Cost-Effective Placement Machine Capability Analysis and Process Control

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Abstract
New component packaging formats create the need for greater production process stability, reproducibility and precision. This leads to a growing demand for process control solutions.

As manufacturers set zero-defect goals, process control solutions have been developed, which are going beyond defect detection towards defect prevention. In order to reach those zero-defect goals it is necessary to develop a comprehensive quality assurance (QA) strategy. Part of this strategy must be, to observe and continually correct the different processes, which build the SMT process. The use of AOI (Automated Optical Inspection) systems plays a central role in most of those strategies.

Introduction
There are different strategies representing the different philosophies in regards to process control. One of the sources of variability in SMT processes is the component placement process. The capability of the placement machinery to achieve the required product quality is a fundamental prerequisite for a good process.

The mere awareness of the existence of process variability is, however, insufficient to automatically reduce it. Continuous equipment maintenance in order to keep the capability of the equipment up to requirements represents additional processes, the cost of which must be offset against the cost-saving effects of a QA program. In this paper the cost-effectiveness of the two main approaches for placement process control involving AOI is discussed. A newly developed method for placement machine capability assessment and placement process control, utilizing post-reflow AOI, is introduced.

In-line post-placement AOI
A common method to reduce placement machine variability (and hence process variability) is the implementation of an in-line, high-accuracy AOI system directly after the component placement equipment as shown in Figure 1. In this configuration the AOI can accurately detect different placement related defect types like missing, misplaced, skewed or shifted components. In addition to the detection of positioning defects, the AOI can measure shift values in real-time.

However, in order to achieve 100% defect detection it is also necessary to perform solder joint quality inspection. This means, that further investment in a post-reflow AOI system will be necessary.

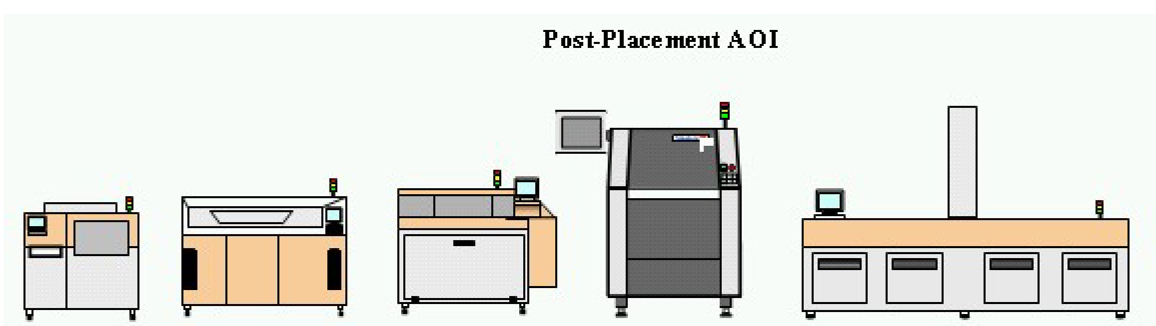

Figure 1 - Inline Process Control. Solder Joint Inspection would Require Further Investment in Post-reflow AOI

Here the AOI serves as a quality control tool (Go, No-Go decision). At the same time it serves as metrology tool for continuous QA, indicating drifts of components placement away from their predetermined target position.

Utilizing this information by taking corrective action to the process would guarantee the desired quality standard:

Every manufacturer has to specify the required quality level for his product(s). Usually this is done by specification of an allowed DPMO (defects per million opportunities) rate, which is then expressed as an n-sigma specification. For example a 4-sigma process would correspond to a defect rate of 63 DPMO (=ppm).

On the other hand a product specification (tolerance) exists, usually defined as a range between an upper and a lower specification limit.

From the product specification and the desired sigma quality level, a threshold standard deviation can be calculated. The component offsets measured by the AOI system directly after the placement can be used to calculate the sample variance and sample standard deviation. These can then serve as an approximation of the actual process variance and process standard deviation.

If the approximated process standard deviation is larger than the calculated threshold standard deviation, the process needs to be readjusted in order to produce not more than the allowed DPMO rate.

