As originally published in the SMTA Proceedings

Improved Process Yield with Dynamic "real-time" Dual Head Dispensing

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Abstract

Today's unique assembly challenges are comprised of complex PCB panelization, involving identical PCBs with a goal towards increased production capability, due to a reduced footprint of the Production Floor. Identical PCBs that are within the same panel, with uniform spacing in an array or carrier, need to be dispensed at the same time. All these high-mix challenges have gone mainstream and affects the real productivity and throughput. Existing manual dual head dispensing systems do not consider the rotational correction for the second head, which leads to yield loss. To eliminate the yield loss on second head, there is a mini XY drive system incorporated that provides fast and accurate dispensing to double the process capabilities over the same work area. Dynamic dual head dispensing uses a unique mini XY drive system on left head, mounted on a separate Z-axis, to dynamically control the position of the second head for accurately aligning to a second part, while synchronously dispensing both parts. Machine vision system performs the substrate alignment for each identical PCBs that are individually placed in a carrier, which provides greater potential for variation in offset and skew. During synchronous dispensing for the second part with the DDH, all the kinematic adjustment is performed with calculated values, from the skew angle and scaling factor. This technique guarantees increased productivity whilst maintaining yields through unsurpassed accuracy. DDH also provides the same level of adjustment and rotational correction for all step and repeated PCB's, flex circuits and panel designs. If product contains odd number of units then either of the head can be programmed for dispensing while the others can't.

This paper examines proven methods to determine the dot/line positional accuracy along with mass flow rate for both heads during synchronous dispensing. This paper will also address the challenges faced, and how the rotational correction can achieve up to 2X higher dispense productivity then existing single/dual head dispensing systems.

Introduction

Automated high-speed fluid dispensing systems are used to dispense complex patterns onto the substrate with high accuracy and long-term repeatable performance. When it comes to PCB assembly, panelization has been a good manufacturing tool, which has been referred to as grouping of PCBs into a single panel array. In high volume, PCB manufacturers use panelization for higher throughput. In low manufacturing PCB manufacturing, panelization might not be the required due to more expenditure required to resolve design restrictions on thickness and space between individual PCBs. In this scenario customers usually prefer individual PCBs in a carrier tray like a JEDEC tray. All these scenarios can be covered through dual dispenser valves simultaneously dispensing side by side, having either identical substrates laid out as individual pieces or in a single PCB panel.

Standard fluid dispensing systems involve a dispenser valve mounted to the XY gantry, which is movable to dispense patterns at desired locations onto the substrate, and is positioned in horizontal XY plane, through the conveyor system. Dispenser valve can be positioned in the three-dimensional space, dependent upon the component's orientation on the substrate. The gantry system is driven through a drive mechanism and controlled through a motion control system. To dispense a pattern, the controller determines the location and orientation of each substrate through a camera system mounted on the gantry system itself. The camera system does the vision capture of reference points or fiducials located on top of the substrate, through a pre-programmed path set in the dispense process program. Captured vision images of the reference points determine the location of the substrate, in the XY coordinate plane. Height sensing is performed through a height sensing laser, mounted on the gantry, to determine the dispenser valve needle tip position from the substrate. The motion controller then positions the dispenser valve at the XY programmed location, followed with the dispenser valve needle tip coming down to the programmed dispense gap from the substrate. At this point, the dispenser valve starts dispensing a pre-programmed fluid pattern onto the substrate.

To optimize the line throughput, dual dispenser valves pitched at a desired distance are used to dispense identical substrates synchronously. If PCBs are panelized in a single processing panel then all the PCBs must be rotated in the horizontal XY plane, in the same manner as shown below in Figure 1. First and second substrate alignment can be found through global reference points or fiducials located on the body of the panel. Existing dual dispensing methods automatically realigns patterns to make a one-time automated adjustment of valve 2 relative to valve 1 prior to dispensing, and only considers the global skew. Therefore, both identical PCBs get dispensed synchronously, based on global skewness.

