ACHIEVING HIGHER ACCURACY in NEXT-GENERATION STENCIL PRINTERS

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ABSTRACT
Stencil printing today requires a higher degree of printer accuracy than ever before. Printer accuracy becomes increasingly difficult to maintain as demands for higher speeds and throughput test the limits of a printer's capabilities, particularly with tiny apertures and tight land patterns. Today's equipment design engineers are tasked with building machines with tighter performance tolerances and accuracy. Printer accuracy must first be defined in terms of real and measurable printer parameters (such as machine alignment accuracy) and then verified. Different tools are used to verify printer accuracy; these include MCA, or Machine Capability Analysis, and PCA, or Process Capability Analysis, both of which are typically administered by independent 3rd party testing companies. Printer manufacturers may also have in-house accuracy checking tools designed for frequent use to maintain printing accuracy, as well as systems that communicate with an external Solder Paste Inspection (SPI) machine; such tools are designed to automatically correct registration errors based on closed-loop feedback from the SPI machine. This paper will discuss defining and verifying printing machine accuracy, and how said accuracy relates directly to SMT printing applications; and some machine design and engineering considerations that go into next-generation high-accuracy, robust printers for SMT fine-feature printing in volume.

Introduction: The Drive for Greater Accuracy
Greater printer accuracy has always been a key goal. In the early days of SMT, nearly three decades ago, when technology transitioned from hybrid circuits printed on small squares of alumina substrate to FR-4 epoxy/glass, accuracy became a factor as board size increased. Those early SMT PCBs were single-sided, with the largest component typically a 20-pin QFP with J-leads on standard-pitch land patterns. The average size of any of these boards was perhaps 6" square, but this was still much larger than a hybrid circuit device. As the surface area of PCBs increased, so did print registration problems. Back then, wire mesh screens were used for printing solder paste, and they stretched during the print stroke due to squeegee pressure. They were followed by stainless foil stencils that were still mounted in a flexible border; a better solution, but not enough. Today's stencil foils are mounted directly to the frame. So the focus on accuracy, as assemblies became more compact and standard pitch went to fine pitch and then to ultra-fine, began to turn toward the stencil printing machine.

Unlike some other workstations in an SMT PCB assembly line, the stencil printing machine is probably the most complex and multi-featured next to the pick and place machine. The printer has many moving parts, and many components to each cycle that is part of the successful printing of a single PCB. The PCB indexes into the machine, is positioned or clamped in place, often with the aid of programmable support tooling; vision alignment of stencil to board follows, then the lowering of the squeegee blade to the stencil and the print stroke follows that. This is of course an oversimplification, because each cycle, which may include paste kneading, print stroke speed and pressure adjustments, paste addition, and Z-axis motion of the stencil and frame and squeegee head are all involved. For a very high accuracy print that is repeatable from board to board, all of the parts of the machine that are involved in motion must be manufactured and machined with extremely tight tolerances and precision. *The effects of out-of-tolerance parts are cumulative, and are reflected in the accuracy and repeatability of the printing.*

But Do I Need This Much Accuracy?

It may seem hyperbole, but in fact there is no such thing as a printer being 'too accurate.' Even though common consensus in the industry is that one should never purchase excess capacity or capability that isn't needed, or may never be needed, 'accuracy' with a printer isn't the same as board size handling capacity, for example. A new printer is introduced to the market with 8 micron alignment and 15 micron wet print repeatability (>2 Cpk @ 6σ), significantly more accuracy than current available models. The engineer who is shopping for a new printer might say, "Our company specs only require 25 microns @ 6 sigma > 2 CpK, so I don't need such extreme accuracy." But, in fact, he does, because higher accuracy in the machine means a greater 'cushion' of tolerance room to accommodate variations in other elements in the process. To the printer's tolerances, we must take into consideration variations in batches of boards/fiducials, variations in stencils, and any variations introduced by other process elements, whose effects on the overall accuracy of the printing process are cumulative. Variations must be added together; the sum will be the true accuracy of the process, and the lower that overall number, the greater the probability of building a robust, stable, repeatable, high-yield, low-defect printing process.

