Accuracy Improvements for the Dispensing Operation

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Abstract
Technology requirements within the electronics industry are rapidly driving the miniaturization of and increasing component densities on the printed circuit board. As a result, assembly equipment must offer increased accuracy capabilities while delivering both the required high yield and high throughput capabilities.

Typically, dispensing platforms only specify XY repeatability and/or dot placement accuracy, expressed 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 and camera-to-needle offset calculations.

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. Call it "Total System Accuracy™." By calculating the "Total System Accuracy" of a dispensing platform, including material placement accuracy on a substrate relative to a defined target, it is possible to determine the true platform capability and provide a better understanding of how the product will work for various applications.

Introduction & History
In the early days of dispensing, much assembly equipment was neither as accurate nor precise as today's technology. This was acceptable because early dispensing tasks were neither rigorous nor demanding. The processes being automated were relatively easy – such as latex solder masks, inks and gasketing materials. Most of these processes were "taught" to the machine by the operator tracing the desired path and which was subsequently stored for replay. A successful process relied on accurate fixturing and pattern replay repeatability.

Gantry Accuracy
When SMT exploded in the early 1990's, machine accuracy started to become important. Users wanted to dispense small quantities of surface mount adhesive between pads to bond passives and SOIC's to the board. A trend toward data-driven dispensing vs. "taught" patterns began to emerge and accuracy of the system became more important. Equipment suppliers began to express their capability in varying ways, and in some cases accuracy was stated as "plus or minus" some value:

$\pm$.005 inches

When reviewing accuracy data, it is important to know how the data was collected. 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, a table can be plotted showing the desired vs. actual positions –for a sense of 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. Results might look like this:

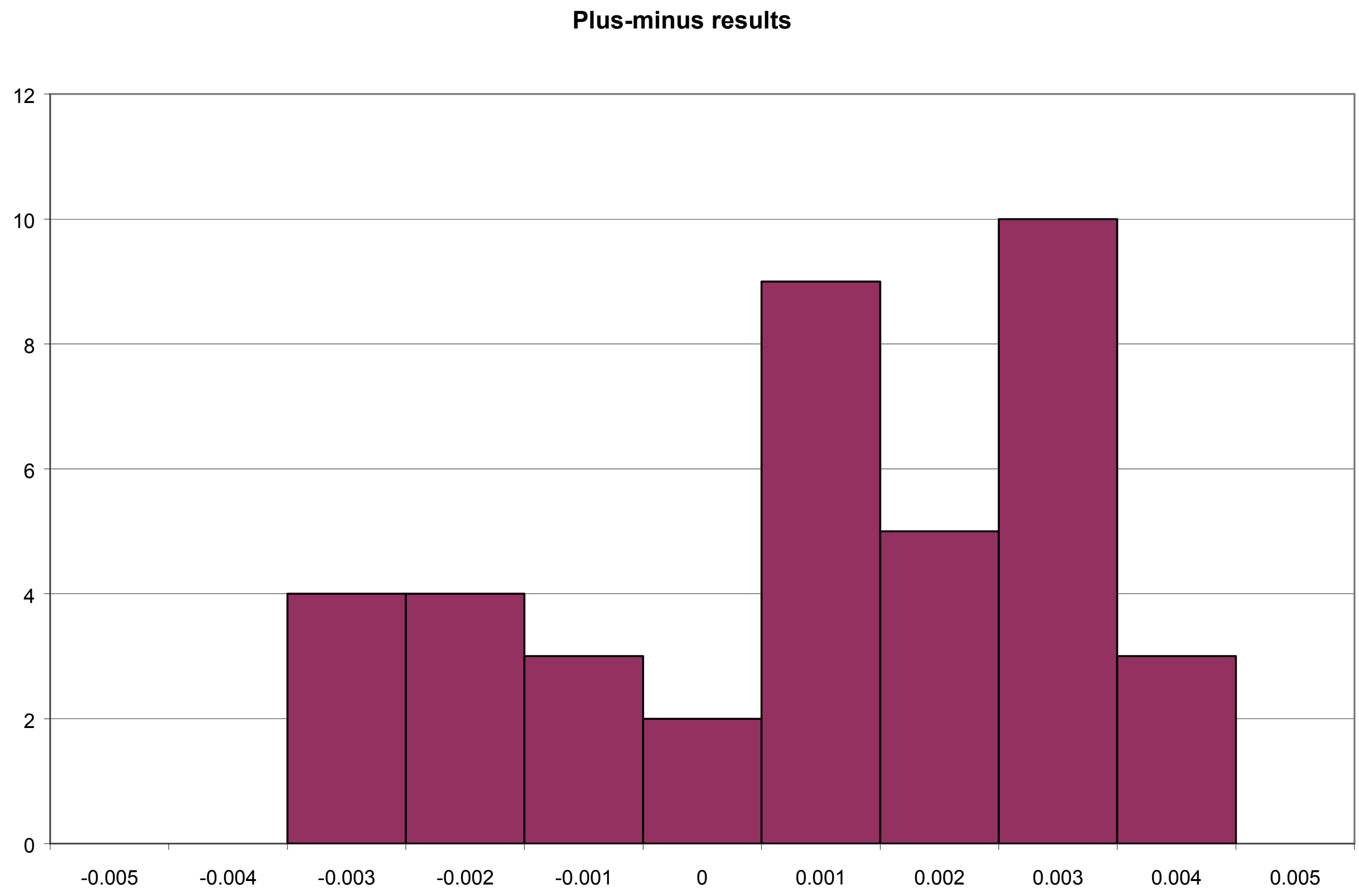

Figure 1 - Typical plus-minus results.

This result passes the plus-minus requirement, but the trend is disturbing. Only two measurements are ‘dead on’ and the data is spread over a large area. This method fails to provide a clear, overall trend view. Therefore, Statistical Process Control is necessary to fully understand the capability of a gantry and its accuracy.

Introduction to SPC.
While this paper is not intended to teach SPC, a quick review of background and definitions involved in SPC will assist in the understanding of how the use of SPC methods can simplify the understanding of machine capability.

Definitions of Terms
Standard deviation or sigma:
This is the hardest term to understand. Loosely stated it is “the mean of the mean”. The standard deviation is a statistic that tells you how tightly all the various examples are clustered around the mean in a set of data. When the examples are pretty tightly bunched together and the bell-shaped curve is steep, the standard deviation is small. When the examples are spread apart and the bell curve is relatively flat, that tells you have a relatively large standard deviation.[i])

It is sometime expressed with the Greek letter σ.
Cp: This is a good expression of process capability. Specifically it is the desired range of variation divided by the spread.

$$\frac{\text{Upper spec limit-Lower spec limit}}{\pm 3\sigma}$$

It is generally understood that values less than 1.0 are not in control. Anything greater than 1.0 is desirable.
CpK: This is an expression of process capability with respect to a target. The lesser of:

$$\frac{\text{Average-LSL}}{3\sigma},\ \frac{\text{USL-Average}}{3\sigma}$$

Spec limits: These are values, determined by the user, to define the boundaries of the process. If unstated, it is generally understood that they are equal to the 3σ goal. Experienced professionals will quickly notice that this leaves no room for targeting error and forces a Cp of greater than 1.0 to achieve a CpK equal to 1.0.