Process Variation and its Influence on the Measurement Process

The benefit of having an inline AOI directly after the component placement process for QA purposes is unquestionable. It enables the line operators to spot events and monitor fast-developing trends in real-time allowing quick corrective actions before defects occur (at least before too many defects occur).

However, the value of such an approach with regard to the end-of-line product quality raises some questions:

- Experiments and investigations have shown in the past, that misaligned components, including chips down to 0402 size, show a strong self-centering characteristic during the reflow soldering process. This means that during the wetting process in the oven the solder paste pulls even misplaced components back to their target position on the pad due to adhesive forces. This gives reason to doubt the value of measuring the position as well as manually correcting component alignment (One has to admit, that for lead-free solder process this may be different).
- Many defects materialize after the reflow process. This would suggest further investment in AOI equipment to inspect solder quality and gain 100% defect detection, thus allowing correct quality analysis.
- The most important consideration of all is the question, if the capability of this post-placement AOI configuration to precisely measure process parameters on regular production assemblies is sufficient. This capability would be required to be able to find slowly developing trends caused by mechanical wear of machine parts over time. This is highly questionable, because the measurement itself includes considerably more variation than just the process variation, i.e. there is too much noise to find the signal.

When measuring the machine and process variance $s_{\mathrm{Pr}ocess}$ in a regular SMT in-line post-placement AOI environment, the measurement result is influenced by:

- Variations in materials (FR4 board material and components)
- Environmental conditions (temperature coefficient)
- Total variation of the measurement gauge, (which itself is caused by the quality and speed of measurement algorithms, compensation of stage or camera movement and resolution of the optics)

All these variations contribute to the measurement process variability (Here called $s_{Measure}$.).

Each of the elements in the formula given in Figure 2 has associated cost. For example to minimize the gauge influence in the AOI system, high-resolution cameras and position encoders, fast frame grabber cards and sophisticated measurement algorithms must be used to precisely detect, analyze and calculate the position of each real component on real solder paste and PCB (Printed Circuit Board). A gauge is commonly rated acceptable, if the variation associated with the measurement process is not more than 15% of the process tolerance of the measured process. With modern AOI Technology it can be assumed, that the total variance of the gauge can be reduced to conform to this requirement.

$$s_{Measure} = \sqrt{s^2{}_{PCB} + s^2{}_{Components} + s^2{}_{Optics} + s^2{}_{Position} + s^2{}_{\mathrm{Alg}orithms}}$$

Figure 2 - Process Variances Influence the Measurement Process

However, the multitude of variances involved here suggest, that it would be very dangerous to base corrective actions on a process variance measurement obtained with the method described. For example variance in FR4 PCB material alone can contribute an inaccuracy of 30 μm, while component variation also contributes several percentage points. A 2° C temperature change would add several percentage points again.

So, because not all variables in the total process capability equation are known or determinable, it is impossible to include any correction coefficient without a strong risk of over-adjustment. Furthermore, corrective actions based on such a process variance estimation may lead not only to the wrong conclusion on the necessity of a relatively simple calibration, but also to the unnecessary replacement of relatively expensive mechanical parts.

Optimized Process Capability Measurement

Considering the prevailing methods for process capability appraisal in manufacturing and the cost penalties involved, the need for a more effective approach using AOI is apparent. This can be reached by combining the solder joint inspection capabilities of a post-reflow AOI with a newly developed, more optimized method: The process control and capability module Line ADVISOR™, delivering at the same time full defect coverage plus high precision machine capability measurement [This unique process control method was developed with in cooperation with the Technical University of Dresden, Germany as a joint venture between Orbotech-Schuh, GmbH, Bad Pyrmont, Germany and CeTaQ GmbH, Dresden, Germany].

The objective of this method is to assess placement machine capability while concurrently minimizing the influence of the measurement process on the measurement results, i.e. minimize measurement process variability. This is achieved by implementing a procedure that focuses on reducing the sources of variance at each step of the component placement process. If the total process capability is to be measured, obviously all variations except those associated with machine capability must be reduced to a minimum or eliminated.

