OMRON

The impact of smart factory solutions on PCB manufacturing

Introduction

Advancements in technology continue to shape our way of living. More and more of the services and products that humans use each day are driven by printed surface boards (PCBS). Automobiles which were once largely powered by mechanical systems, now feature multiple electric motors, auto-assisted parking, lane departure, driving assistance, and sophisticated routines which charge hybrid batteries as brakes are applied. Like countless other devices, these applications require high quality PCBs to operate and any malfunction could seriously compromise the user's safety.

The surface mount technology line responsible for manufacturing these PCBs typically consists of the following machines shown in [Figure 1]. While some manufacturing sites may not have quite as many inspection machines in their production line, having at least 3 is important since they enable the ability to monitor multiple assembly steps.

Inspection machines excel at catching defects immediately after their introduction, which, can reduce scrap and rework time. These machines also ensure that other aspects of the production line are operating at full capacity and are critical in detecting potential failures. For example: an in-circuit test machine may pass a joint, but an automated optical inspection machine can determine that the joint only has 20% of the recommended solder amount.
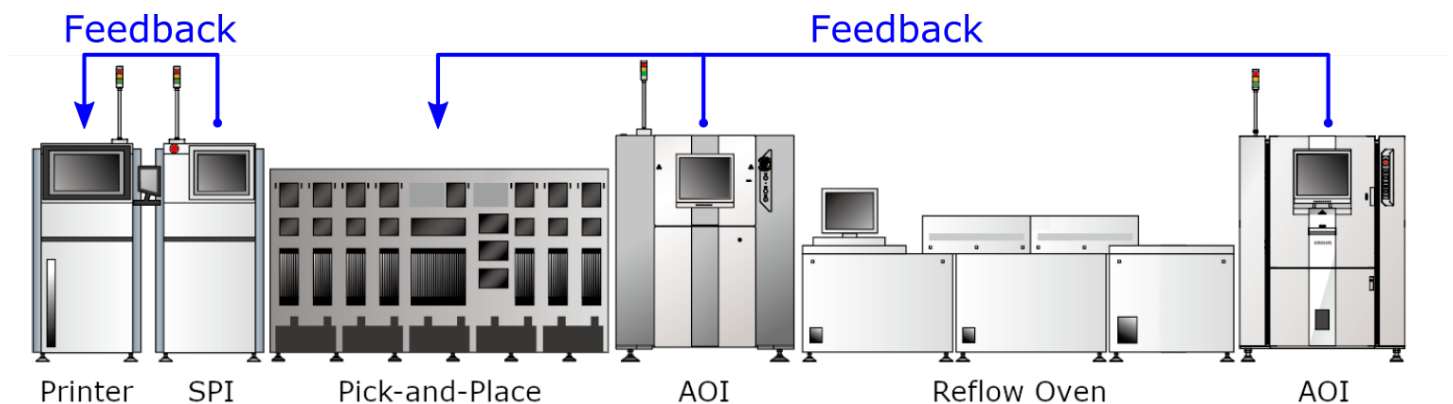
Figure 1 : Typical SMT Process line

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Evolving the production line

As previously shown, an SMT line is frequently composed of 6 machines (not including conveyors or buffers), each of which juggles its own data. The printer manages the paste and stencil placement. The solder paste Inspection machine measures the amount of applied paste, alignment, and defects. The pick-and-place tracks part orientation, placement, and nozzle used. Pre-reflow inspection measures part orientation, placement, and defects. The reflow oven maintains precise temperature profiles. The post-reflow Inspection measures part orientation, placement, and solder defects. Correlating the aforementioned data helps engineers understand their process and, given its clear importance, limited data tracking solutions do exist (Manufacturing Execution System, MES). Many of these solutions provided by vendors are a great start to troubleshooting defects; as this software allows engineers to review inspection data from multiple inspection machines throughout the SMT assembly line simultaneously. For example: If a defect is detected during the post-reflow inspection, images and measurements can be compared with the previous paste and pre-reflow results. Upon review, it is easy to see that a slight issue with the solder paste

Figure 2 : Inspection images for a defect

alignment was likely the root cause [FIGURE 2]. After a defect like this is understood, an engineer can review settings on the production machine and hopefully prevent the issue from repeating.

However useful data comparison may be, seldom is it ever correlated on a level where it can pin-point precise machine issues or predict potential machine failures. And, it is even less common for machines to talk directly to one another without additional software or human intervention. Part of the reason why low-level data is not used in this manner is due to the fact that different vendors are responsible for different machines and few communication standards exist. The industry has identified the strong need for standardized data formatting and common servers, but initiatives like Hermes and IPC-CFX are still in their infancy. Such precise data tracking can only be accomplished if machines are able to share all of the data that they are managing in a common format or centralized server.