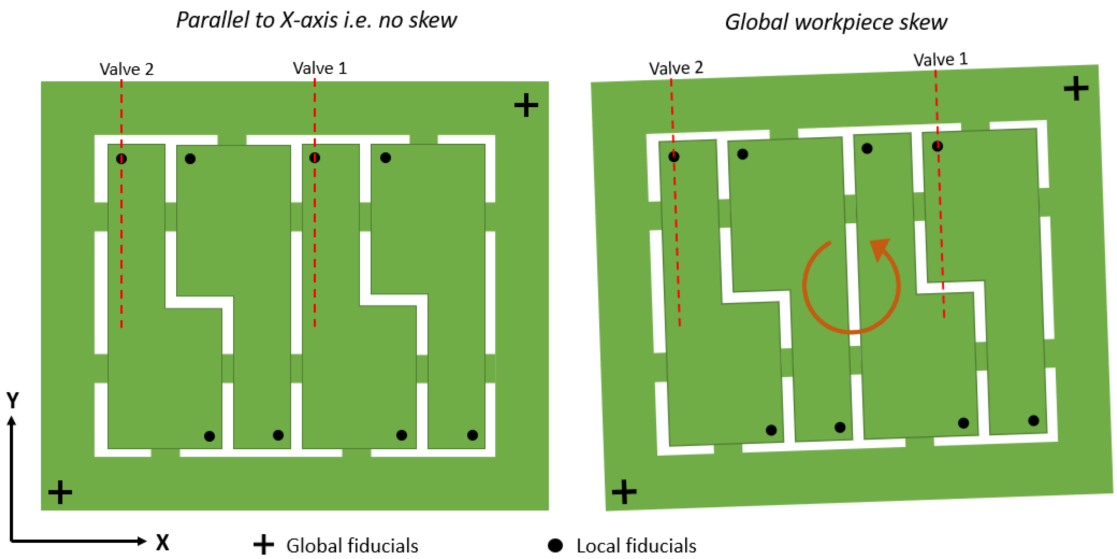


Figure 1 Synchronous dispensing based on global skew

Advances in Dual Head Dispensing

Dual head dispensing has been driving on a single Z-axis to dispense identical patterns with each dispenser valve synchronously. Most of the existing techniques only considers the lateral shift of the second identical pattern in either X or Y direction but not the part-to-part rotation. Lateral shift is generally considered with the fixed micrometer adjustment on either X/Y or both directions on the mounted dispenser valves, prior to dispensing operation as shown in Figure 2 below.

Conventional dual dispensing methods does not incorporate the dynamic real time adjustment of both heads during active dispensing onto the identical substrates. If parts are skewed to each other in a tray and only global skewness is considered, then the dispense pattern gets misaligned, as shown on right side of Figure 2. Only global fiducials are captured which defines the global alignment of the tray/board leaving behind the part to part rotation of individual parts in the tray. For part to part rotation, movable gantry system is required to capture the local fiducials or reference points through the camera vision system for each individual PCB. Parts can be locally skewed due to improper tooling or substrate sized smaller than the carrier pocket tray where the part is seated. Therefore, conventional dispensing methods are uncapable of active correction, to consider the skew angle and scale factor locally. Scale factor is based on where the gantry vision system finds the fiducials or reference points in comparison to the programmed locations in the process program. Mounting each dispenser valve on an individual Z-axis drive system, provides the capability to compensate for part-to-part rotation through the local reference points or fiducials. Part to part rotation considers the skew factor and scale factor for each individual PCB.

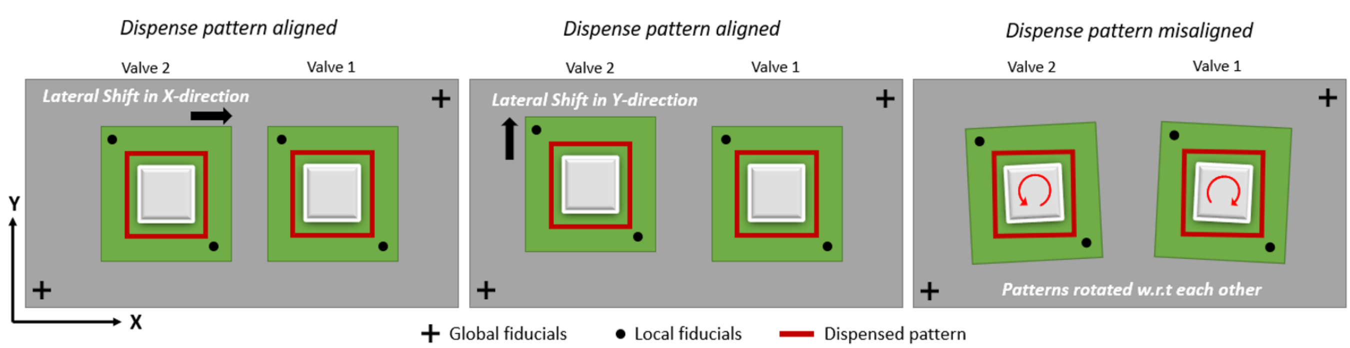


Figure 2 Synchronous dispensing during different scenarios

The machine gantry system is configured to provide movement in XY direction with the first dispenser valve coupled to the gantry for dispensing. A second dispenser valve is coupled to the gantry through the automatic adjustment mini drive system to drive the second dispenser valve for dispensing. A mini XY drive system is mounted and configured onto the second Z-axis to move the second dispenser valve in XY direction, to manipulate spacing between the first and second dispenser valves. A controller controls a dispense operation of the first dispensing valve on the first electronic substrate pattern and a dispense operation of the second dispensing valve on the second electronic substrate pattern.