When re-evaluating the data used in the plus minus example, one standard deviation of the data used is equal to .0022. Multiplied by 3 results in 3 standard deviations or 3σ. Simply put, the data that appears to fit within ±. 005 is:

±. 0066@3σ.
Cp=(USL-LSL)/6σ=.010/.0132=.76
CpK=min of: (.005-.0001)/3σ=.74,(-.0001-.005)/ 3σ=.74

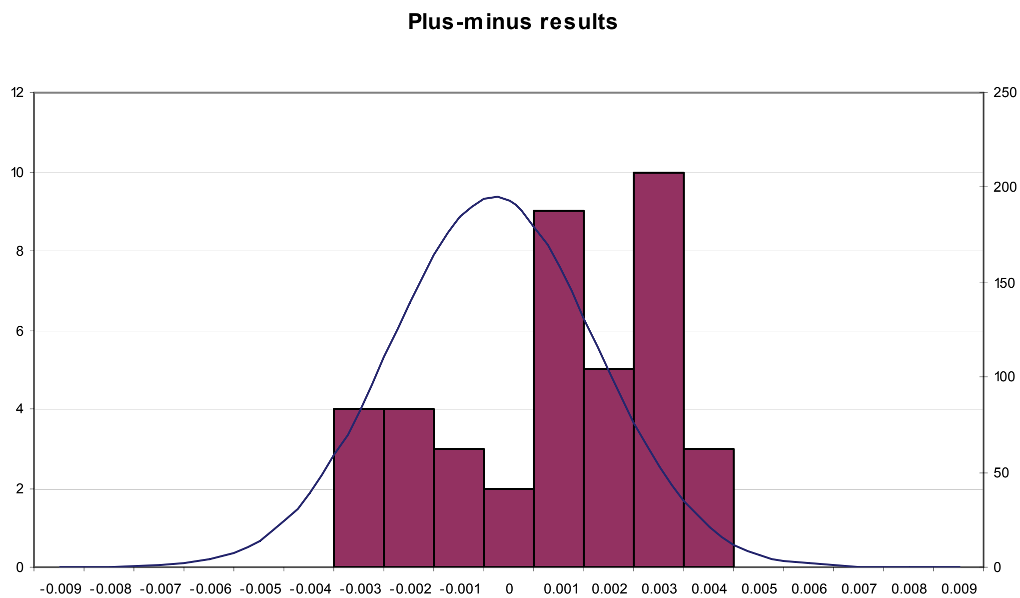

Figure 2

The same chart as figure 1, includes a bell curve showing the distribution. One can conclude that the axis measured on the system measured is not in control.

Placement Accuracy.
In the previous example, the data was taken directly from a gantry axis. To better evaluate a systems capability one would use an Optical Inspection machine, such as the Avant Supra, made by Optical Gaging Products, Inc. in Rochester, NY, or the View Summit, made by View Engineering of Simi Valley Calif., to measure the actual X and Y location of the dispensed dots or lines of liquid. This method more accurately measures a systems performance as it includes all the aspects of the system in the evaluation, and not just the motion of the gantry. The output of the measuring machine is a list of X and Y coordinates for the dispensed dots or lines. The more sophisticated systems include an SPC software package that will calculate the process capability.

Error Mechanisms
There are a number of mechanisms in a dispensing system that can contribute to placement errors. Some are:

1. **Gantry capability.** The ability of the axis or axes of a gantry to achieve an accurate position. Contributing factors are:
    a. <u>Foundation</u>: A stiff, well-damped support system is needed to ensure that the gantry has a solid base.
    b. <u>Moving parts</u>: Need to be equally light and stiff for maximum acceleration and minimal deflection under load.

c. Bearings: Conservatively rated, low friction, high stiffness bearing ways are required..
d. Drive motors: Should be closely and stiffly coupled to the load to ensure sufficient motion capability and swift settling.
e. Feedback: High-resolution linear feedbacks tightly coupled to the moving carriages.
f. Compact design: The closer that the bearings and feedback device are to the work plane the less Abbe' error is introduced.
g. Motors and controls: Must provide swift motion and crisp positioning with minimal overshoot and steady state error.