Only through recent collaboration efforts by multiple companies, has software been produced that is capable of linking a component's inspection results directly to its complete assembly history. This level of traceability can dramatically reduce the amount of time that it takes to fix a problem since a single defect can be caused by any number of different factors from the pick-and-place step alone (including different placement machines, different feeders, different placement heads, and different nozzles).

The following studies utilize software solutions, which exist today, to investigate the results from direct machine-to-machine communication and detailed process data analysis from SMT printers, paste inspection equipment, pick-and-place machines, and both pre and post reflow inspection machines.
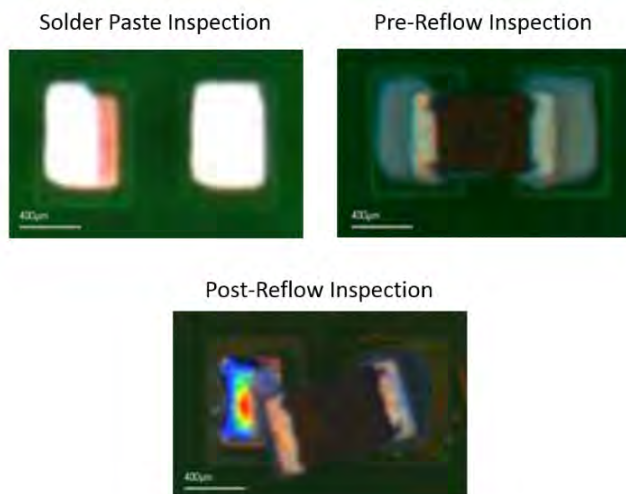
Case study I – printer and paste inspection

After the bare PCB has been fabricated, the next step in the SMT manufacturing process is to apply the solder paste with a printer. During this step, it is critical for the stencil mask to be perfectly aligned with the PCB. If the mask is not properly aligned, defects such as solder bridging, shifted components, or even missing components, are likely to occur. By inspecting solder paste and analyzing its measurements, defects can be both spotted and prevented. But, while it is undoubtedly helpful to have a tool that engineers can use to spot and stop solder defects, it is even more valuable for that same tool to automatically prevent defects from re-occurring.

The first study demonstrated the impact that a solder paste inspection machine can have on production if it were directly connected to the printer and able to assist with stencil alignment. Two sample sets were tested, each beginning with an intentional mask offset [TABLE 1]. For each set of tests, solder paste was applied to the first PCB (with the offset) and was then measured at the paste inspection machine. Upon gathering measurements from solder pads, the paste inspection machine instructed the printer to shift the mask in the appropriate direction to remedy the intentional mask offset. The printer continued to receive this alignment feedback after each inspection, consequently reducing the paste offset for all subsequent PCBs.

Data from the first sample set was taken from the pads of a BGA and averaged. All 10 boards were run consecutively with the squeegee alternating strokes (rear-to-front and front-to-rear) and used continuous feedback from the paste inspection machine to correct shift. For this sample set, the inspection machine was programmed with a "gentle" correction factor. With this less aggressive setting, the paste will slowly approach the ideal zero offset. While the factor will likely differ for each machine and production line, the ideal value would result in zero scrap and maintain the smallest offset possible. Results show the alignment slowly improving by 50% within just a few samples for each stroke [FIGURE 3]. It is worth pointing out that while the Y-Offset does overshoot slightly, the offset is still greatly reduced. The improvement or reduction in the shift offset can be clearly seen by reviewing images from multiple solder pads [FIGURE 4].
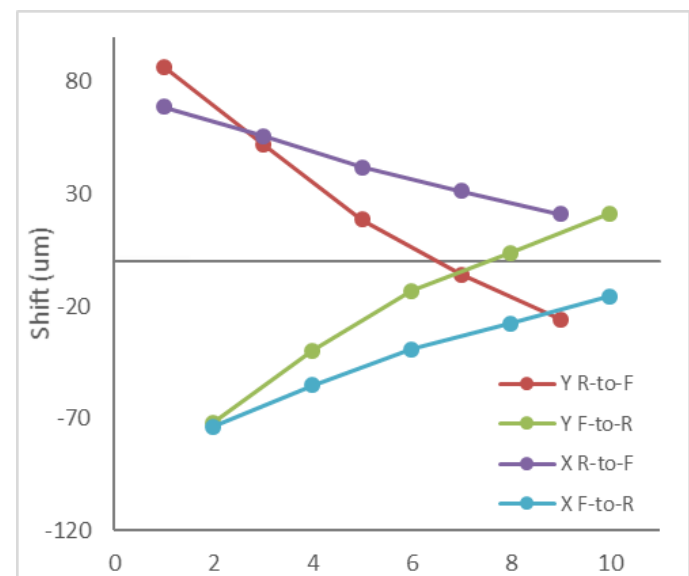

