Synchronizing the stencil printing process for successful central database recipe control

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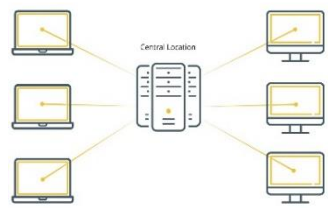
Abstract:
This paper will focus on the requirements needed to implement a central database for printer recipes and minimize setup time required to begin production. The SMT process works best the more we minimize the human intervention required. With electronic manufactures embracing the concepts of Factory 4.0, it has become clear that recipe control has become a vital element to maintain a stable and repeatable process. Removing recipes that are machine-based and implementing a central database has shown to improve overall quality and job-to-job repeatability. This capability has been available on equipment for years and the advantages known; however, the issue has been setup time from when the recipe is loaded until the product is running at acceptable results for both alignment and print results. This machine-to-machine variation has stifled the implementation and is often the cause of failure. The following paper will outline the steps to implement a central database recipe process and how to synchronize the individual machines to minimize setup and time to production.



Background:
Presently the vast majority of SMT manufactures have individual recipes for their printers residing on the machine. This can apply to any facility running a single line or greater. The issues are numerous where individual recipes can vary greatly from machine to machine. It was observed at one facility where the same product was running on six individual lines and each machine was running with different printer parameters. Two issues become clear: the longer a product is run, the more likely the recipes become corrupted over time and the larger the facility the greater the chance for variability.

Issues with machine-based recipes:

The issues with not having a central depository and having a machine-base for recipes are as follows:

- Lack of flexibility for line utilization.
- Machine to machine recipe variability.
- Inconsistent results and defect creation based on machine condition and parameter settings.
- If recipe is moved to a different line the recipe offsets are machine dependent resulting in requiring “tweaking” of the board to stencil offsets at startup, resulting in loss production time.
- Printing issues that are addressed with parameter settings and saved, once the root cause is fixed, are required to be adjusted back to the original parameter settings.
- Loss of control of recipe revisions resulting in inconsistent results and unnecessary loss of production time at startup.

Advantages to having a central database for printer recipes:

One of the concepts of Factory 4.0 is to eliminate chaos and bring order to the SMT assembly process. As this concept matures, this is where finally results can meet expectations. As the process becomes more automated, it will become vital that all the machines "sing from the same hymn book and be in tune as well". There are several advantages to having a central data base:

- The recipe can be run with the same predicable results each time – repeatability each time the product is run.
- Increased yields and less scrap.
- More flexibility for line utilization – a product is not anchored to any one line.
- Line management and scheduling becomes much easier with more flexibility.

With these advantages, there has been one issue that has plagued this concept and that is the setup and startup times. Variances in machine configuration, calibration, and condition, combined with, tolerances in the stencil and substrates, increase the setup time needed to get the line running. A new step will be introduced to this process of implementing a central database for printer recipes that will reduce the setup time significantly and make the process more repeatable over time.

Challenges with developing a central database for printer recipes:

The challenge to make a central database recipe process work is to synchronize the individual variances in each machine to eliminate any adjustments during startup. Most factories accumulate machines and expand additional lines over time. This results in machines that are at different levels of software, operating systems, and overall condition. There are cases where calibrations or machine damage can trigger process parameters that are compensating for these issues resulting in machine specific recipes. This results in a loss of flexibility as recipess become more machine specific. One key point is that the individual machines should be identical in vendor, model, and option configuration. If your factory has a mixture of machine vendors or model types, then this application will not work. For example, if some machines are configured with side clamping while others are using top clamps this may produce different results. Another issue is when an option is called out in the program, and it does not exist on the machine, this may produce an error that will prevent the machine from operating. If the machines are identical in option sets this will make the implementation much easier. The ideal situation is that all your printers are identical to produce identical results. If there are individual machines that have different configurations, the central database can still be utilized but have dedicated programs assigned to them.