2. **Vision and alignment.**
   a. Camera scale factor: This conversion factor, usually expressed in mm/pixel, is crucial for accurate calculation of feature position. For example, the difference between .0356mm/pixel and .0354mm/pixel appears small, yet when examining a feature that is 400 pixels wide the reported size of that feature varies by .080mm!!
   b. Errors in reported position during feature find/measure: A stable platform and high resolution and high speed feedback is critical. If a fiducial or an edge is found, but reported to be in a different position due to instability of the gantry, then all subsequent data derived from that position report is in error. This can lead to substantial scaling and rotation errors of a dispensed pattern.
   c. Camera to needle calibration offset errors-Typical camera-to-needle calibration procedures use multiple processes. For example, when a dot is dispensed on to a surface, and the camera is moved to that position, an image of the dispensed dot is acquired. The image is analyzed by the system to determine where the dot is in the field of view. The position is reported in pixels, which are then converted to millimeters using the camera scale factor. One can see that any camera scale and positional errors during this calibration can be additive.

3. **Actual liquid placement errors**
   a. Needle shape and cleanliness: Any variation in how the liquid leaves the orifice/needle will show up as placement error. To minimize this, needles of obvious high quality must be used. Also, exceptional accuracy and repeatability of the Z axis is required to ensure that the needle/orifice is always at the correct height. If the needle/orifice are contaminated this will allow a variation in dot placement, the amount of offset is a factor of three things:- amount of contamination, distance of the material release point to the substrate and material dispense speed or velocity- non contact/jetting methods tend to suffer more due to the nature of ballistic technology.

Total System Accuracy: A New – and the Better – Way To Test

Overcoming the shortcoming and concerns described to this point requires a new testing means that truly evaluates a system – the aforementioned "Total System Accuracy." 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. Dot characteristics (lift height, size, dwells etc are typical for high speed dispensing. To ensure that the results would be the same in an actual production environment, there is no extraordinary programming that wouldn't otherwise be in a typical pattern. An SMT adhesive is used, as they generally have high thixotropic and adhesive properties – meaning that the dots will retain their shape and position on the glass during the measuring process.

