“Total System Accuracy”™ For a Dispensing System

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ABSTRACT:
As the demand for faster and smaller electronic products such as cell phones, pagers and PDAs increase, the demand on assembly equipment capabilities also increases. Boards are becoming denser and components are getting smaller to keep up with the industry’s demand. Manufacturers are continuously challenged to deposit joining materials (solder paste, epoxy and adhesive) in extremely precise patterns. These drivers require that assembly equipment must offer increased accuracy capabilities while maintaining the high yield and high capability. How we assess the true capability of assembly equipment is the subject of discussion here.

Typically for liquid dispensers, XY repeatability and/or dot placement accuracy, expressed as a sigma value has been sufficient in the past. As the demand on accuracy increases, we have come to realize that these specifications do not include the error associated with positional mechanisms, which greatly contributes to final accuracy and repeatability. Many factors influence positional accuracy including the XY gantry, camera calibration, fiducial teaching errors camera-to-needle offset calculations software control to name a few.

This paper describes a new test method, taking into consideration all influencing factors, to determine the true machine capability, including positional accuracy, and express it as a CpK value. The new test method calculates the “Total System Accuracy”™ of a dispensing platform, including material placement accuracy on a substrate relative to a defined target.

INTRODUCTION:
Electronic material dispensing process is a process by which material is deposited onto the PCB for holding and providing mechanical/environmental support to various components. This is known as the electronic assembly process. In the early days of electronics assembly process, demand on accuracy and repeatability was not as high as it is today. Two decades ago, the primary method of dispensing was done by applying air pressure to force the material through a needle. Since then, dispensing process has evolved into a highly automated and inline process that employs sophisticated pumps and vision system with improved accuracy, repeatability and throughput. As the technology in component packaging continue to advance, dispensing is becoming highly critical to the electronic assembly process. Some of the examples are; flip chip underfilling, micro BGAs, fine pitch leaded devices, CSPs, various display and MEMS devices.

Typically, dispensing platforms only specify XY repeatability and/or dot placement accuracy, as a sigma value. These specifications do not include the error associated with positional mechanisms, which greatly contribute to final accuracy and repeatability. Many factors influence positional accuracy, including the XY gantry, camera calibration, fiducial teaching errors, camera-to-needle offset calculations and the software that controls all of these functions. As the finer pitch components becomes more common, validating accuracy and repeatability of dispensing equipment becomes highly critical.

To determine the true machine capability, including positional accuracy and express it as a Cpk value, a new test method must be developed to take into consideration all influencing factors. This is called “Total System Accuracy™.” The “Total System Accuracy” concept is highly beneficial when comparing machine-to-machine repeatability. Using “Total System Accuracy™” as a gage, continuous tweaking of the machine to meet the demand of high mix lines can be practically eliminated.

Key words: Accuracy, repeatability, machine capability, Cp, CpK

ACCURACY:
In Six Sigma terminology, accuracy is defined as “the degree of conformity of a measured/calculated quantity to its actual (true) value.” In another word, accuracy means the degree to which a given quantity is correct and free from error. For example, a quantity specified as 100±1 has an (absolute) accuracy of ±1 (meaning its true value can fall in the range 99-101), while a quantity specified as 100±2% has an (relative) accuracy of ±2% (meaning its true value can fall in the range 98-102). While considering accuracy, one cannot discuss accuracy without discussing the concept of precision. Figure 1 explains the difference between accuracy and precision using the classic ‘bulls eye’ concept.

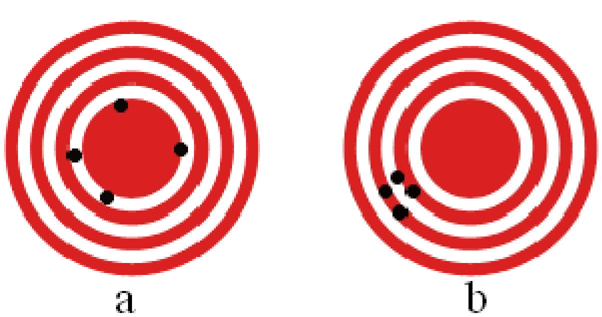


Figure 1a. Highly accurate but low precision, figure 1b. Highly precision but low accurate.