Figure 3 : Shift results for the first sample set

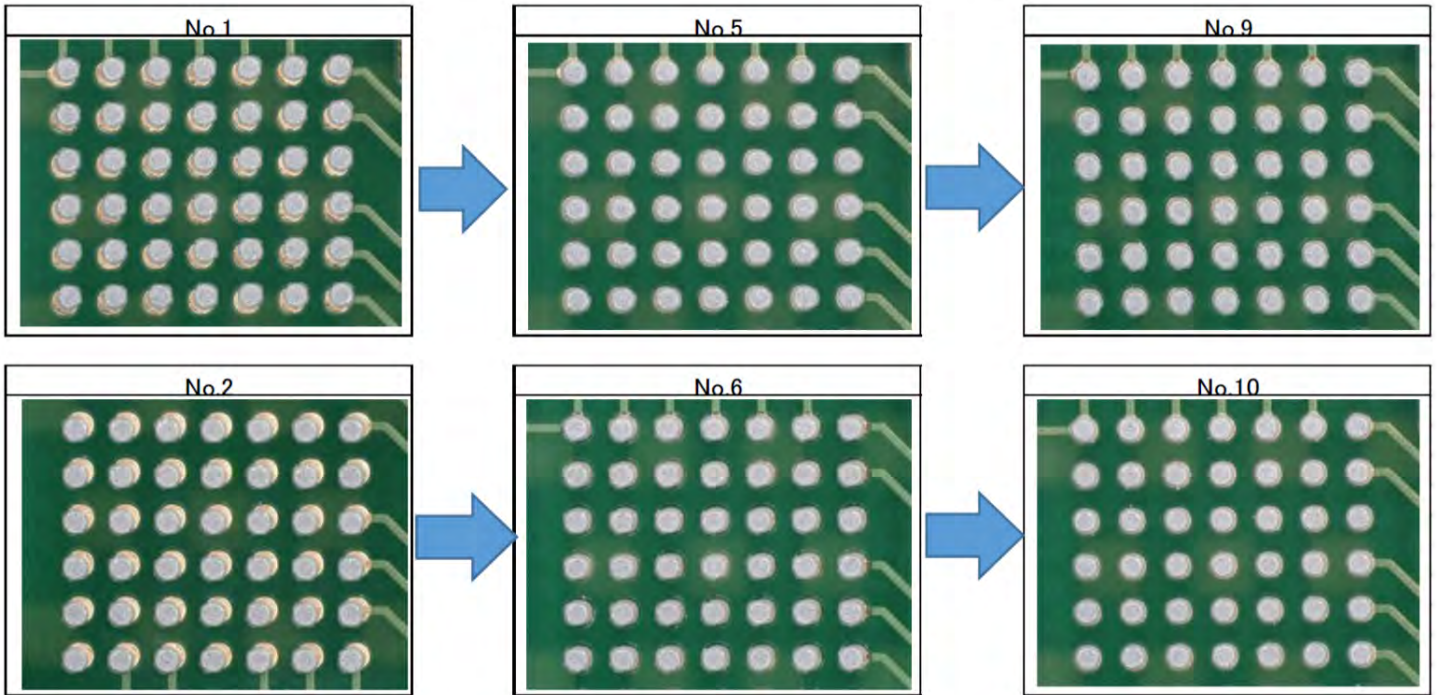|	Squeegee Direction	X-Shift Direction	Y-Shift Direction	Theta Shift Direction
First Set 10 Samples	Front to Rear	-0.10 mm	0.10 mm	0.05
	Rear to Front	0.10 mm	-0.10 mm	-0.05
Second Set 10 Samples	Rear to Front	-50 um	50 um	0.03

