

Figure 6 s **Chart**

Since the points on the graph represent mean values rather than individual measurement points, one obtains a trend for any shifts and rotation as they occur over time. If such a graph is charted against some control limits, it is then also possible to use the chart to distinguish between random background noise and non-random behavior of the equipment. Once the chart pattern has been analyzed in this respect, and if a trend indicates a non-random violation of the control limit, then the tested process is found as being out-of-control, and an e-mail message can be sent to the relevant personnel.

The assessment of a control limit violation is subject to a number of decision rules. If control limits are set very tight, frequent out-of-control messages may occur. From a practical point of view, this means that the customer must be able to specify control limits himself, and, possibly, be able to set and use temporary control limits.

Furthermore, he must be able to control the decision rules and be able to switch them on and off. Both processes are highly sensitive and must be password protected.

If a process were to indicate an out-of-control state, the next step would be an SMT equipment calibration. This calibration can also be implemented with the help of the PCCM (process control and calibration module) in the AOI system, but requires professional personnel utilizing a very high-accuracy glass board so as to measure and calculate data shifts, standard deviations and capability indices per machine together with placement head level data.

The ultimate step of this process would be a machine capability certification. However, such a step goes beyond the typical in-house capability assessment which this process tool – Process Control and Calibration Module or PCCM - offers the normal AOI user and would require specialist services.

Certification, however, is not the aim of this **Process Control and Calibration Module or PCCM.** The objective is to provide post-reflow AOI users with a simple, easy to use and straightforward tool that allows them to eliminate equipment related defects from the overall defect equation. In so doing, the AOI system allows an assessment of the total production yield and the development of strategies which address root causes of defects as related to materials, design and process (ex equipment). AOI inspection thus confirms its role as an "unproductive" production machine rather than a test system. In the medium term, the integration of AOI and process monitoring and calibration tools point toward a scenario where test – as a parasitic add-on to production – may be eliminated by implementing total quality management strategies where production is centered on AOI and which make ICT and functional testing redundant. If nothing else, post-reflow AOI can help to actually allocate scrap and repair of defects to production, thereby incentivizing manufacturing to improve processes.

[i] High-end placement equipment vendors such as Siemens have long recognized the importance of a calibration tool and process to insure long-term placement stability. For further reference, see, Gunter Schniebel, "Achieving Long-term Stability in the SMD Placement Process," SMT, June 2001, pp.46-50.