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Improved Throughput with Dynamic "Real-Time" Dual Head Dispensing in Electronics Assembly

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Abstract*—Today's unique assembly challenges are comprised of complex printed circuit board (PCB) panelization, involving identical PCBs with a goal of 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 affect 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 the 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 (DDH) dispensing uses a unique mini *XY* drive system on the left head, mounted on a separate *Z*-axis, to dynamically control the position of the head for accurately aligning to a second part, while synchronously dispensing both parts. The machine vision system performs the substrate alignment for each identical PCB that is 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 PCBs, flex circuits, and panel designs. If a product contains an odd number of units, then either of the heads can be programmed for dispensing while the others cannot. This paper examines proven methods to determine the dot/line positional accuracy along with the 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 2× higher throughput than existing single/dual head dispensing systems.

***Keywords*—PCB, throughput, synchronous dispensing, jet valve, process capability**

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 the 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 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. JEDEC trays are constructed from molding compounds which are used for safe handling, transport and storage of Integrated Circuits (ICs), modules and other components. 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 a horizontal *XY* plane, through the conveyor system. Dispenser valves can be positioned in a 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 the top of the substrate, through a preprogrammed 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 by the dispenser valve needle tip coming down to the programmed dispense gap from the substrate. At this point, the dispenser valve starts dispensing a preprogrammed fluid pattern onto the substrate [1].

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 Fig. 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 realign patterns to make a one-time automated adjustment of valve 2 relative to valve 1 before dispensing, and only consider the global skew. Therefore, both identical PCBs get dispensed synchronously, based on global skewness.

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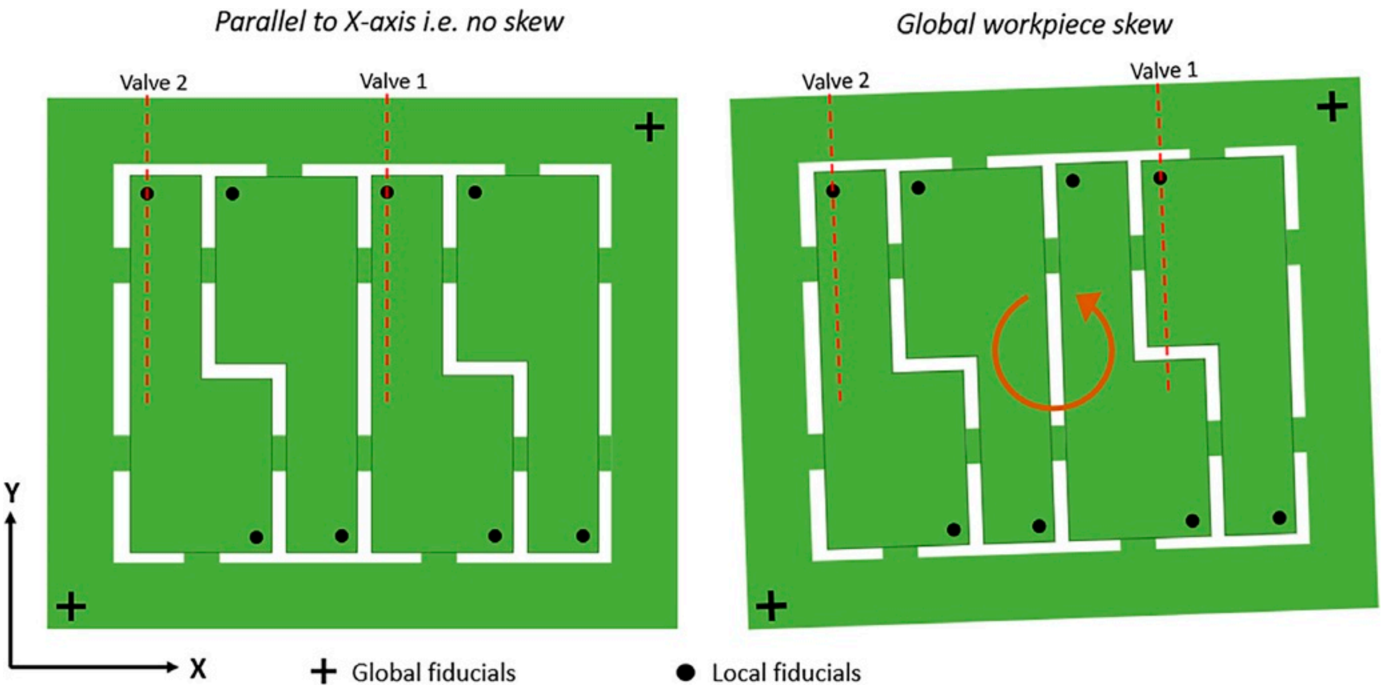