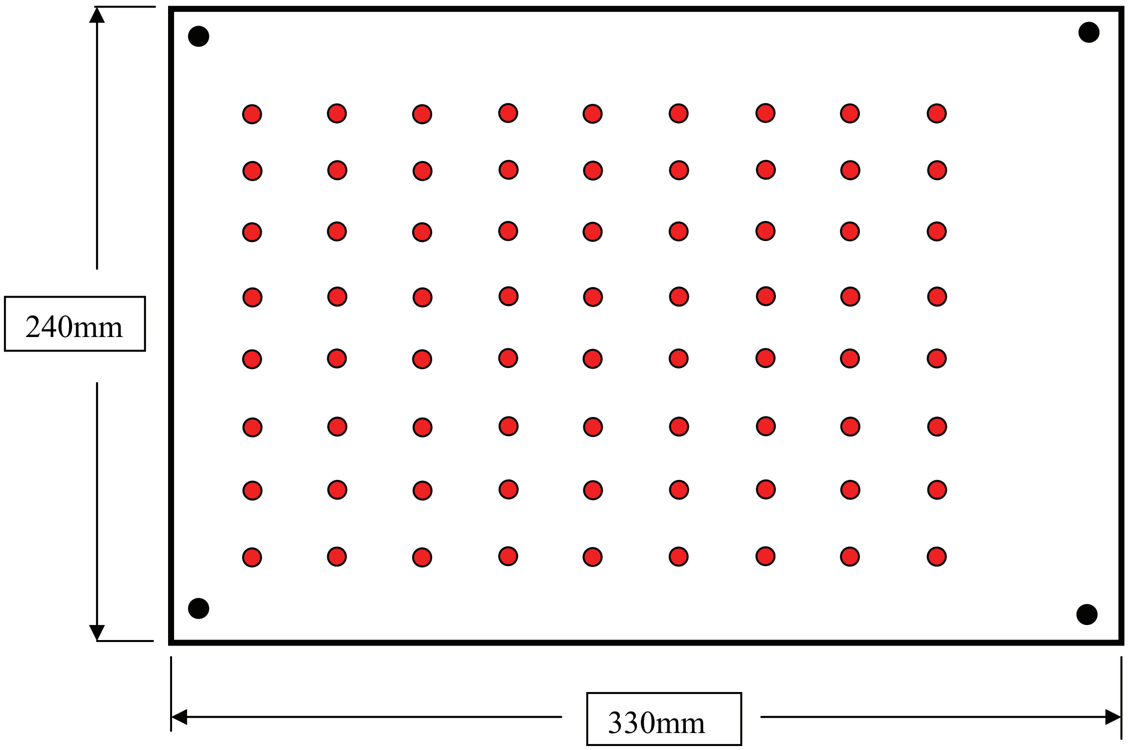

Figure 3 - Dispense Test Substrate

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.

Interpreting results
The "Total System Accuracy" test method makes the diagnosis of errors much easier. Some examples:
Low Cp and low CpK. This is the worst condition. The machine can neither dispense repeatably nor on target. Causes for these kinds of results are typically: (See Figure 4.)

- Flimsy gantry
- Dispense technology used
- Poor settling
- Poor board clamping
- Poor camera to needle offset calibration
- Poor fiducial finding techniques or models

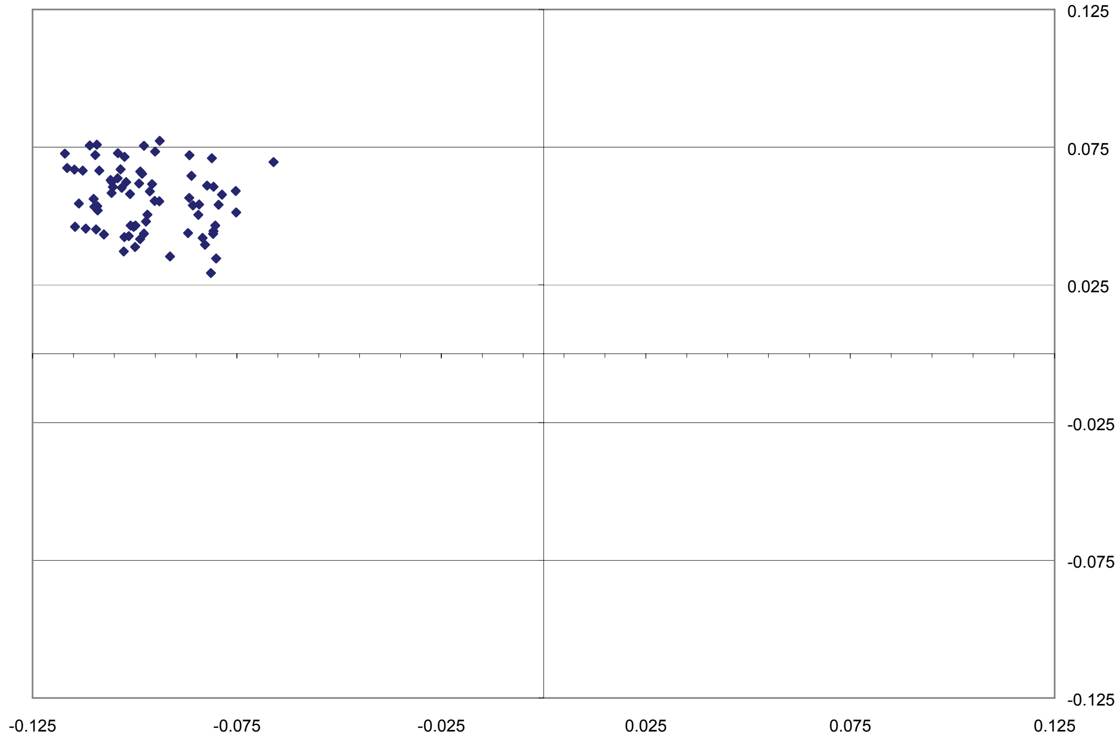

Figure 4

High Cp or low standard deviation value and Low CpK value

- Poor camera to needle calibration
- Poor fiducial alignment

These conditions lead to a well-grouped pattern that is not well targeted. While some of the system is working well, those parts of the system that affect targeting need improvement. (See Figure 5.)