The mini drive system includes a linear bearing secured to the gantry and mounting block, configured to ride along the linear bearing, and coupled to the second dispensing valve. The automatic adjustment mechanism includes a first linear drive motor assembly configured to move the mounting block along the linear bearing. The first linear drive motor assembly includes a ball screw driven linear actuator, which is driven by a mechanically coupled motor. The automatic adjustment mechanism further includes a first bracket secured to the mounting block, the first bracket extending in a direction perpendicular to a direction of the linear bearing, and a second bracket secured to the second dispenser valve and configured to ride along the first bracket. The automatic adjustment mechanism also includes a second linear drive motor assembly configured to move the second bracket along the first bracket. The second linear drive motor assembly includes a ball screw driven linear actuator, which is driven by a mechanically coupled motor. For each of the first dispensing unit and the second dispensing unit, the automatic adjustment assembly also include a Z drive mechanism configured to support and lower the dispensing unit when performing a dispense operation with the first dispensing unit.

Technological Advantages

Multiple independent dispensing systems are sometimes used to increase the production of dispense operations. This solution is often expensive, requiring multiple machines, additional manufacturing space and in some cases multiple machine operators. In typical operations, manufacturing floor space is both limited and expensive. It is therefore desirable to reduce the "footprint" of each manufacturing system on the manufacturing floor and to reduce the number of separate machines that need to be operated and maintained.

For some applications, multiple instances of the same circuit pattern are fabricated on a common substrate. A common example is a circuit pattern for a cell phone, wherein four or more patterns may be disposed on a single substrate. In such cases, there is often a fixed and uniform offset between the multiple instances of the circuit patterns, which may be disposed on a common substrate and separated from one another after completion, along the perforations. Furthermore, it is known in the industry that a dispensing system with multiple dispensing units or pumps may be utilized to increase throughput. In such systems, the offset distance between the multiple dispensing pumps may be adjusted to be substantially the same as the offset distance between the multiple circuit distances, and if the accuracy of this offset adjustment is within the accuracy requirements of the resultant dispense pattern, then the multiple dispensing pumps can be positioned simultaneously by a single X, Y, Z gantry and operated simultaneously.

Experimental Set-up and Analysis

The main objective of this research is to conduct a detailed study to match the positional accuracy of the fixed right dispenser valve to the left dispenser valve mounted on the mini XY drive system, along with good dot and line dispense quality. The study involves the use of a high-speed dispensing system with a pneumatic jet pump installed, which can currently dispense material in a repeatable manner without affecting the dispense quality.

The study begins at a point of performing the experiment on a pneumatic jet pump. A nozzle heater was used to maintain the fluid temperature equivalent to ambient temperature conditions. The study concludes by running the experimental run to determine the dot and line positional accuracy to confirm the robustness of the mini XY drive system with minimal effect on dispense quality. Experiment involves the use of glass jig plates to perform the dot and line positional accuracy tests.

Dot Positional Accuracy

Dot positional accuracy is measured as the difference between the commanded position and the actual dispensed position for each individual dot, through dispensing an array of dots. Positional accuracy also defines whether the dot can shoot vertically or not (i.e., downwards) from the needle tip onto the substrate. From the customer’s point of view for field engineering applications, the dispensing should allow for certain dot characteristics such as good shaped circular dots with good positional accuracy. Measurement of dispensed dots on the glass jig are performed with the Optical measuring machine, through back lighting to measure the shift in XY direction. Each head needs to dispense 84 dots for each orientation type. The Orientation type displayed, resembles the smartphone manufacturing board, which generally has patterns oriented either at 0 degree or 180 degrees as shown in Figure 3 shown below. Height sensing is performed on the glass to ensure correct dispense height from the glass jig top surface. Each pattern is rotated either clockwise or counter clockwise by 2 degrees to prove the left head dispense accuracy is equivalent to the right head in real synchronous mode dispensing.