The first step is to minimize the variation associated with measurement reference inconsistency and inaccuracy. This goal is achieved by the use of a high-accuracy board, which is not exposed to large thermal and humidity changes and is not sensitive to reasonable changes encountered in the traditional manufacturing environment. The first requirement is accomplished using a dedicated board rather than real production boards, i.e. those that go through the reflow oven with a temperature difference in excess of 200°C. To fulfill the second requirement a substrate material other than FR4 should be used. Glass is a good candidate because of its string thermal stability.

The problem of component-to-component variation can be dealt with in a similar manner. By using only one type of component, the same image processing algorithms can be used and, consequently, the possibility to avoid systematic errors related to the measurement method is established.

The third source of variation is the measurement accuracy and repeatability of the measurement gauge itself. As mentioned above, this can be seen as a combination of variations owing to inherent mechanical inaccuracies, optical resolution and image processing.

Following the concept of variation source reductions, it is possible to design a system with a measurement method independent of the relative displacement of the measurement device and the object under investigation.

Typically each assembly contains at least two fiducials to convert movement system coordinates to those of the board. Once a board is registered and the moving system coordinates of each fiducial are determined, it is possible to measure the absolute position of each component in the board's coordinate system.

To eliminate motion system dependency, both the component and the reference have to be in one field of view. The solution is the use of a fiducial grid in the same field of view as the measured component as shown in Figure 3 and Figure 4.

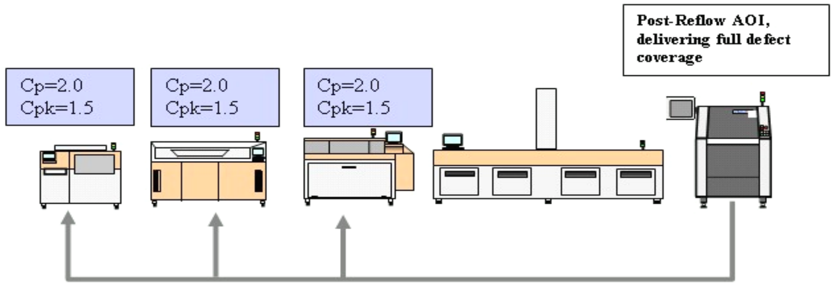

Figure 3 - Optimized Process Control. AOI Provides Full Defect Coverage and, with the Process Control and Capability Module Approach, Real Placement Process Control

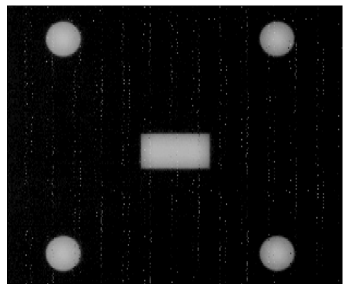

Figure 4 - Component and Four Reference Grid Fiducials in One Field of View

Accurate Indication of Machine Capability

To reach the minimum level of sources of variance, the unique process control method consists of the following steps:

1. A high precision glass board is populated with a number of special 2012(0805) chip components by the P&P machine according to a placement plan with the exact coordinates of the grid positions for all components.
2. High-Resolution images are acquired of each component and its four reference grid fiducials by the Post-Reflow AOI system.
3. Offsets of the component positions relative to their target position (center of fiducial grid) are measured. This includes linear offsets ΔX, ΔY and the angular displacement from the desired location ΔΘ,, which forms the basis for machine capability assessment.
4. The mean values $\overline{\Delta X}, \overline{\Delta Y}, \overline{\Delta\Theta}$ and standard deviations $\sigma_{\Delta X}, \sigma_{\Delta Y}, \sigma_{\Delta\Theta}$ are calculated for each axis and used for machine calculation of the machine capability indices Cp, Cpk and Cpm. Upon calculation the capability indices are compared to the minimal acceptable threshold capability set by the operator. In the case where either of these is less than its threshold value the machine is classified Not Capable. Where they are equal or greater than their threshold value, the tested machine is classified as capable.
5. The result of each capability measurement is presented in a results table together with a scatter diagram, visualizing the position offsets of the placed components.