Procedure to implement a central database for printer recipes:

The following are the steps to implement a central depository for printer recipes for a multi-line SMT facility. Each step is important where skipping any step will result in variability in the process. The steps are:

- Machine audit – repair / calibration / update
- Synchronize machines
- Access to database folder / Engineering / IT
- Test plan of procedure
- Implementation plan
- Develop master program development procedure – Engineering
- Develop operator procedure – startup / operation / completion
- Maintaining the process

Machine Audit:

The process begins by getting all the machines on the same level of software, calibration, and preventive maintenance status. As factories grow and equipment is installed over time, the state of the machines can vary greatly. One of the keys to successfully implementing a central database for recipes is to eliminate any machine variance. This begins with a full and thorough audit of the machine. It is suggested that a factory trained field service technician be called to perform this audit. Having a professional perform the audit, calibration and repairs can eliminate errors and catch issues that can go undetected that can be affecting the machines overall performance. A good starting point is a detailed cleaning of machine followed by a full PM and calibration of the machine's key functions. Key points to address are as follows:

- *Clean-up of machine*
  One of the key contributors of machine issues is solder paste contamination. As hard as we try, the material has a way of contaminating the machine and over time, can affect the performance of the machine. Prior to scheduling an FSE visit, it would be prudent to give the machines a thorough cleaning, so the FSE can focus their time on the machine and not on cleaning. Solder paste residue left on linear bearings and ball-screws will damage these parts over time and any residue on the worktable and adjacent components can reduce print quality. The cleanliness of internal working surfaces and axis is critical for printing quality and accuracy.
- *Visual inspection for wear or damage Items such as pulleys, belts etc.*
  A detailed visual inspection of the machine for any wear or damage. This may require removing covers and some disassembly to gain access for inspection. Repair or replace any parts needing attention.
- *Lubrication*
  Clean and lubricate all required axis per manufactures recommendations. Make sure to remove any excess lubricant, this can cause motion issues in the axis. Adhere to any PM requirements for lubrication.
- *Testing axis motion controls and input/output sensors*
  Jog all axis for full range (limit to limit) making sure there is no binding or interference. Verify all sensors are operating and are triggering properly.
- *Vision inspection and calibration*
  The vision system should be inspected, as well as any calibration performed, to bring the machine up to specifications. Synchronizing the machine's vision system will be done in a later step.
- *Print pressure calibration*
  The print pressure calibration should be performed and validated. This is usually done with a force/strain gage that has been certified for the system being worked on. To ensure we have the same print results on from machine to machine.
- *Rail alignment and level*
  Rail to rail alignment should be verified, along with the parallelism of the transport tracks. Over time the rails can get bumped thus becoming misaligned and out of specification, resulting in print issues or parameter changes to compensate.
- *Table to stencil rail level*
  This is a key calibration point, as this will determine our position of the board to the stencil and how well we are gasketing. The previous recommended table to stencil rail specification was 0.004" (however, thinner substrates and more challenging aperture sizes have determined that this specification be reduced to 0.002" or less).

Once a list of parts is generated, a time should be scheduled with the least impact so all required repairs and the associated calibrations can be performed properly. This can be done by a factory FSE or by internal personnel if the required calibration tools and knowledge base are available.

Synchronization of the printers

One of the main benefits of using a central database for recipes is the flexibility to utilize machine availability for scheduling production. However, this benefit is frequently offset by the time it takes to dial in the printing process. Once the variation in machine state and calibration is addressed, the next is to synchronize all the machines. "One stencil and PCB to rule them all" is the concept we will apply to create a common datum point which each machine will share. This calibration board and stencil will be the reference point going forward to anchor the machines to address any variance in positioning. It should be noted that once the synchronizing process is introduced, this is the point of no return. We will be changing the global offsets of the machine which now will affect all the existing recipes offset data. Based on the number of lines, the verification of the process should be isolated to two machines so not to disrupt production. This way one can prepare ahead before becoming fully vested in this process.