Table 1 : Study I first sample set

Figure 4 : Images from BGA showing pad shift

The second sample test began with conditions similar to the first, an intentional stencil offset, 10 PCBs, and direct feedback from a paste inspection machine (50um offset, Rear-Front sweep). However, this time a much more aggressive correction factor was utilized and the stroke direction was limited to only rear-to-front. The intent of this scenario was to observe the effect of the correction factor and determine how quickly the printer was able to maintain a repeatable, minimal offset. Inspection results from this second set of samples displayed extremely promising results. Here, measurements were collected for a specific pad of a QFP. For this pad, shift was reduced to less than 10um in both the x and y directions after only the third PCB, and the theta offset was completely eliminated by the 7th [FIGURE 5].
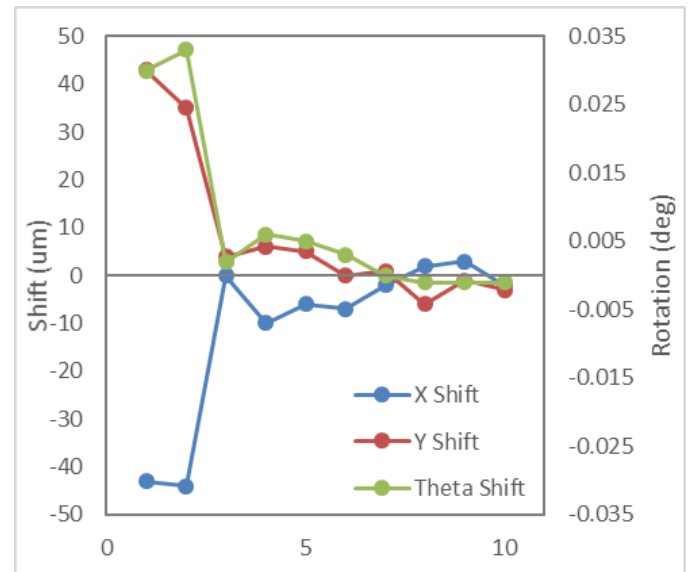

Figure 5 : Shift results for the second sample set

Case study II – placement monitoring

Once the paste has been applied to the PCB, parts are carefully put into their correct position via a pick-and-place. Much like the printer, the placement process can introduce any number of defects. As shown in [FIGURE 6], inspection machines are usually installed after the pick-and-place and after the reflow oven. Having both machines is the only way to determine precisely when a defect was created, and in turn prevented. As mentioned previously, most existing inspection software allows for engineers to review defects found at several points throughout the assembly process, but only recently has software been developed that can take process monitoring one step further. This new software was installed and configured on a production line and enabled engineers to track a components complete history, by aggregating data from the placement machine with data from both inspection machines. The precise data mined from the pick-and-place included information about the reel, nozzle, head and machine used for each component.

In this study, data from the placement machines and defect information observed by the inspection machines were collected and stored in a single location. The new production quality software was used to correlate data from each machine and not only display current production metrics, but also call attention to concerning trends or outlying data points. This feedback provided engineers with real-time information about the quality of the production line. After a period time, the quality software indicated that 56 (~1%) of samples exhibited a common shift defect [FIGURE 6].

Upon closer review, each of these defects involved a specific chip capacitor that was either shifted or lifted off of the solder pad. The quality software also indicated that each samples was picked with

a specific 1.0mm nozzle. At first glance, since the nozzle was smaller than the component, engineers did not assume there would be an issue. However, because the capacitor had raised features, the nozzle struggled to consistently lift each component with the same orientation [FIGURE 7]. This abnormal orientation caused the part to be tilted during placement and remained so throughout the assembly. The solution, was to replace this 1.0mm nozzle with a smaller 0.7mm nozzle. This smaller diameter allowed the pick-and-place to repeatedly grab and place the component with the correct orientation. Once the nozzle was changed, another 5662 components were placed and inspected; 0 defects were found [TABLE 2]. Through the use of the process quality software, engineers were able to isolate the root cause for these defects and take quick, corrective action.

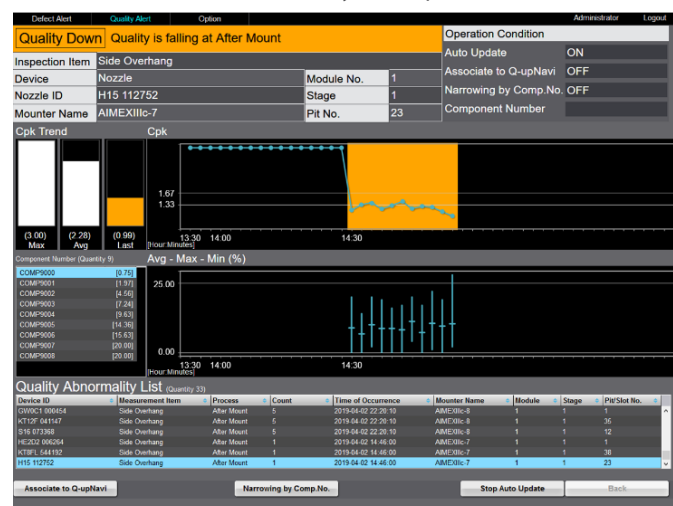|	Before	After
Sample Size	5620	5662
Number of NG	56	0
NG Rate	1%	0%
Max Tilt	5.5	0.5
Min Tilt	-6.6	-2.5
Standard Deviation	0.87	0.27