Fig. 1. Synchronous dispensing based on global skew.

A. Advances in Dual Head Dispensing

Dual-head dispensing has been driven on a single *Z*-axis to dispense identical patterns with each dispenser valve synchronously. Most of the existing techniques only consider 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, before dispensing operation as shown in Fig. 2.

Conventional dual dispensing methods do not incorporate the dynamic real-time adjustment of both heads during active dispensing onto identical substrates. If parts are skewed to each other in a tray and only global skewness is considered, then the dispensing pattern gets misaligned, as shown on the right side of Fig. 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 [2]. For a part-to-part rotation, a movable gantry system is required to capture the local fiducials or reference points through the camera vision system for each 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 incapable of active correction, to consider the skew angle and scale factor locally. A scale factor is based on where the gantry vision system finds the fiducials or reference points in comparison with 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 PCB.

The machine gantry system is configured to provide movement in the *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.

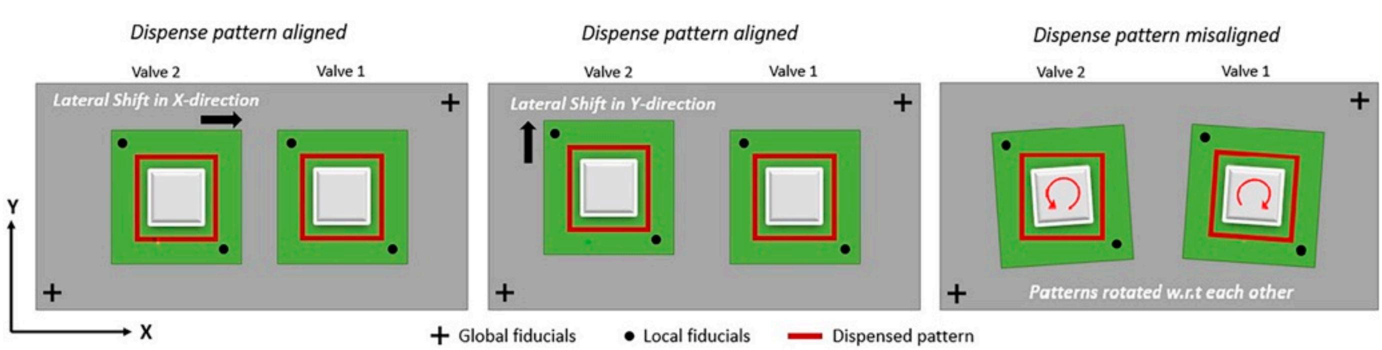

Fig. 2. Synchronous dispensing during different scenarios.

A mini *XY*-drive system is mounted and configured onto the second *Z*-axis to move the second dispenser valve in the *XY* direction, to manipulate spacing between the first and second dispenser valves as shown in Fig. 3. A controller controls the dispensing operation of the first dispensing valve on the first electronic substrate pattern and the dispensing 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 the direction of the linear bearing, and the 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 includes a *Z* drive mechanism configured to support and lower the dispensing unit when performing a dispensing operation with the first dispensing unit [3].