The whole test procedure, including board population, image acquisition, image processing and presentation of the results take no longer than 15-20 Minutes per placement machine.

This way the sources of variance are reduced to the remaining material variation (accuracy of the glass substrate and components) and the resolution of the image acquisition and image processing process as given in Figure 5.

$$s_{Measure} = \sqrt{s^2_{Material} + s^2_{Optics}}$$

Figure 5 - Remaining Sources of Variance for the Line ADVISOR Method

Several GR&R (gauge repeatability and reproducibility) as well as accuracy tests have documented, that the accuracy of unique process control method for machine capability assessment is better than ± 6 µm and the GR&R based on a ± 90 µm process tolerance and AIAG suggested 5.15s spread is less than 4.5%, using for example a standard type 2 study with 15% acceptance threshold.

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Upon calculation the capability indices are compared to the minimal acceptable threshold capability set by the operator. In the case where either of these is less than its threshold value the machine is classified Not Capable; where they are equal or greater than their threshold value, the tested machine is classified as capable. Figure 6 depicts an example of a machine capability result following these calculations.

Presentation of Results (extract)

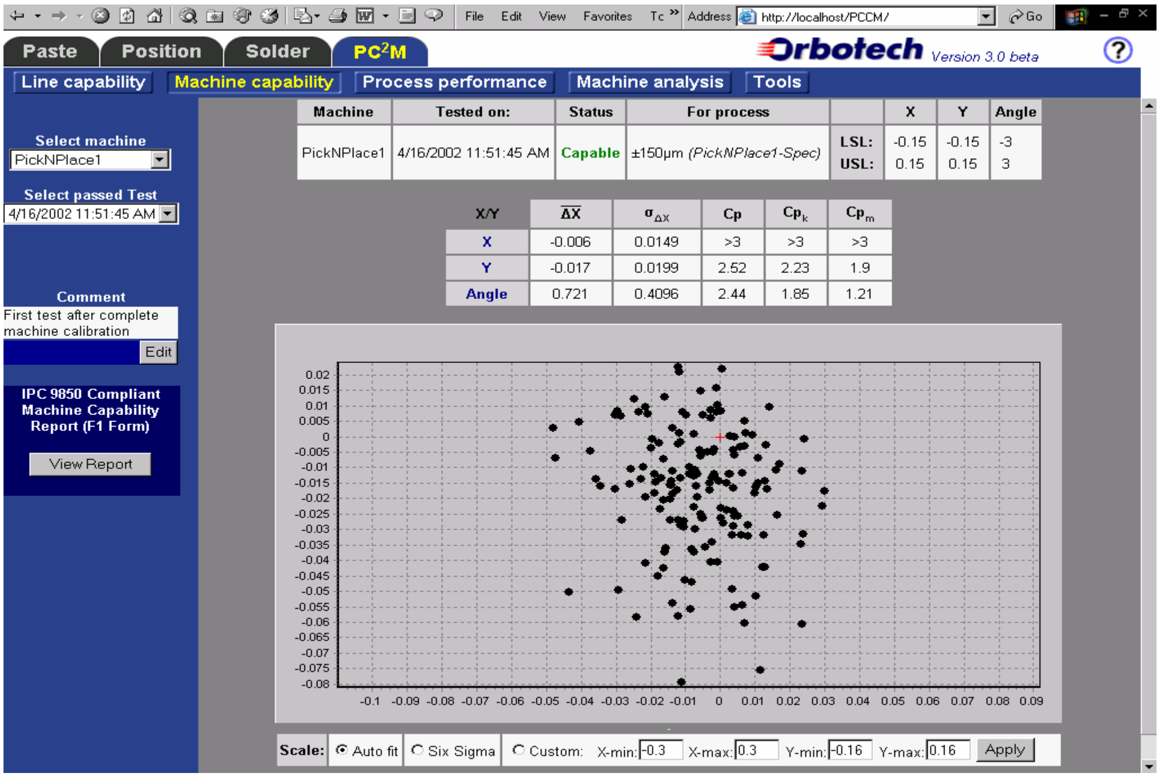

Figure 6 - An Example of a Machine Capability Result

The machine capability test results can also be presented in IPC-9850 Placement Performance Form F1 format as depicted in Figure 7.