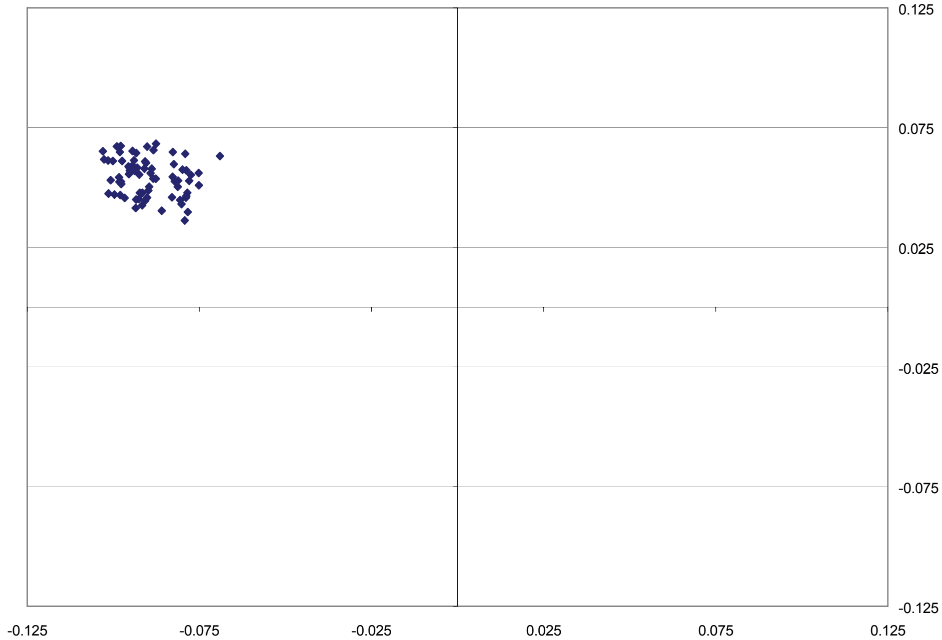

Figure 5

Cp ≅ Cpk. A system that is not repeatable, but is well targeted. (See Figure 6.)