B. *Technological Advantages*

Multiple independent dispensing systems are sometimes used to increase the production of dispensing 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

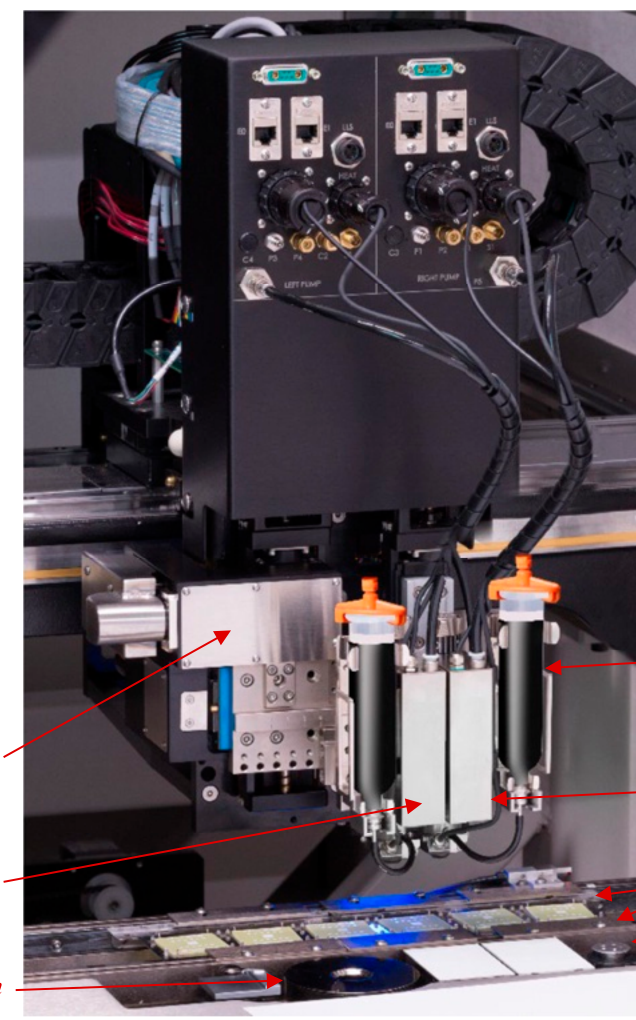

Fig. 3. Experimental setup.

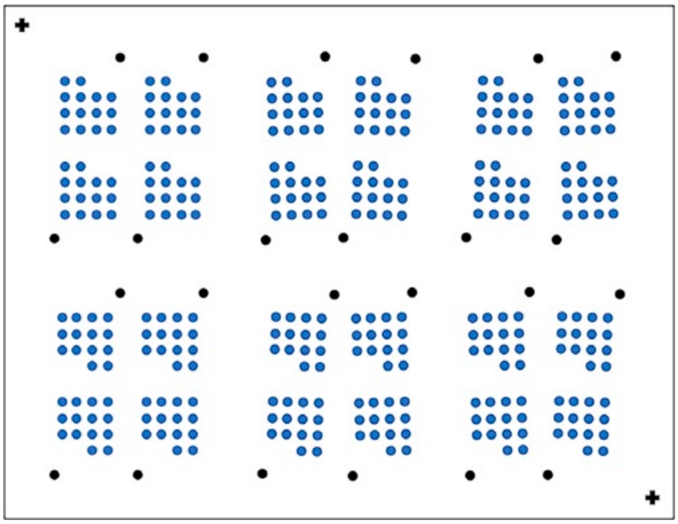

Fig. 4. Glass plate jig for dot positional accuracy.

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 valves may be utilized to increase throughput. In such systems, the offset distance between the multiple dispensing valves 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 valves 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 valve installed, which can currently dispense material in a repeatable manner without affecting the dispensing quality.

