Placement Machine and Process Control Optimization

By Igor Sosman and Simon Davis

New component packaging formats demand greater stability, reproducibility and precision in production processes and equipment.

Process control is playing a central role in quality-improvement efforts. As manufacturers strive toward zero-defect processes, control and optimization systems have evolved that function concurrently with the process rather than as an afterthought. This has led to quality control systems going beyond error detection to error prevention. To achieve this goal, it is necessary to build a quality-assurance (QA) program in which specific assembly processes are observed and corrected continually.

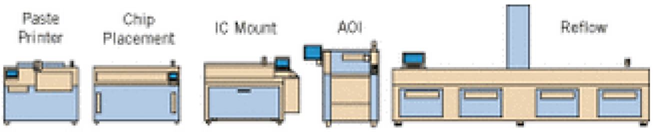

Figure 1. Inline process control. AOI is placed directly after the component placement equipment where the system monitors the process for untoward drifts and when remedial action is indicated. Solder joint quality inspection would require further AOI investment after the solder reflow process.

Machine Capability

One critical source of variability in SMT manufacturing is undoubtedly the component placement process. As a prerequisite for a good (qualitative) process, the machines must be capable of achieving the quality requirements.

There are numerous approaches to monitoring and reducing the ill effects that a machine has on the quality of a finished assembly. Unfortunately, an awareness of process variability is insufficient to automatically reduce it. In fact, continuous assembly process and equipment maintenance and adjustment adds additional processes, the cost of which must be offset against the cost-saving effects of a QA program.

Measuring the Process

A common method to reduce machine (and, therefore, process) variability is the implementation of an in-line, high-accuracy automated optical inspection (AOI) system directly after the component placement equipment (Figure 1). In this configuration, AOI accurately can detect various defect types, e.g., missing, misplaced, skewed or shifted components, as well as measure "exact" shift values in real time. Thus, AOI serves as both a quality control and metrology tool for continuing QA, i.e., indicating drifts away from a predetermined position, which would guarantee acceptable quality standards.

The component offsets measured by the AOI system directly after placement can be used to calculate the process variance:

$$s^2 = \frac{\sum_{i=1}^{N}\left(\Delta x_i - \Delta\bar{x}\right)^2}{N-1} \qquad (1)$$

and the sample standard deviation:

$$s = \sqrt{s^2} \qquad (2)$$

Using this method, the calculated sample standard deviation is substituted in the formula for process performance; the results are compared to the desired threshold:

$$P_{pk} = \min\left(\frac{USL-\hat{\mu}}{3s}, \frac{\hat{\mu}-LS}{3s}\right) \qquad (3)$$

Where:

USL = process Upper Specification Limit,

LS (corresponds to) the Lower Specification limit and.. = sample mean.

A possible scenario: The process quality is set to 63 ppm, i.e., only 63 devices per million are permitted to fail to meet the required quality specification, which here equates to a 4-sigma process. For a centered, normal distribution, this means that symmetrical specification limits are located at a distance of four standard deviations (s) from the mean: LSL = -4 s; USL = 4 s:

$$P_p^{Th} = \frac{8s}{6s} \approx 1.33 \qquad (4)$$

For reasons of simplicity a centered, non-shifted normal distribution is considered:

Pp = Ppk.

From the sample variance (1) and the process performance (4), the target for sample standard deviation can be calculated:

$$s^{th} \le \frac{USL - LSL}{6 * 1.33} \qquad (5)$$

From AOI measurement data and using the sample variance (1) and the sample

standard deviation (2), the sample standard deviation of the actual process can be assessed.

Thus, the rules for maintenance and calibration of manufacturing equipment are clear. If the actual standard deviation sac is greater than the sample standard deviation sth, the process must be readjusted to produce not more than 63 defects per million operations. Through this method, additional costs are hidden in the assessment of the sac. Or, if the assessment is inaccurate, this can lead to hidden costs.

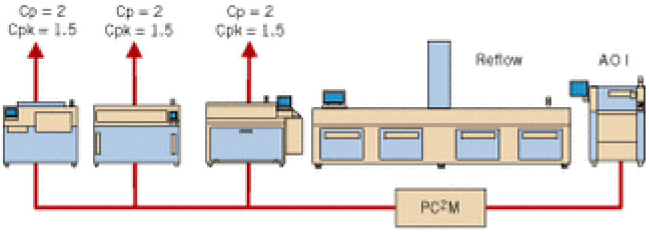

Figure 2. Optimized process control. AOI provides higher process defect coverage, and with the process control and capability module approach, provides inline process control to analyze machine capability accurately and eliminate placement variance.

The Tendency to Overadjust

While the benefit of using inline AOI directly after the component placement process to monitor trends and respond in real-time to untoward drifts is unquestionable, the actual value of such an approach with regard to end-of-line quality raises some questions:

- Investigations have shown that misaligned components, including chips down to 0402, show a remarkable self-centering characteristic during the reflow soldering process. This gives rise to uncertainty about the value of measuring the position as well as manually correcting component alignment.
- Many process defects materialize after the reflow process. This would suggest further investment in AOI equipment to monitor solder quality and the general health of the process.
- And perhaps the most important consideration of all, the capability of such a configuration to precisely measure process parameters on production assemblies can be overestimated. The measurement itself actually includes considerably more variation than just the process variation, the determination of which is the goal.