Synchronizing will be discussed using three different methods: Printer Verification Tool, Solder Paste Inspection (SPI) and CeTaQ.

Print Verification:

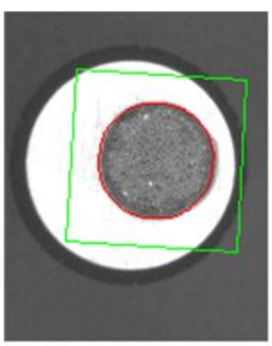
Description: Print verification is a tool developed by a leading printer company as a process verification tool. This tool utilizes the printer vision system to analyze the position of paste deposits that is referenced to the pad to determine wet print accuracy and repeatability of the machine. Limits are programmed into the test, based on the published machine specifications. The test produces a pass / fail result, to validate if the machine is meeting its wet print specifications. Later, the tool was also used where the machine vs the PCB repeatability was in question. The machine now could be either confirmed or eliminated as the source of the instability. For our application we will now use this tool to calibrate all machines to a common set of offsets that will be applied to the global settings of the individual machine.

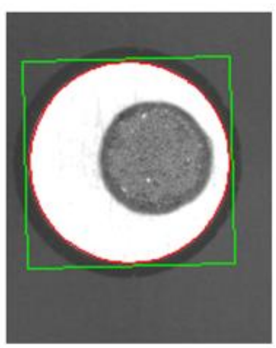
The question most often asked is that “We already calibrated our machines, why do it again?” The answer is that printers are calibrated using two methods: static and dynamic. Static often involves using a calibration board and stencil as reference, to apply global settings to the machine’s database. The next level is mapping where a glass substrate and stencil are used to address the cameras “pitch and yawl” across the entire limits of the cameras travel. These offsets should be tied to a common datum point that all the machines share. This will shorten the walk to dial in any offsets we encounter when we now go into production mode.

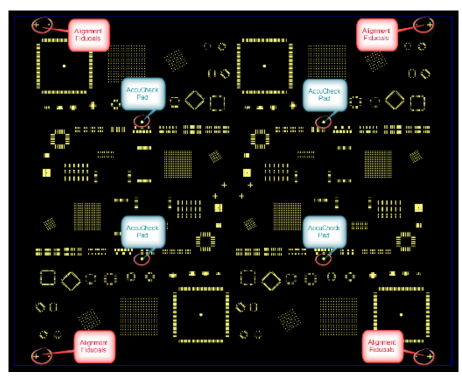
However, this calibration does not include any material transfer and is considered static as we are not implementing all the motions of the machine. This would include movement of the print-head, creating friction between the stencil and the blades, and measuring the accuracy of the machine at the critical point where the stencil and PCB meet. To synchronize the machines, we need to take into consideration all the motions of the machine and its position at print to determine any mechanical intolerance these motions create.

How Print Verification works:

This feature allows the user to easily verify the machine’s print process capability by measuring the actual print deposit position versus the target pad. This is a viable method of obtaining machine quality and process capability information. The method of measuring used in this situation takes into consideration the machine related motions and calibrations, thus allowing the machine to accurately measure itself. The system uses an algorithm to compute the positional deltas between each pair of paste deposit and target pad. This requires that the paste deposit be smaller than the target pad by a considerable amount (in this case by 50%) so that the system can accurately locate both features, pad, and deposit, in a single picture.







Dialing in common print offsets from machine to machine

A single PCB is used to eliminate board stretch and board-to-stencil offset variation, this can be further refined by scaling the stencil to the PCB. This will also be a key tool used in applying common print offsets from machine to machine. Stencils are normally cut using a common artwork but tolerances in the board, can add noise to the results. The print offset results from the print verification test, can be added to the global print offsets, to standardize offsets from machine to machine. The first recipe developed for print verification should be loaded and accessed in the same folder where all recipes will reside, for standardization, control, and easy implementation on other equipment.