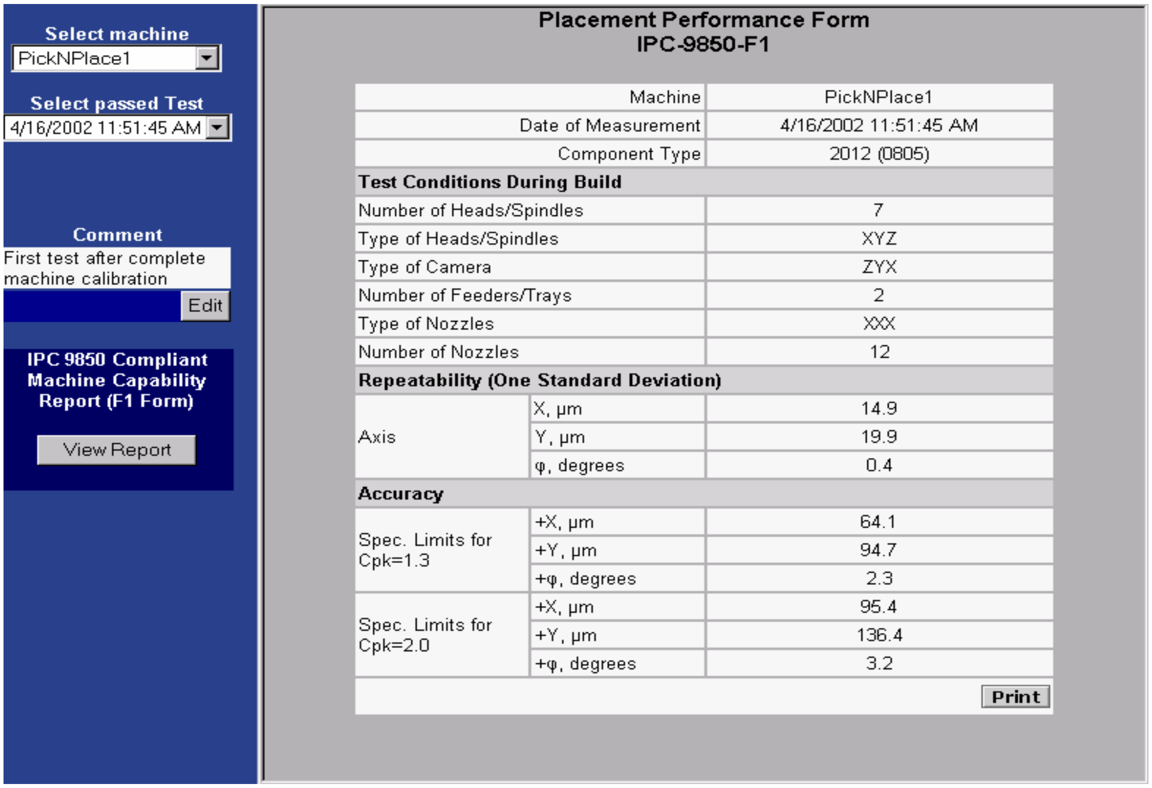

Figure 7 - IPC-9850 Placement Performance Form F1

Repeated capability tests over time represent classical SPC sampling and the performance of a P&P machine can be monitored over time using automatically updated SPC control charts (X-Bar/S-Chart) for each placement machine in a line as depicted in Figure 8.