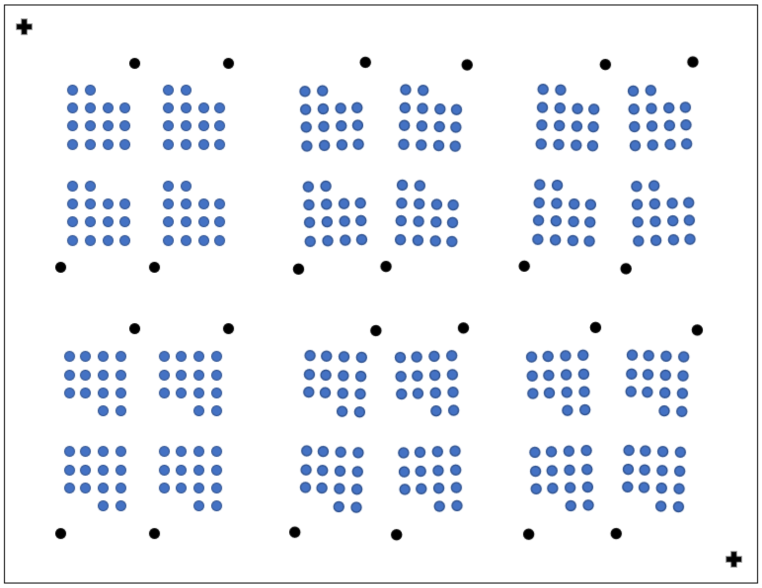


Figure 3 Glass Plate Jig for Dot Positional Accuracy

Process capability index, *Cpk* measures how close the process is to the target and how consistent the process is around its average performance. An operator may be performing with minimum variation, but he/she can be away from his/her target towards one of the specification limits, which indicates lower *Cpk*, whereas *Cp* will be high. For both the shifts, high value of *Cp* and low value of *Cpk* indicate that the process has a centering problem. A generally accepted minimum value for the indices is 1.33 according to industry guidelines to determine whether the process is capable or not. Process capability is determined for ±50 microns specification limits at ±3 sigma capability. Table 1 indicates the process capability for left head is found to be equivalent to the right head for both 0 degree and 180-degree board orientation. *Cpk* values are also much higher than the industry acceptable standard for both heads in real time dynamic dispensing in synchronous mode.

Table 1 - Process Capability in synchronous mode with mini XY drive system

Head Type	Left	Right	Left	Right
Pattern Orientation	180°	180°	0°	0°
	Standard deviation, millimeters			
X Position	0.0077	0.0075	0.0079	0.0062
Y Position	0.0083	0.0055	0.0055	0.0064
	Cpk value			
X Position	**2.02**	**2.01**	**2.08**	**2.24**
Y Position	**1.84**	**2.54**	**2.61**	**2.59**

Line Positional Accuracy

Line positional accuracy is measured as the shift between the commanded location of the programmed line to the actual dispensed line. Line comprises of series of dots stacked together at a correct spacing and align properly to form a straight and non-scalloped line. Once the dots touch each other, the boundary is scalloped but the dots are compressed further, and fluid takes the shortest path to the deepest scallop, to form a perfectly straight line. The closer the dispense valve is to the substrate, the better the line quality.

Experimental test was performed on the glass accuracy plate shown below in Figure 4. Patterns on the left side are skewed at an angle of 1.5 degrees in counter clockwise direction, while in the middle patterns are skewed at an angle of 1.5 degrees in the clockwise direction. Patterns on the extreme right side are not skewed at all. Pattern on both extreme sides are pitched at 44 millimeters. Fiducial alignment is performed before dispensing the lines around the edges on the chip. The machine vision system locates the chip edges through a vision algorithm and dispenses line patterns along the chip edges at the programmed position offset. Position offset is defined as the offset distance away from the center of the chosen chip edge, in the direction perpendicular to the chip edge. Lines highlighted in blue color are dispensed at a position offset of 0.75 millimeters from dispense height of 2 millimeters. Patterns are dispensed with both heads in synchronous mode with the mini XY drive system set-up.

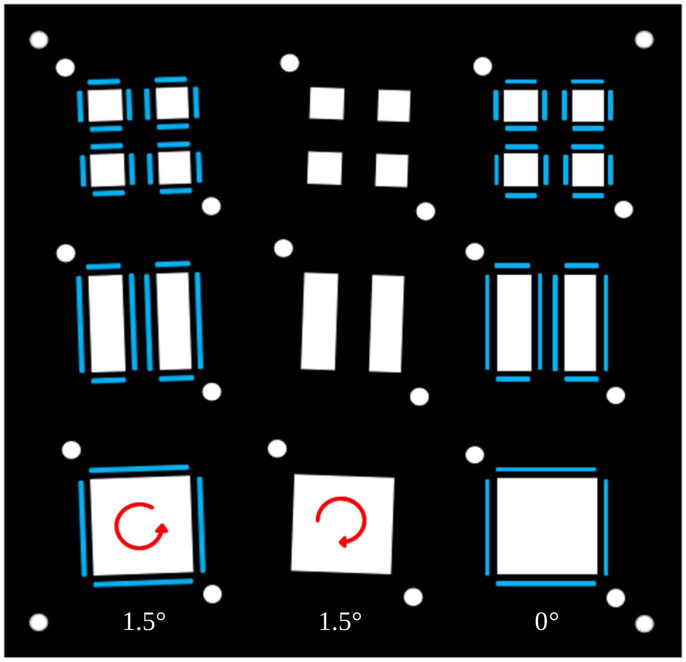


Figure 4 Glass Accuracy Plate for Line Positional Accuracy

A metrology tool named SmartScope has been programmed to measure the distance between the center point of the programmed centroid on the dispensed line (highlighted in red/blue) and the midpoint of the programmed chip edge as shown below in Figure 5. Below is the diagram of the description of measurement on the metrology system. Specification limits are based on tolerances of ±50 microns around the 0.75 millimeters position offset.