Printer Accuracy Factors

Printer accuracy begins with design. A structurally stable printer is key to maintaining repeatable accuracy at high speeds when the acceleration/deceleration forces of components within the machine are greatest. Stability dampens vibration, which itself can negatively affect accuracy when such tight tolerances are being maintained. Rigid positioning of the PCB that will be printed is also critical; one does not want it moving at all once it has been aligned with the stencil. For this reason, PCB clamping systems have been developed that keep the board tightly secured in place during print processing. One such system uses a side snugging technique. Flippers engage to secure the board across the top edge, which ensures board flatness, and removes any warpage from the board. The Z tower raises the board to the programmed height based on board thickness, software-controlled snuggers clamp the board edge across entire length of the PCB, and then the flippers retract so that there is no interference with full board-to-stencil contact. This technique addresses two issues; the first being rigid positioning of the board for optimum print accuracy, and the second is achieving optimal stencil to board gasketing for a good print. This approach is especially well suited to thin PCB printing applications.

Another design-related contributor to printer accuracy is reduction of unnecessary motion of parts and systems within the machine. For example, reducing the amount of Z-axis height travel for such elements as the print head, if that amount of travel isn't needed, can enhance stability and, again, reduce vibration for improved accuracy particularly at high speed, high throughput printing.

To be sure, the accuracy of a stencil printer is not solely decided by the precision employed in machining its various moving parts. The value of a production printer is not in perfectly printing a single board, but in printing hundreds and even thousands of boards that follow with the same quality outcome as the first. Thus, different factors affect long term and continued accuracy, and one of these is the software controlling the machine. Software is designed to control the machine's operation as well as assist in keeping it operating optimally, just as an auto-pilot system is needed to make small course corrections in a ship's heading when underway. Many different factors can contribute to a printer 'drifting' out of registration over time; these range from the aforementioned machine tolerances to temperature changes in the manufacturing area, stencil stretch and deformation, and more. Most can be addressed to some degree but not eliminated. Thus, keeping the printer 'on course' can be achieved nowadays by occasional printing process checkups using automated inspection technologies such as Solder Paste Inspection (SPI).

SPI and Closed-Loop Feedback

A Solder Paste Inspection (SPI) machine directly downstream of the printer automatically checks the newly-printed board for paste height on pads, paste insufficiencies, bridging, and other defects that are directly a result of problems in the printing process that don't all have to do with print registration, but misregistration is one of them. Software and advanced communications today allow the SPI machine to communicate directly with the printer through a specially-developed common interface. Simply put, when the SPI machine 'sees' X, Y, and Theta offset problems on PCBs being printed, it analyzes the data almost instantly and gives the printer instructions to correct those offsets, automatically, and 'on the fly' without requiring operator intervention. Big changes aren't made all at once; each time a PCB is printed, the offsets are incrementally corrected until, after a few boards, print deposition is 'zeroed in' precisely where it's supposed to be on the pads. This is especially useful for fine pitch/fine feature print process optimization. However, if the printer is not printing to factory specifications or is out of adjustment, inspection and closed-loop feedback will be working overtime and never get the printer printing consistently well or repeatably, at least not as much as it should. The printer quite literally doesn't 'know' that it is out of adjustment. This is where Machine Capability Analysis (MCA) testing comes in.

Machine Capability Analysis (MCA) Testing

A machine process capability analysis confirms printer performance in term of mechanical accuracy and stability. This test proves the stability (repeatability) of the printing process using specific tools. Manufacturer (or customer) specifications are used to qualify the equipment. This is important because a printer manufacturer OEM can 'claim' any machine accuracy that they want, but MCA testing, especially independent 3rd party testing by a reliable and professional testing company proves and verifies a printer's accuracy without any ambiguity. There are two types of MCA testing employed to learn whether or not a printer is 'mechanically' accurate when printing. One method is home-grown; the other involves testing by a 3rd party. And, while an advantage to using 3rd party testing is that it is an unbiased, dedicated and independent method, it is expensive to use frequently. In many cases, printer OEMs will purchase the testing machine and its dedicated glass plate fixtures to perform tests within their own facility on new machines, or ones that are being refurbished or rebuilt. But this doesn't solve the printer customer's need for frequent, affordable testing for print process optimization. For that, there are tools such as one printer manufacturer's accuracy checking system.