Currently, equipment suppliers express machine capability (which should takes accuracy and repeatability into consideration) in many different ways. One common practice is to express machine capability as ± X. Where X is a number that is chosen by the machine supplier (example: ± 5mil) without taking the specification (requirements) in to consideration. A better way to express machine capability would be to use statistical measure such as Cp and CpK.

CAPABILITY:
The true machine capability should be expressed as a comparison of output of a ”in control” process with the specification limits by using “capability indices”. The comparison is made by forming the ratio of the spread between the process specifications (the specification "width") to the spread of the process values, as measured by 6 process standard deviation (6σ) units (the process "width"). A capable process is one where almost all the measurements fall inside the specification limits. This is represented graphically in figure 2.

In a statistical term, process capability is expressed as “capability indices” and represented by the term Cp and CpK. Most capability indices are only valid if the population size is “large enough” and the data fall under a normal distribution curve.

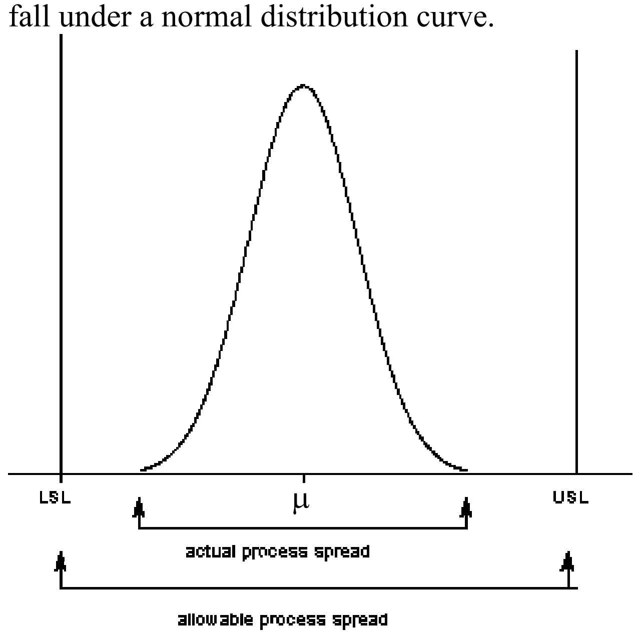


Figure 2: Process capability

The process capability indices, Cp and CpK is defined as:

Cp: Process capability index, is a measure of the ability of a process to produce consistent results. It is the ratio between the permissible spread and the actual spread of a process. Cp is expressed mathematically as;

$$C_p = \frac{USL - LSL}{6\sigma}$$

Higher the process capability index the more capable the process is. If Cp<1, the process is considered to be incapable of meeting specification. In certain instance Cp could be greater than one, but the process still be incapable of meeting specification if the process is not centered. Thus, there is a need for a capability index, which takes process centering into account and is called "process performance index".

Cpk: Process performance index with respect to the target and is expressed as follows;

$$C_{pk} = \min\left[\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right]$$

Where,

USL = Upper specification limits.
LSL = Lower specification limits.
σ = Standard deviation
μ = Target

Similar to Cp, the higher the CpK value more capable the process is.

CASE STUDY:

A case study is presented here comparing and contrasting the traditional method of $\pm$X vs. "Total System Accuracy" method in characterizing machine accuracy of a dispensing system. One method of determining a gantry's capability is to measure each axis independently with some external means of validation. Long travel indicators and laser interferometers are good methods. A less desirable method is use of the machine's own feedback mechanism. From these tests (data taken directly from the gantry axis) , a graph can be plotted showing the desired vs. actual positions to show the system's ability to go to a commanded position. As long as all the measured positions fell within the limits, the gantry was considered good. Figure 3 shows the result from the laser interferometers with a specification of $\pm$ 5mil.

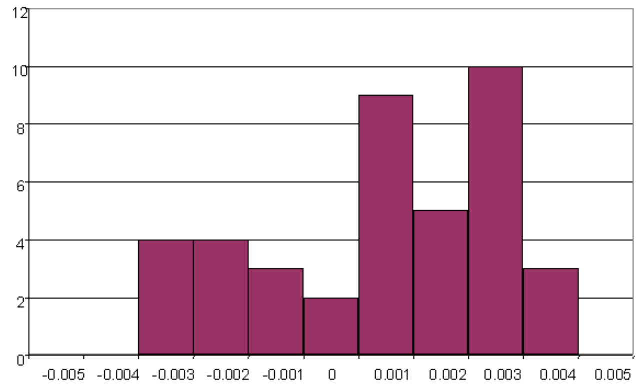


Figure 3. $\pm$X data for gantry accuracy

Clearly, the above data provides very little information about the capability of the process except that all points fall within the specified $\pm$X value.