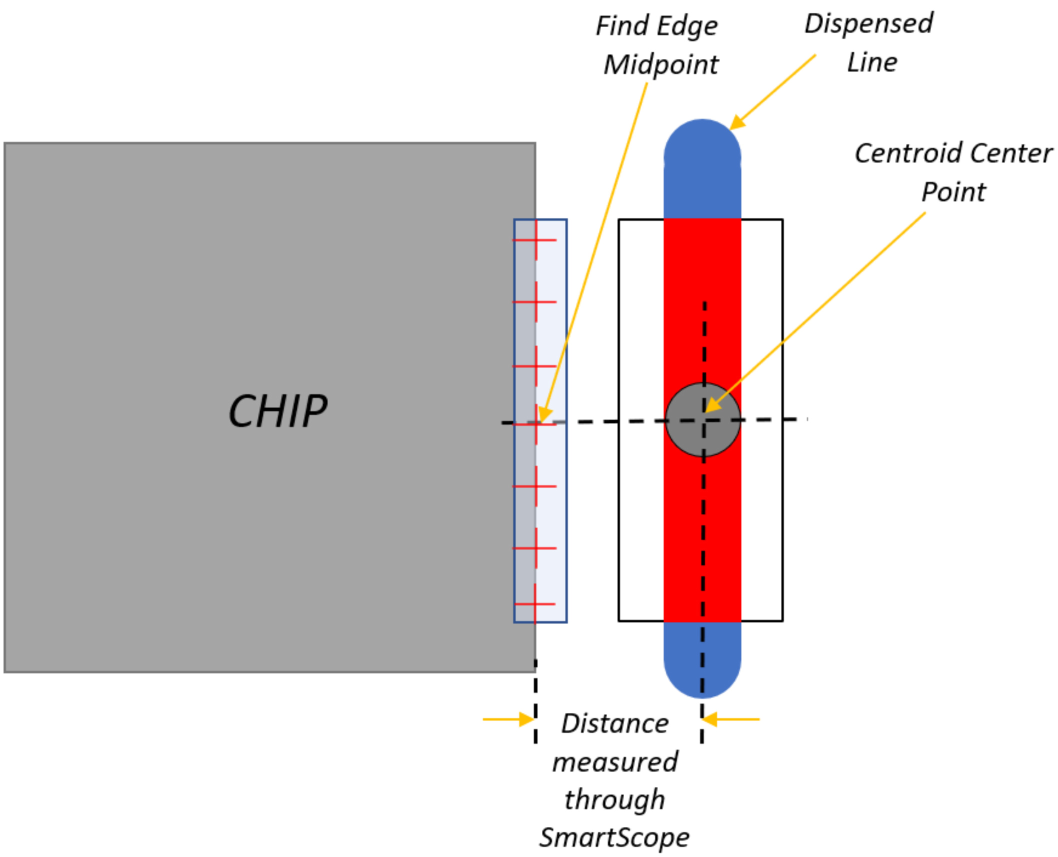
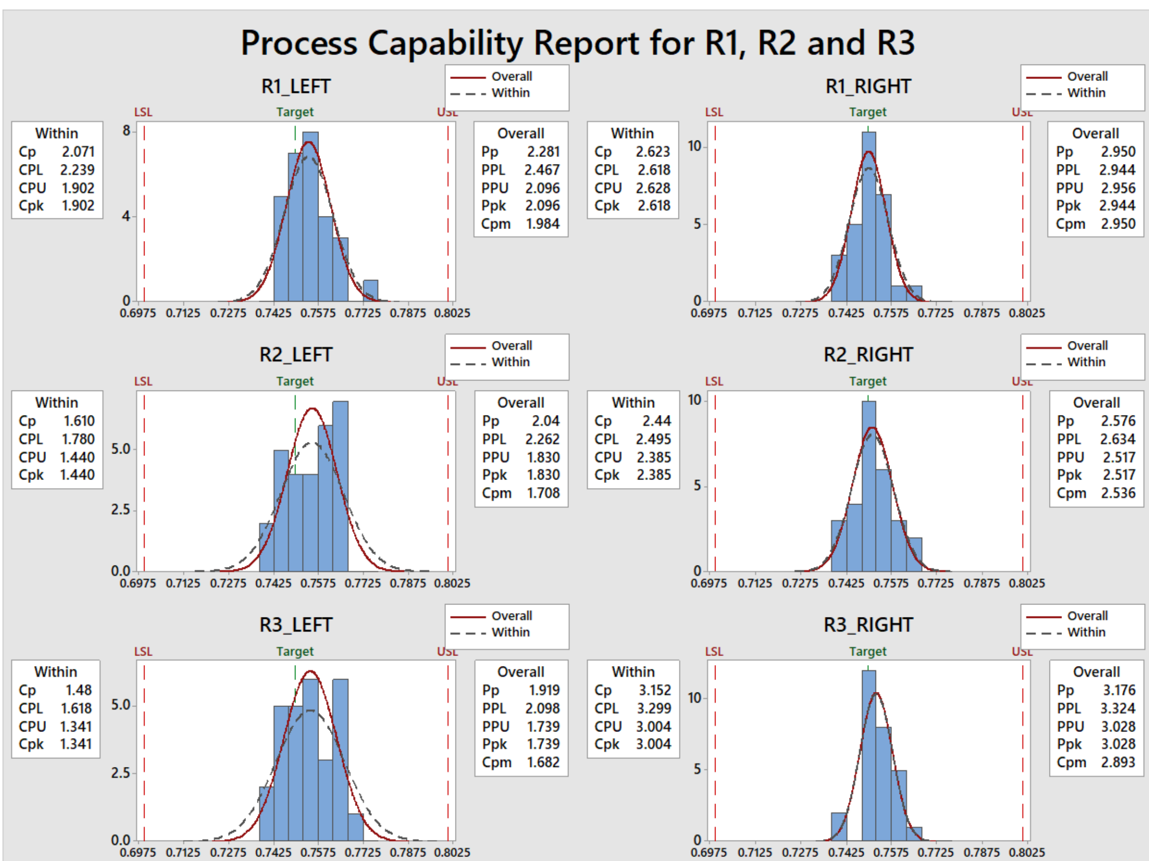