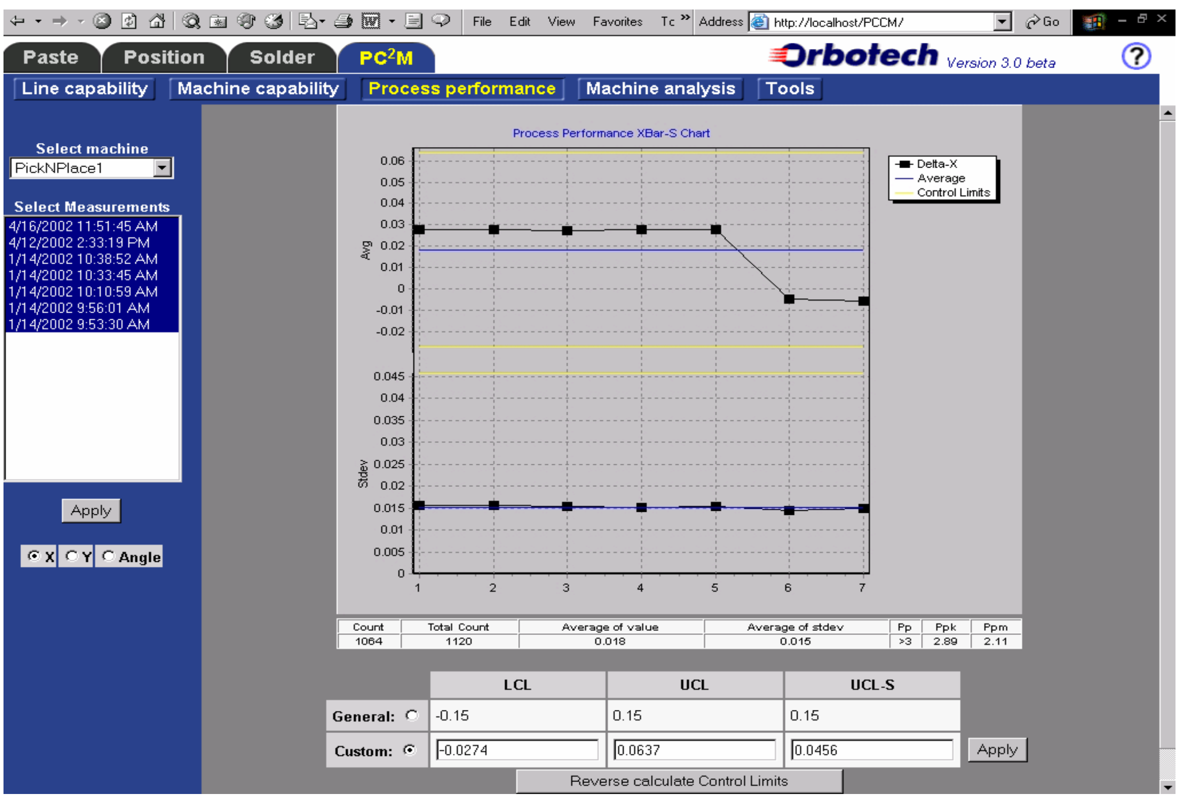

Figure 8 - Process Performance Monitoring

Future Development steps include the use of IPC-9850 defined QFP and BGA glass slugs in addition to chip components in order to be able to better assess the capability of IC-Mounters.

Summary

The unique process control method approach guarantees highly accurate data on machine capability in terms of variance and central tendency and has decisive advantages over prevailing approaches:

- It can be implemented on a post-reflow AOI system, which provides at the same time full defect coverage and optimum utilization.
- The process takes less than 20 Minutes and can be implemented at regular intervals or during product changeover (or before new product introduction).
- It enables separation of equipment related variability from other process defect sources.
- It reduces the influence of the measurement method on the measurement result to an absolute minimum.
- It can be integrated on a factory floor level as part of a quality-management program helping the line operators to decipher the quality capacity of different placement machines and lines.

Conclusion

The unique process control and capability module uses machine capability analysis to determine process capability during regular line downtimes without stopping the line for long periods just for this purpose. Implemented as a part of a QA program manufacturers can assess their capability continually by characterizing the ability of a line to produce to exact product specifications. Placement machine related sources defects can be identified quickly. Additional benefits include the capacity to analyze all placement equipment regardless of manufacturer or machine type. It can also help to better understand machine performance and to optimize maintenance intervals fro improved cost control.

References

For a list of references please contact Christoph Torbohm at Orbotech-Schuh GmbH, c. Torbohm@orbotech.com