Applying the statistical methodology, the above plot can be represented as in figure 4 with a normal distribution. Cp and Cpk for the process is also given below.

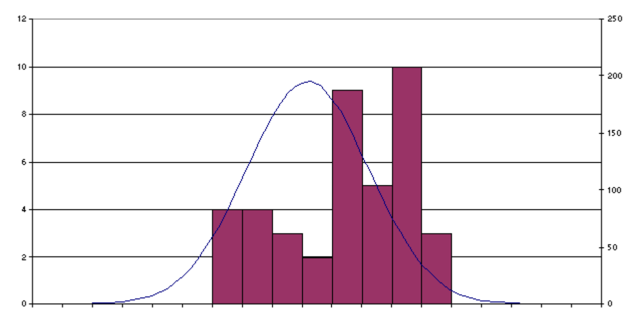


Figure 4. $\pm$X data with the normal distribution curve.

$\sigma = 0.0022$

$$Cp = \frac{USL\text{-}LSL}{6\sigma} = \frac{0.010}{0.0132} = .76$$

$$CpK = \min \text{ of } \frac{.005\text{-}.0001}{3\sigma} = .74, \frac{\text{-}.0001\text{-}.005}{3\sigma} = .74$$

As it can be seen from figure 4 and the above Cp and CpK value, the process is out of control and appears to be quite incapable. Again, to stress the short fall of this type of machine capability assessment, it does not take any other factors effecting dispensing into account except the gantry motion. Clearly, that is not the case in real world.

“Total System Accuracy” method on the other hand takes all other aspect of the dispensing into account and uses an external inspection tool such as optical inspection machine to measure the actual X and Y location of the dispensed dots or lines of liquid. This new test uses a stable substrate with well-defined fiducial features etched onto the surface. The substrate is optical quality float glass, given its high clarity and thermal stability, and measures 240mm wide and 330mm long. Black fiducials, 1.5mm in diameter are etched in each of the four corners. Their positions relative to each another are known and are verified by the optical inspection system.

The glass is loaded into the system, lifted and clamped in the same manner as a printed wiring board. A pump suitable for dispensing dots of adhesive is mounted and the usual calibration routines are carried out. The fiducials are taught to the system and their precise distance is entered into the pattern. A uniform grid of dispensed dots 8 rows high by 9 columns wide is then programmed relative to the lower fiducials, where the lower left fiducial is the anchor point and the lower right fiducial angularly aligns the pattern. Typical dot dispensing characteristics (such as lift height, size, dwells etc) for high speed dispensing, are used in this test. To ensure that the results would be the same as in an actual production environment, no extraordinary programming steps are used in this test. An SMT adhesive is used, as they generally have high thixotropic and adhesive properties. Due to high thixotropic nature of these adhesive, they retain their shape and position on the glass during the measuring process. Figure 5 shows a typical glass test plate.

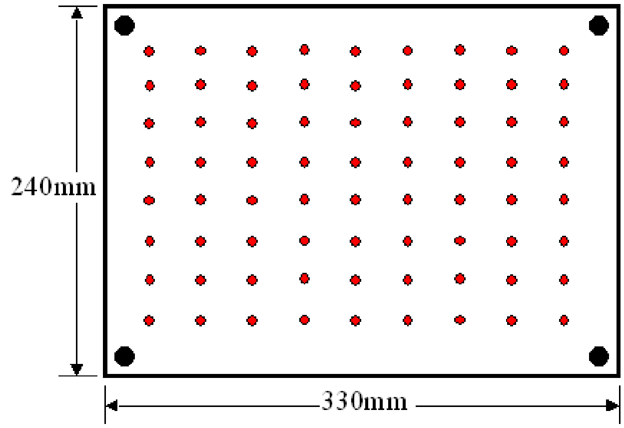
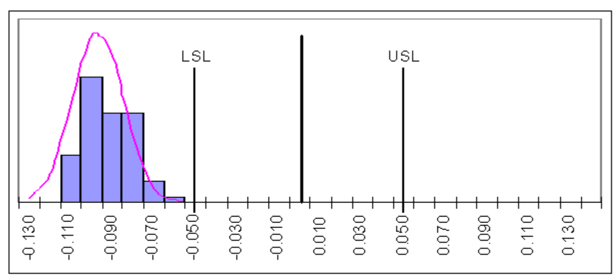