Figure 5 Line Positional Accuracy measurement on metrology tool

Table 2 indicates the standard deviation of left head to be quite close to the standard deviation of right head on most of the runs. Process capability is higher than the 1.33 value which is the industry acceptable standard for both heads in real time dynamic dispensing in synchronous mode. The Right head has a little bit higher process capability than the left head due to its fixed mechanism onto the right Z-axis, while the left head is mounted on a movable mini XY drive system on left Z-axis. Process capability charts for all six runs are shown in Figure 6 below.

Table 2 Process Capability for Line Positional Accuracy

	USL	0.8008 mm				LSL	0.6992 mm					
RUN	1		2		3		4		5		6	
HEAD	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT
Cpk	**2.10**	**2.94**	**1.83**	**2.52**	**1.74**	**3.03**	**1.78**	**4.24**	**1.75**	**2.86**	**1.75**	**2.08**
Cp	**2.28**	**2.95**	**2.05**	**2.58**	**1.92**	**3.18**	**2.02**	**4.38**	**1.95**	**2.90**	**1.89**	**2.17**
Cpu	2.10	2.96	1.83	2.52	1.74	3.03	1.78	4.24	1.75	2.86	1.75	2.08
Cpl	2.47	2.94	2.26	2.63	2.10	3.32	2.26	4.51	2.14	2.94	2.04	2.26
TARGET, *mm*	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
AVG, *mm*	0.754	0.750	0.755	0.751	0.755	0.752	0.756	0.752	0.755	0.751	0.754	0.752
STDEV, *mm*	0.007	0.006	0.008	0.007	0.009	0.005	0.008	0.004	0.009	0.006	0.009	0.008
MAX, *mm*	0.776	0.765	0.767	0.765	0.769	0.763	0.768	0.758	0.767	0.763	0.767	0.768
MIN, *mm*	0.743	0.739	0.742	0.739	0.741	0.738	0.741	0.740	0.742	0.739	0.740	0.740
RANGE, *mm*	0.032	0.026	0.025	0.026	0.028	0.025	0.027	0.018	0.025	0.025	0.028	0.028