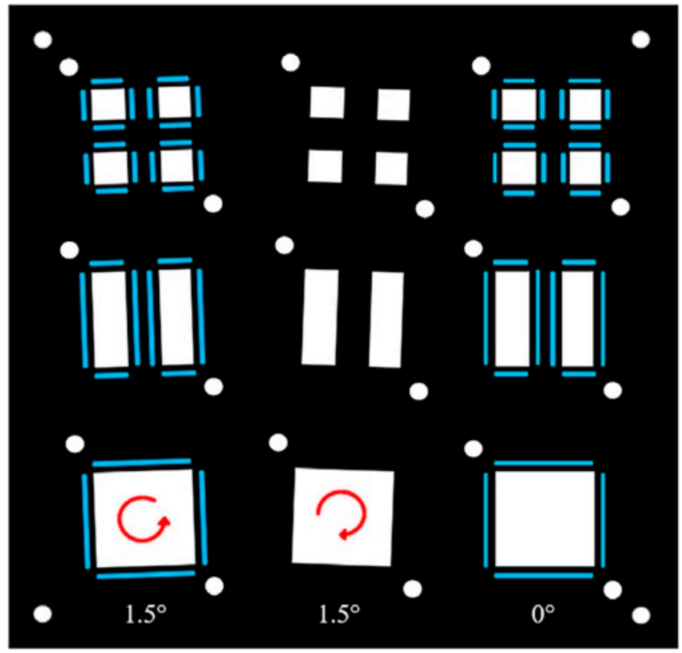

Fig. 5. Glass accuracy plate for line positional accuracy.

The study begins at the point of performing the experiment on a pneumatic jet valve. 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. The experiment involves the use of glass jig plates to perform the dot and line positional accuracy tests.

A. Dot Positional Accuracy

Dot positional accuracy is measured as the difference between the commanded position and the actual dispensed position for each dot, through dispensing an array of dots. Positional accuracy also defines whether the dot can shoot vertically or not (i.e., downward) from the needle tip onto the substrate [4]. From the customer's point of view for field engineering applications, the dispensing should allow for certain dot characteristics such as circular-shaped dots with good positional accuracy. The measurement of dispensed dots on the

Table I
Process Capability in the Synchronous Mode with the Mini *XY*-drive System

Head type	Left	Right	Left	Right
pattern orientation	180°	180°	0°	0°
	Standard deviation, mm			
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**

Green values are greater than the industry standard of 1.33.

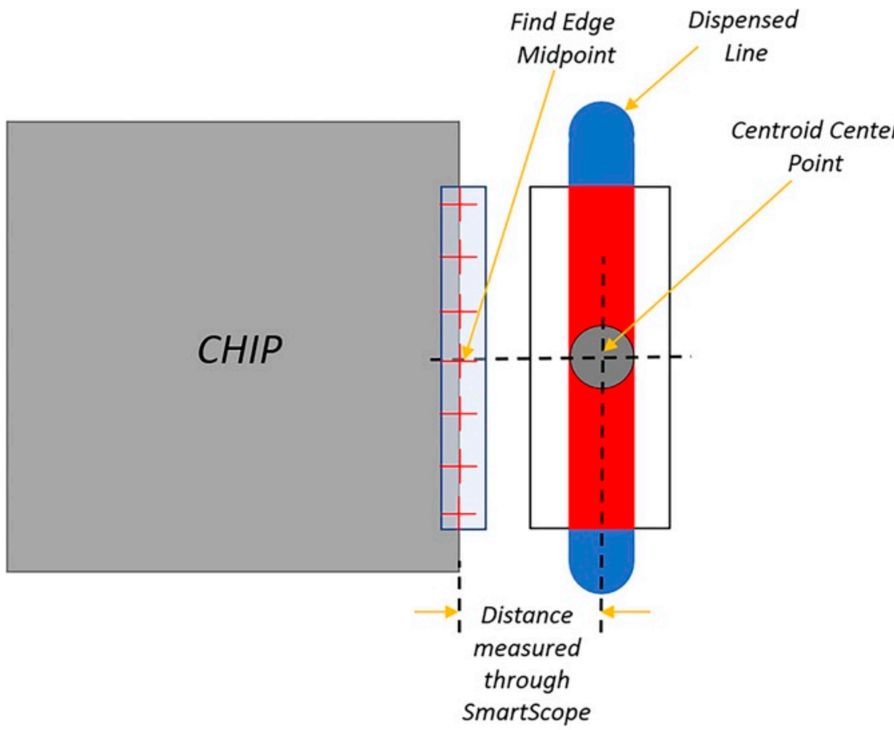

Fig. 6. Line positional accuracy measurement on metrology tool.

glass jig is performed with the optical measuring machine named SmartScope, through backlighting to measure the shift in the *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° or 180° as shown in Fig. 4. Height sensing is performed on the glass to ensure the correct dispense height from the glass jig top surface. Each pattern is rotated either clockwise or counterclockwise by 2° to prove the left head dispense accuracy is equivalent to the right head in real synchronous mode dispensing.