The inherent variation existent in any manufacturing process is manifold. In the assembly process, the total variation of the measurement gauge smes, the component-to-component variation scom and board-to-board variation sbrd all have an influence on the measurement of machine and process capability (Figure 1):

$$s^{ac} = \sqrt{s_{mes}^2 + s_{brd}^2 + s_{com}^2 + s_{prs}^2} \qquad (6)$$

Where: sprs = the variation in the process and is a process capability criterion.

Each of the elements in this formula has associated costs. For example, to minimize the gauge influence in the AOI system, high-resolution cameras and position encoders, fast A/D cards, and sophisticated algorithms must be used to precisely detect, analyze and calculate the position of each real component on real solder paste and board. A gauge is thought to be acceptable if the variation associated with the measurement process is not more than 15 percent of the measured process. Accordingly, with modern AOI technology one can assume that the gauge conforms to this requirement.

Thermal Factor

According to PCB manufacturing data, thermal stress applied to FR4 board material can contribute as much as 400 ppm for each 2°C change. Thus, relative to the same fiducial mark at the board edge, component displacement on one and the same board before and after the reflow process could contribute a variation of several percentage points. Additionally, board-to-board variation from the manufacturing process can reach as much as 30 µm, while component-to-component variation also contributes several percentage points.

In an example of a ±150 µm process with an actual process variance of sprs = 35 µm, the process performance Pp is calculated as follows:

$$P_p = \frac{300}{6*35} \approx 1.42 > P_p^{Th} \qquad (7)$$

Assuming that the variance reported by AOI is only 15 percent greater than sprs, the result is sac ˜ 40 µm and, subsequently, the following:

$$P_p = \frac{300}{6*40} \approx 1.25 > P_p^{Th}$$

Hence, the machine, which is better than pTh, would have to be stopped and adjusted.

There would be no problem if all components in the total process capability equation (6) were known or determinable. Unfortunately, in reality, they are not. Therefore, it is impossible a priori to include any correction coefficient to estimate properly the relationship between sprs and sac. This, as shown, probably would lead to overadjustment.

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 inherent cost penalties involved, the need for a more effective approach with AOI is apparent. An example of a newly developed, more optimized method is the process control and capability module (PC2M). Its objective is to assess placement machine capability while concurrently minimizing the influence of the measurement process on measurement results. This is achieved by implementing a procedure that focuses on reducing the sources of variance at each step of the component placement process. If total process capability is recalled, obviously all variations except those associated with machine capability itself must be reduced or minimized (Figure 2).

The first step is to eliminate the variation associated with measurement reference (sbrd) inconsistency and inaccuracy. This goal is achieved using a high-accuracy board, which is not exposed to large thermal and humidity changes and is not sensitive to the 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 strong thermal stability.

The problem of component-to-component variation scom 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 assess systematic errors related to the measurement method is established. High-accuracy component use increases the reliability of image processing and minimizes measurement result variations.

The third variation source is the measurement accuracy and repeatability of the measurement gauge itself (smes). This could be seen as a collection 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 scrutiny.

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 coordinates of each fiducial are determined in those of the movement system, 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 must be within one field-of-view. The solution is a synchronization fiducial grid in the same field-of-view as the measured component.

Accurate Indication of Machine Capability

Using the PC2M method, the measured linear offsets from the component's target location ? X and ? Y, plus angular displacement from the desired orientation ? Q from one single board, form a basis for machine capability assessment.

$$\overline{\Delta X},\ \overline{\Delta Y},\ \overline{\Delta \Theta}$$

Mean values and standard deviation for each are calculated for each axis and used for machine capability calculations. Upon calculation, the capability indices are compared to the minimal acceptable capability indices set by the operator. In the case where either of these is less than its corresponding threshold, the tested machine is classified as not capable; where both are equal or greater than their threshold value, the tested machine is classified as capable (Figure 3).

$$\sigma_{\Delta X}, \sigma_{\Delta Y}, \sigma_{\Delta \Theta}$$

The PC2M 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 where it provides better process defect coverage and optimum utilization.
- The process takes approximately 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 measured results.
- It can be integrated at factory floor level as part of a quality-management program, helping users decipher the quality capacity of different machines and lines.

Conclusion

The process control and capability module approach uses machine capability analysis to determine process capability when introducing new products (or before a product change) without stopping the line for long periods. Implemented as part of a QA program, manufacturers can assess their capability continually by characterizing the ability of the line to manufacture to exact process specifications and by quickly identifying sources of placement machine-related defects. Additional benefits include the capacity to analyze all line equipment regardless of manufacturer or machine type, to better understand machine performance, and to optimize maintenance intervals for improved cost control.

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