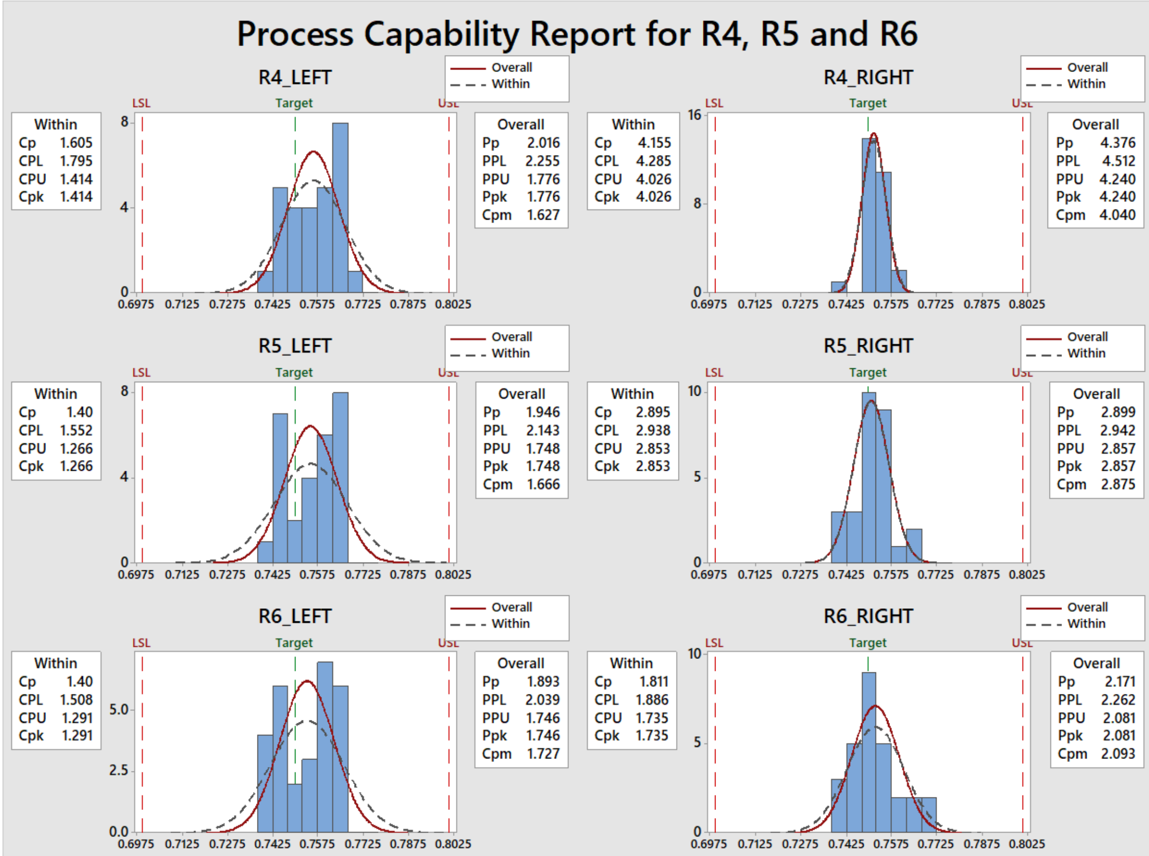


Figure 6 Process Capability Report for six runs of line positional accuracy

Dispense Quality

Line quality depends on the dot characteristics in terms of dot positional accuracy and circularity. Line width is defined by the series of dots dispensed at a correct spacing to align properly to form a straight and non-scalloped line. Visual inspection relates to human-based optical inspection of line quality under the microscope to capture any satellite formation during the dispense cycle. Visual inspection also helps to determine whether the lines are misaligned or not and the lines are fine across the edges. Line quality in Figure 7 below shows both heads have good dispense quality in dual head synchronous mode.

Left Head Right Head Left head Right head Left head Right head

Figure 7 Dispense quality for both heads in synchronous mode

Increased throughput

Increased throughput in the production environment has been a significant factor to meet the required units per hour (UPH) set mostly by the electronic device manufacturers to satisfy the customer's demand. UPH is used to measure an industrial production process in terms of how many units produced per hour of the final product. Some of the major factors contributing to throughput are better vision capture and imaging system, conveyor mechanism, powerful software-controlled architecture and laser height sensing which is mounted on a more precise and faster platform to deliver consistent dispensing results.

The cycle time calculation does include the time interval for the board transfer, board clamp, capture board fiducials, height sensing, clean needle, dispense, board unclamp and transfer downstream. Total process time went down by 46.75 percent which is quite close to cutting the process time to half, from switching single head to dual head with mini XY drive system. The cycle time and UPH calculation involves dispensing operation of one carrier containing 16 pieces of the product.

Indicated UPH and cycle time percentages have been calculated through running a programmed test which includes lines and dot commands in the process program, to simulate the production environment at most of the manufacturer's facility.

The blue column in Figure 8 indicates 24.00 percent reduction in height sensing and fiducials feature scan while switching from single head to dual head with mini XY drive system. Dispense time shown as the yellow column went down by 49.18 percent which is a significant savings, almost cutting down the dispense time to half with a switch to dual head dynamic dispensing. There is no savings with board load, clean needle, board unload and board transfer time as they have no effect on the process. The desired high actuation speed can only be achieved for a small interval of time, limited by gantry motion along the three axes and mechanical friction between the parts. UPH is shown as green column which went up by 87.79 percent while switching from single head to dynamic "real time" dual head dispensing.