OEM Printer Accuracy Check

The 'homegrown' printer accuracy testing method developed by one printer manufacturer enables the user to quickly and inexpensively verify the precision and repeatability of the printer. Since it is an option built into the printer, it's available any time and is far less expensive than independent 3rd-party testing, but is not as precise a verification. Eventually, one may have to bring in 3rd party testing (audits) but using it reduces that frequency significantly. This 'homegrown' method uses the alignment fiducials and print verification pads on the user's PCB (or a special test PCB supplied by the printer manufacturer) to verify alignment accuracy. These verification 'locations' are user-definable, as are the customer's upper and lower process limits. A customer inputs these locations and limits when launching the program. It measures targeted paste deposits, and compares them to the verification locations using printer's software program and machine vision (camera). It will then automatically locate both the pad model and the paste model simultaneously resulting in a measured print offset. How accurate is it? The method was proven accurate by the OEM by comparing the Print Verification data generated by the test to years of 3rd party (CeTaq) data before the option was released for customer use. While not a replacement for independent testing, it does give the printer customer the ability to know that their printer is performing accurately and reliably on a daily basis, to user-set tolerances based on a test PCB or actual production PCB.

This testing measures performance. Should results begin to vary, or accuracy begins to wander outside of acceptable tolerances, it may be considered an 'early warning sign' that the printer needs examination by the factory or authorized distributor service professionals. The testing provides the user with the measure of machine performance repeatability, which is most important for a printer, and can't be influenced by software. Total machine accuracy (offset) can and is influenced and adjusted by software. Accuracy is important for precise offset-free printing but is not built into the machine, as is repeatability. Thus, this test is essentially Process Capability Analysis, or PCA, whereas machine Capability Analysis (MCA) measures the innate accuracy that is built into the machine. Evaluation of a printer's accuracy and process potential must include both, ongoing.

Integrity of the MCA Testing System

With the CeTaQ test procedure, the stencil and squeegees are installed and configured in the machine. The board is loaded and clamped, fiducials marks are identified by the camera. Once the board is printed, the glass board is inserted into the testing machine which measures the positioning accuracy (X,Y) and evaluates the results. A minimum of 6 boards are printed and measured. Results are then pooled together and analyzed depending on printing direction. Printing offsets of angle between board and stencil can be determined at this state. Some corrections are applied into the machine software (X,Y or Theta) and a batch of boards are printed again. Once the corrections are done and the process became stable, a minimum of 20 printed boards without any process/machine modifications is necessary to evaluate the stability of the process. When the measurement is completed, statistical results and graphical analysis are exploited to evaluate the machine's performance. The stability of the printing process is proven. The machine is able to print product within the original quality specifications set forward by the manufacturer. The measurement system and glass boards are calibrated using international metrology standards. Most importantly, the testing ensures that the printer is performing within the machine manufacturer's claimed specifications.

Verification of New Printer's Capabilities

We look to the 3rd party-administered MCA testing for unassailable verification of performance claims; this is necessary simply because when selling machines in a competitive market, one must back up claims that, at first glance, might give one pause, particularly in a market where printer manufacturers (and others) can claim any level of 'process accuracy' that they please, but this term is essentially meaningless. Earlier we mentioned the emergence of a new printer with capability and performance specifications that, when compared to current best-in-class SMT printers, are literally 'off the charts'. A new printer has proven, through independent 3rd party MCA testing and verification, 8 micron alignment, with 15 micron wet print repeatability (>2 Cpk @ 6σ). This represents a 25% improvement in wet print accuracy over current best-in-class machines including successful flagship models long produced by this manufacturer.

Conclusion

SMT stencil printer accuracy has become a more important issue than ever before as SMT components and land patterns shrink and PCB topographies become denser. Accuracy is a function of design and engineering, and can be measured and verified using MCA tools and testing. Process capability is also measurable and can be enhanced by software and the aid of external systems such as closed-loop communication with an SPI system and mechanical performance validation, on occasion, through accuracy check tools. Variations in different elements in the printing process, e.g., PCB fiducials, stencils, and other factors ensure that there is no such thing as a printer that is 'too accurate' for any SMT assembly application; rather, a high degree of accuracy combined with tight process control and optimization will ensure a robust and repeatable printing process so that the user will obtain the full value out of their production stencil printing machine.

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