Table 2 : Summary of sample results

Figure 6 : Quality Software showing trend of defects7

Additionally, by knowing the exact nozzle that introduced the problem, engineers were able to find a very subtle, specific issue and fix it. This software yielded an efficient, fast solution with a minimal amount of production down time.
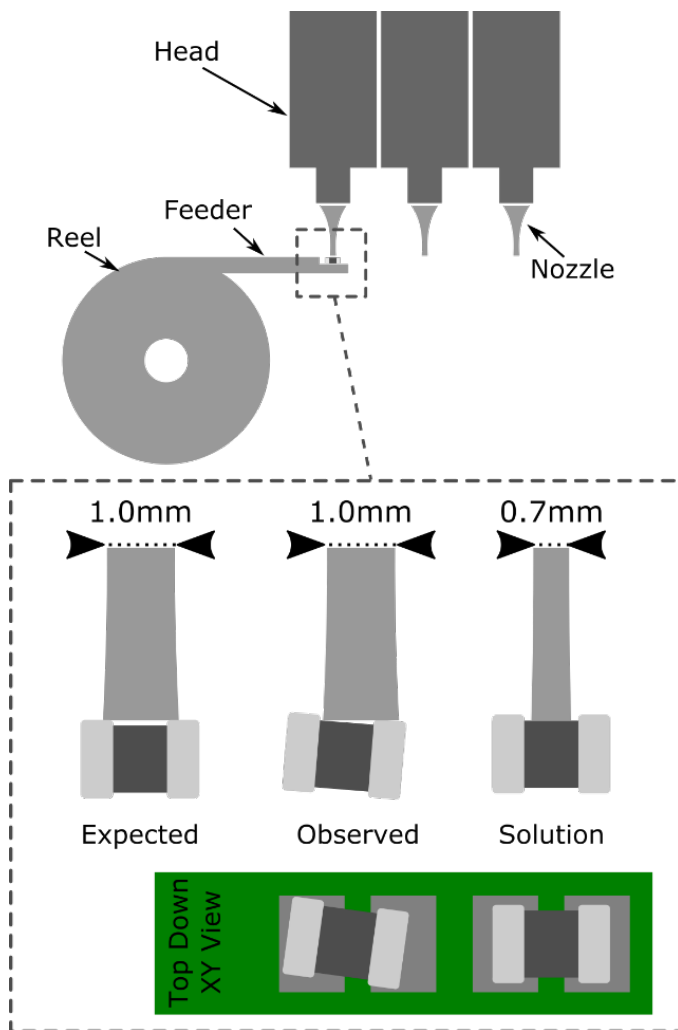
The process quality software also called attention to a few instances where measurements were approaching the allowable specification limits. Luckily, these measurements did not constitute a defect since the measured shift was between 100um and 200um. While these flagged components were not considered defects, production was still able to benefit from knowing that their process needed to be further optimized [FIGURE 8]. In this manner, the quality software was able to help predict a potential processing issue, should the component placement not be addressed. Having this level of information available for every component in the production line (some PCBs can easily have thousands) allows engineers and operators to observe even the smallest deviations.

Figure 7 : Graphic showing incorrect nozzle size

Figure 8 : Quality software showing low measurement

Conclusion

The initial machine-to-machine study allowed a solder paste machine to be governed by a paste inspection machine. Results concluded that this feedback loop was very helpful as stencil alignment problems were quickly corrected with only a few prints. The second study demonstrated that with software capable of aggregating data from multiple production machines, process trends can be called out in real time and pinpoint the root cause of defects.

With an increasing demand for both quantity and quality of surface mounted electronic circuit boards, manufacturing facilities must focus on improving their production capabilities. Machine-to-machine communication and sophisticated process quality monitoring software are capable of performing in-line adjustments and make troubleshooting simple. Not only are they efficient ways to maintain a high quality product, but both save a tremendous amount of engineer and technician time. Through the methods mentioned in these studies these, SMT lines can evolve such that human interaction is virtually non-existent and scrap is eliminated.

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