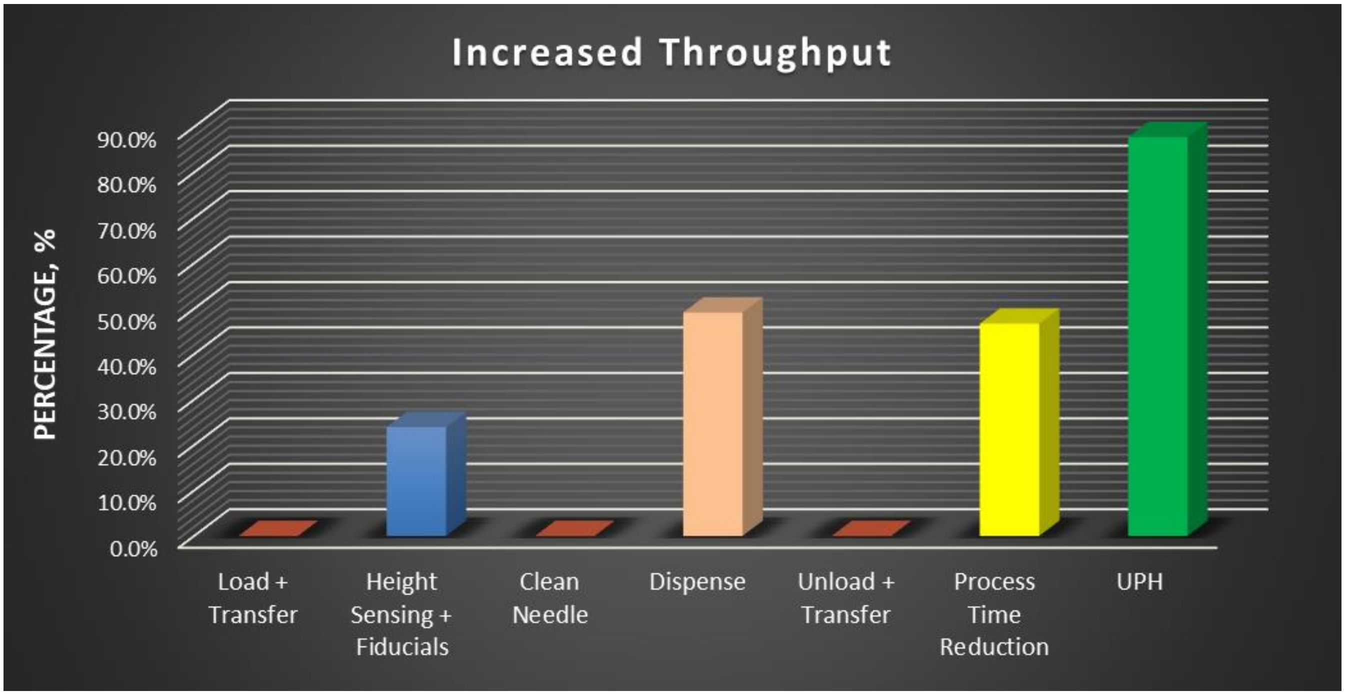


Figure 8 Cycle time savings leading to increased throughput

Summary

Dual dynamic dispensing with the mini XY drive system has brought a new level of robustness to the high-volume manufacturing process. Furthermore, the offset distance between the multiple dispensing pumps is adjusted dynamically in XY direction to be the same as the offset distance between the multiple circuit distances to attain the same level of accuracy as the dispensing system. This way the multiple dispensing pumps can be utilized to increase throughput without any defect count coming from the left head mounted on the mini XY drive system.

With *Cpk* numbers greater than 1.33 for both dot and line positional accuracy at ±3 sigma capability indicates that mini XY drive mechanism does not have any adverse effect on the accuracy of the left head which in turn is close to the right head. Dual head "real time dispensing" with mini XY drive system has arrived offering greater degree of process control with skewed identical substrates adjacent to each other thus providing good product reliability during the production run. Also, less manufacturing floor space required with almost dual increase in productivity.

References

1. Reid, Scott A. et al. Illinois Tool Works Inc. U.S. Patent No. 9,374,905 filed Sep. 30, 2013 and issued July 21, 2016.
2. Reid, Scott A. et al. Illinois Tool Works Inc. U.S. Patent No. 9,775,250 filed May 26, 2016 and issued Sep. 26, 2017.
3. Agarwal, S., (2016) "Improved maintenance and reliability for large volume underfill processes", Institute of Printed Circuits APEX EXPO, Las Vegas, NV. https://n2a.goexposoftware.com/events/ipc16
4. Agarwal, S., "Low Volume Dispensing with High Speed Dispensers," Master's Thesis, State University of New York at Binghamton, December 2012.
5. Giusti, Christopher L. Nordson Corporation. U.S. Patent No. 9,707,584 filed July 9, 2014 and issued July 18, 2017.