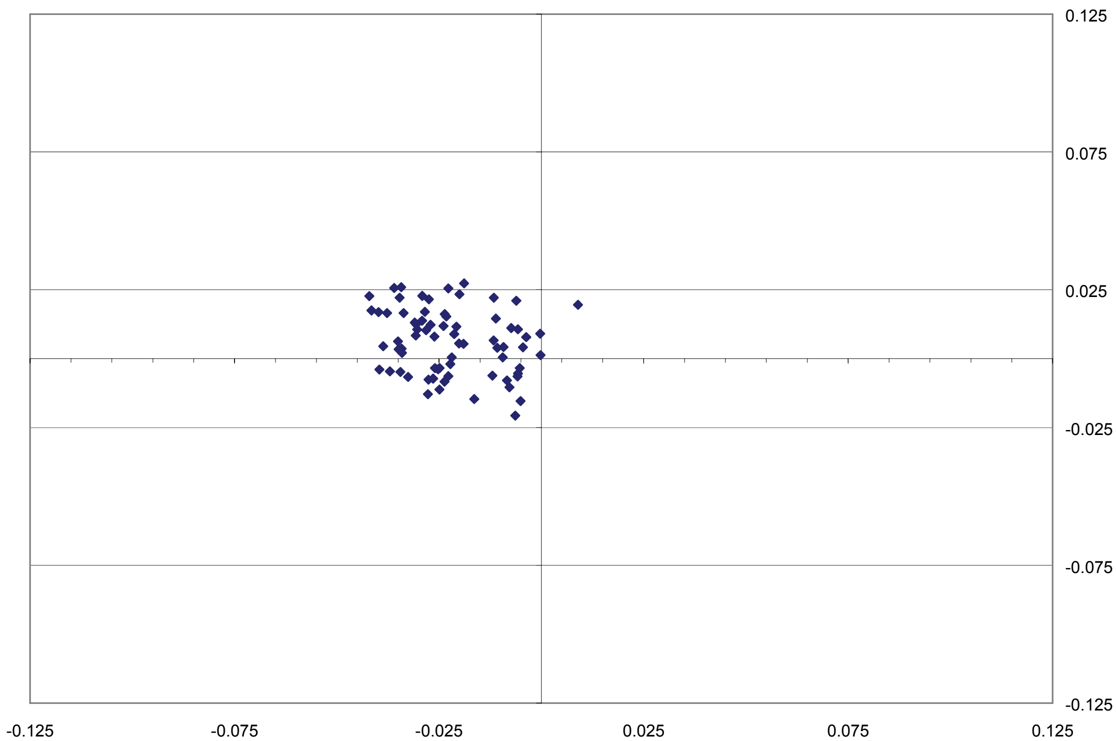

Figure 6

Hi Cp and Cpk. Obviously, the most desirable outcome. The system is both highly repeatable and well targeted. (See Figure 7.)

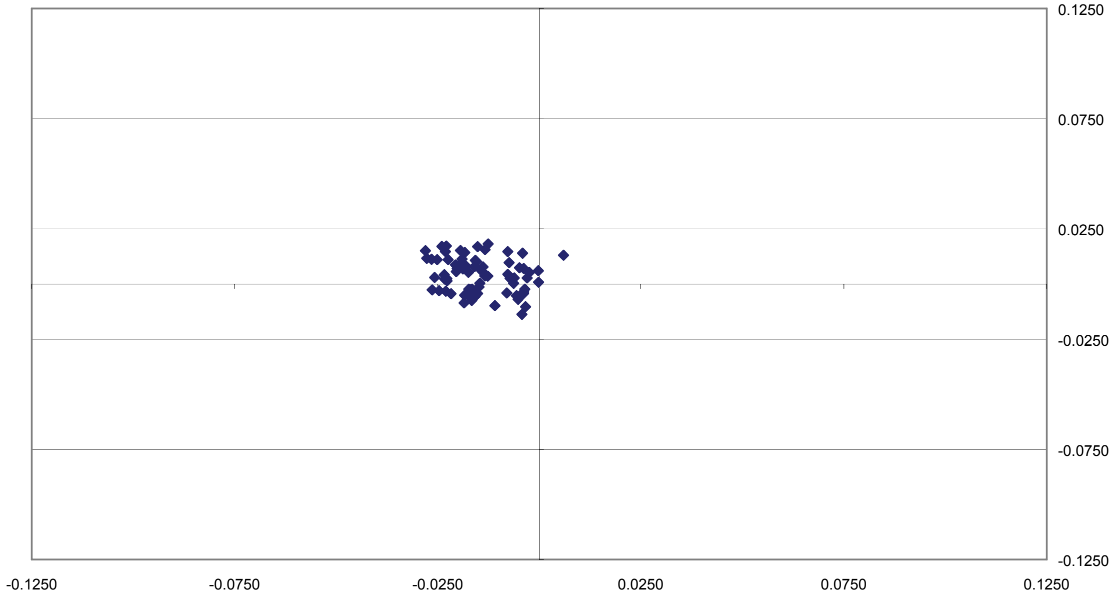

Figure 7

More analysis of this desirable condition:

Table 1

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**		

Units:mm

Figure 7 shows that we have well defined cluster (Cp) that is pretty well (but not ideally) targeted. (CpK)

Table 1 indicates this to us because the CpK value is less than the Cp value of X-axis. The X-axis Cp values indicate that we are capable of being accurate. The Cp and CpK for the Y-axis indicate we are well in control and, in fact, are capable of 6 sigma reliability. The histograms in figure 8 show the individual distribution for each axis. Note that the bell curves are steep and narrow. This is a good visual indicator of the performance of the axis.