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 toward one of the specification limits, which indicates lower *Cpk*, whereas *Cp* will be high. For both the shifts, the high value of *Cp* and the low value of *Cpk* indicate that the process has a centering problem.

Table II
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

Green values are greater than the industry standard of 1.33.

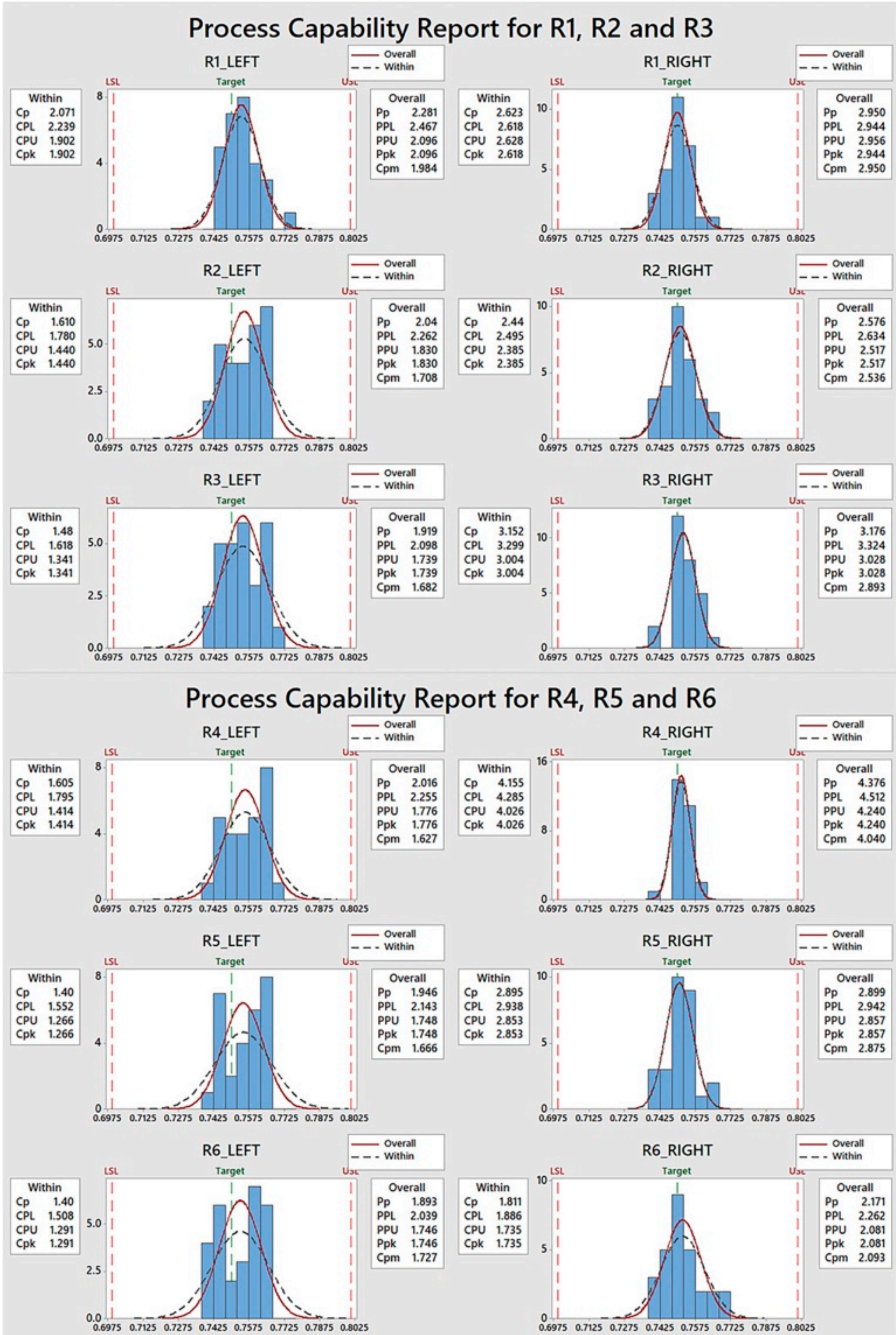

Fig. 7. Process capability report for six runs of line positional accuracy.