Figure 5. Glass test plate

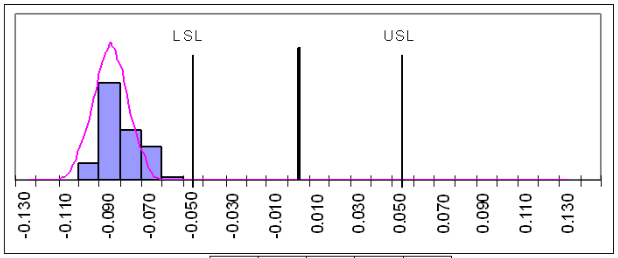
After the pattern is dispensed on to the glass substrate, it is placed onto the measuring system. The measuring system locates the fiducials and measures the adhesive dots in relation to them. Below is an example of results from this type of test and measurement.

This test method makes the diagnosis of errors much easier. Figures 6-8 shows the results from the above test for 3 scenarios: low Cp & CpK, high Cp & low CpK and high Cp & CpK.



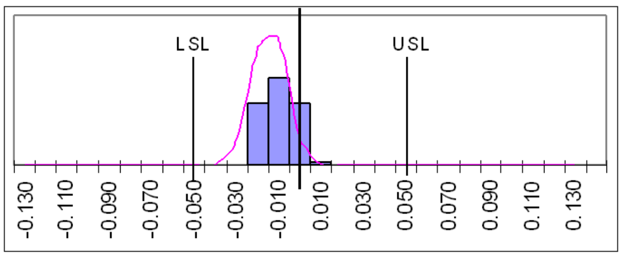
X axis	Y axis			
-0.0970	0.0562	mean	0.0508	USL
0.0121	0.0117	1 std dev	-0.0508	LSL
1.4	1.4	Cp		
-1.3	-0.2	CpK		

Figure 6. Glass plate result with low Cp & CpK



X axis	Y axis			
-0.0896	0.0541	mean	0.0508	USL
0.0080	0.0078	1 std dev	-0.0508	LSL
2.1	2.2	Cp		
-1.6	-0.1	CpK		

Figure 7. Glass plate result with high Cp & low CpK.



X axis	Y axis			
-0.0146	0.0041	mean	0.0508	USL
0.0080	0.0078	1 std dev	-0.0508	LSL
2.1	2.2	Cp		
1.5	2.0	CpK		

Figure 8. Glass plate result with high Cp & Cpk.

Cp and CpK are two very useful statistical measures that can be used to indicate how well the equipment can accomplish a high accuracy dispensing task, In many high density applications, there is little room between a flip chip die and nearby passive components. The dispensing challenge is to get a needle or a stream of underfill material in this gap without contaminating the top side of the die. For example, if the gap is .5mm wide, and the needle is .25mm in diameter, .25mm of total clearance remains before the needle hits. This .25mm (or +/-.125mm) becomes the spec limits for the process. Any deviation greater than this will result in the needle or stream striking the die or contaminating nearby components. The Cp number will indicate, given a target location, how much repeatability can be expected. The Cpk number includes this repeatability and adds in the targeting errors. It is the only true representation of the capability of the system.

CONCLUSION:

There are a number of mechanisms that can contribute to liquid placement inaccuracies. One of the most important tasks of any equipment manufacturer is to identify these inaccuracies and take measure to fix it. “Total System Accuracy” method of characterizing the machine allows you to do just that. For example, when a machine displays a low Cp and CpK value it indicates that machine can neither dispense repeatably nor on target. Causes for these kinds of results are typically due to, flimsy gantry and dispense technology used; poor settling, board clamping, camera to needle offset calibration, and fiducial finding techniques or models used. High Cp or low standard deviation value and Low CpK value usually indicates poor camera to needle calibration, poor fiducial alignment. Finally, a high Cp and CpK value indicates that the process in not only repeatable but also well targeted. Obviously, this is the most desirable status for a dispensing equipment to achieve to meet today’s high accuracy and repeatability demand.

It is highly beneficial to the end user of a dispensing machine to know the exact capability of a given platform. “Total System Accuracy” method has the potential to be used industry wide, as a standard, to provide this crucial information to the customer.