Why is Cp and Cpk so important?
To illustrate how the Cp and Cpk can be used to indicate how well the equipment can accomplish the task, let's examine a typical 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 touching the die as touching the die will lead to top die contamination. 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.

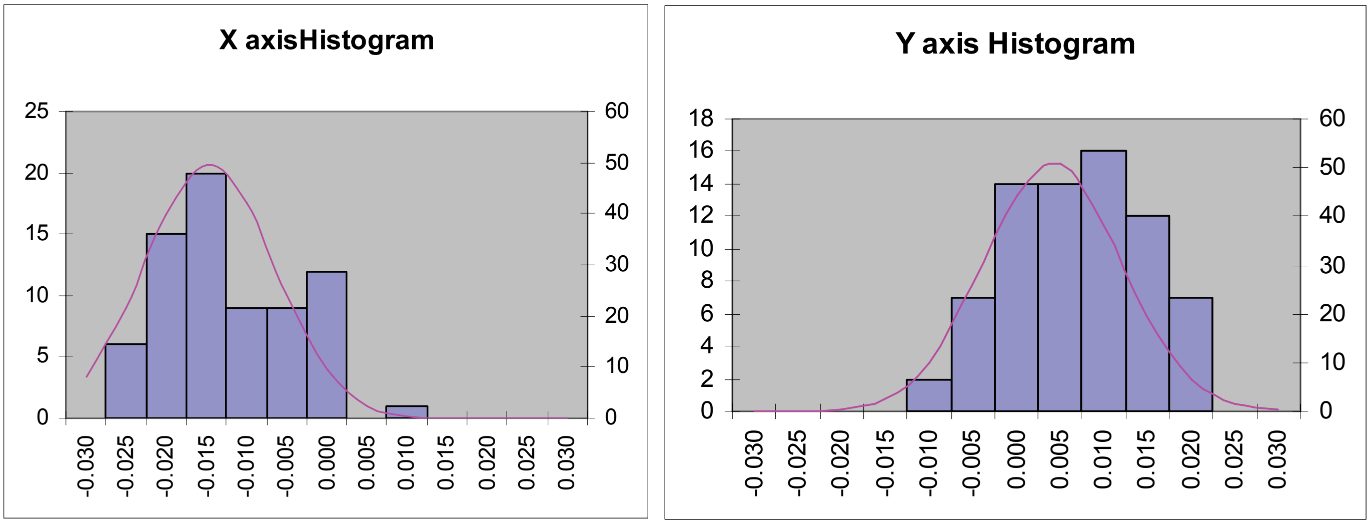

Figure 8 - X and Y axis Histograms

Conclusions

There are a number of mechanisms that can contribute to liquid placement inaccuracies. A new testing method – Total System Accuracy -- can be used to determine which combination(s) of mechanisms exist in a platform. Platforms and gantry systems that are conservatively designed with massive supporting structures, stiff bearing systems, and high-resolution linear feedback devices achieve higher stiffness and response. This results in placement errors that are small and tightly grouped. Well-designed and implemented vision systems and flexible algorithms provide high quality position information to the controller that results in high targeting accuracy. This is true whether you are dispensing dots of adhesives relative to fiducial marks or Lines of underfill relative to die edges.

Assembly equipment users need not to purchase and implement the equipment and methods described in this article – rather it is advised that users check to ensure that their equipment providers have such equipment and methodology in place. Additionally, there are reputable third-party validation services that can provide the same level of information.[ii]

References

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[i] http://www.robertniles.com/
[ii] Cetaq-americas.com