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 μm specification limits at ± 3 sigma capability. Table I indicates the process capability for the left head is found to be equivalent to the right head for both 0° and 180° board orientation. *Cpk* values are also much higher than the industry-acceptable standard for both heads in real-time dynamic dispensing in the synchronous mode.

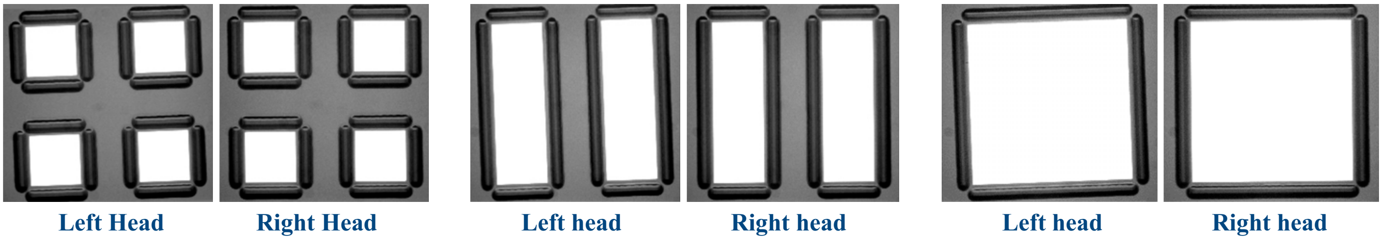

Fig. 8. Dispense quality for both heads in the synchronous mode.

B. Line Positional Accuracy

Line positional accuracy is measured as the shift between the commanded location of the programmed line to the actual dispensed line. The line comprises of series of dots stacked together at a correct spacing and aligned properly to form a straight and nonscalloped 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 [5].

An experimental test was performed on the glass accuracy plate shown below in Fig. 5. Patterns on the left side are skewed at an angle of 1.5° in the counterclockwise direction, whereas in the middle patterns are skewed at an angle of 1.5° in the clockwise direction. Patterns on the extreme right side are not skewed at all. Patterns on both extreme sides are pitched at 44 mm. Fiducial alignment is performed before dispensing the lines around the edges of 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 mm from a dispense height of 2 mm. Patterns are dispensed with both heads in the synchronous mode with the mini *XY*-drive system set-up.

An optical measuring machine 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 in Fig. 6. The figure shows the diagram of the description of measurement on the metrology system. Specification limits are based on tolerances of ±50 μm around the 0.75 mm position offset.

Table II indicates the standard deviation of the left head to be quite close to the standard deviation of the 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 the synchronous mode. The right head has a slightly higher process capability than the left head due to its fixed mechanism on the right *Z*-axis, whereas the left head is mounted on a movable mini *XY*-drive system on the left *Z*-axis. Process capability charts for all six runs are shown in Fig. 7.

C. Dispense Line 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 nonscalloped 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 if the lines are fine across the edges. Line quality in Fig. 8 shows both heads have good dispense quality in the dual-head synchronous mode.

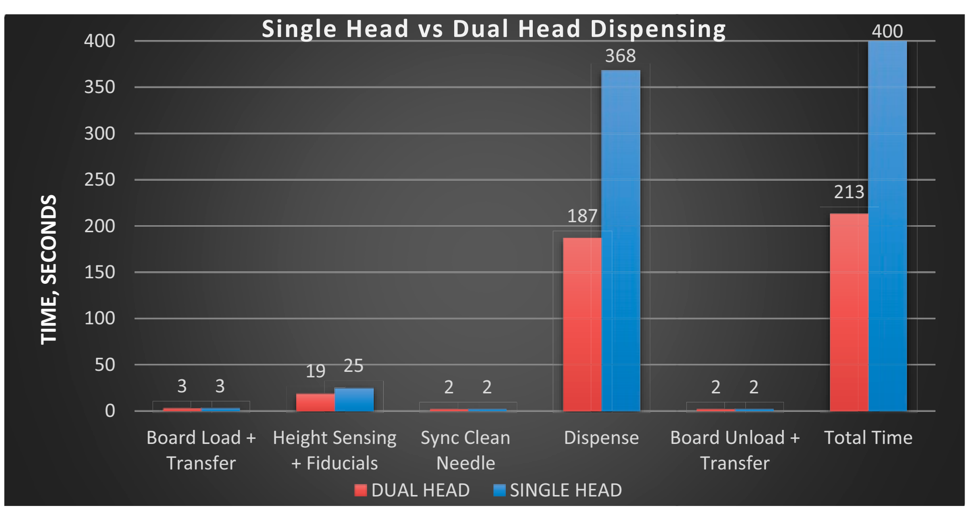

Fig. 9. Single head versus dual head dispensing.

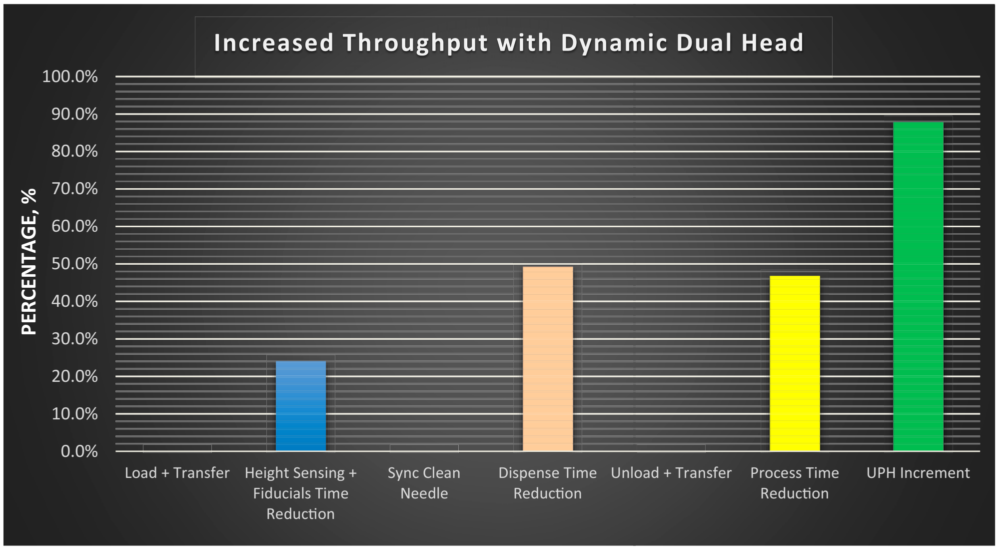

Fig. 10. Cycle time savings leading to increased throughput.

D. Increased Throughput

Increased throughput in the production environment has been a significant factor in meeting 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 are produced per hour of the final product. Some of the major factors contributing to throughput are better vision capture and imaging systems, conveyor mechanisms, 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 as shown below in Fig. 9 The cycle time and UPH calculation involves the dispensing operation of one carrier containing 16 pieces of the product.

Total process time went down by 46.75% as shown in the yellow column below which is quite close to cutting the process time in half from 400 to 213 s, from switching single head to dual head with the mini *XY* drive system along with good dispense productivity from the second head as well. 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 Fig. 10 indicates a 24.00% reduction in height sensing and fiducials feature scan while switching from single head to dual head with the mini *XY* drive system. Dispense time shown as the brown column went down by 49.18% which is a significant savings, almost cutting down the dispense time to half with a switch to dual head dynamic dispensing. There are 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 a green column which went up by 87.79% while switching from single head to dynamic "real-time" dual-head dispensing.

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 valves is adjusted dynamically in the *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 valves 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 the 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 the mini *XY*-drive system has arrived offering a 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 is required with an almost dual increase in throughput.

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