Solder Paste Inspection (SPI):

If an SPI is available, the print verification match board and stencil can be used in the same way for dialing in the common print offsets among the equipment. A match board and stencil can also be designed and used if the stencil aperture is a 50% reduction of the pad, so the system can accurately locate the deposit verse the pad to determine the correct print offset value. The X, Y, and Theta results from the SPI can be directly applied to the correct print stroke. Each print stroke should be dialed in separately, due to the mechanical difference between strokes.

CeTaQ – CeTaQ is a company based in Germany that measures the printer's accuracy and repeatability and is often used in validation of the machines capability and that it meets its posted specifications. This measurement procedure has been widely accepted in the SMT industry and has become the standard operating procedure when accepting equipment for automotive manufactures.

The CeTaQ procedure utilizes an adhesive that is printed on a dedicated glass fixture with 473 individual data points. Each deposit is analyzed using a custom designed analysis tool for X, Y and Theta axis repeatability and accuracy. A total of 20 prints are performed to determine the machine vision repeatability, wet print accuracy and machine offsets. The machine can be "zeroed out" by applying the offsets found by the CeTaQ test results to the global offsets of the machine. This process would be repeated for each machine.
This would be the most accurate way to synchronize the machines; however, later the test would have to be repeated to either verify or recalibrate the machine.

Test procedure

Once all the machines have been calibrated it's time to test the system. The objective of this test is to verify that a recipe can be downloaded from a folder to a printer and requires minimal intervention until producing verified acceptable results. This capability should be repeated regardless of how many machines are part of this recipe. The steps are:

- Test system and communication
- Determine test product
- Develop master recipe
- Perform test
- Maintaining the process

Test System and Communication

At this point of the procedure, it is assumed the folder and network communications should be established, tested, and working properly. Any issues should have been highlighted at this point prior to transferring the Print Verification file between machines. Some of the things to consider when establishing this architecture:

- Operator access privileges should be downloaded only. Preferred to have only one controller with upload privileges that would be allowed to save recipes on the network.
- All recipes must reside on the network. There should be no recipes on the machine. Once a job is completed, the recipe should be deleted from the machine to avoid corruption.
- Develop a backup file located off the network in the event of failure – make sure backup is concurrent – and backup the backup, you can never be too safe.
- Use the security settings on the machine. Take away the save and other functions that might override or contaminate the recipes.
- Any changes to recipes should be reviewed, verified, and uploaded by Engineering with access only privileges prior to save and upload.
- Use revisions and either eliminate or archive older recipe revisions.

In production mode, in theory, we want to be able to have the process parameters at a steady state. However, changes in the production environment, different board suppliers, paste condition and others can individually or combine to force minor adjustments to the recipe parameters. This should be temporary until a solution is found or determined if the changes are the new normal. Otherwise, these changes should not be allowed to be saved. Recommended is a parameter limiting software that limits the number of changes to the parameters. For example, if it is known that the paste gets tired later in the shift, allowing the operator access to both pressure and squeegee speed. The recipe would allow (+/-) 2lbs for pressure and (+/-) 0.5 inches/second for speed. These would be the limits, that if exceeded, will result in an error message.

Reality states that no process is perfectly steady state. Engineers are being spread thin, so we lean more on the operators to make the decisions on the fly to keep production moving. Set the limits so that it allows tweaking but not major shifts. If they reach the limits, then that is an indication something needs to be addressed before proceeding. This will empower the operator and not make them feel locked out of the process.

Determine the Test Product

When choosing a product for this test it's best to use a product that is non problematic. Remember we are testing the network and its repeatability not the printer capability or material design. If you had paste transfer issues before, networking is not going to solve this. This should be a product that is produced regularly and can be run in normal production to verify the results. Once the product is determined, the process parameters should be reviewed for best practices and documented. This review and recommendation for changes would be best done with an Applications Engineer from your machine vendor.

One process that should be implemented, if not being used, is the knead paste function. To begin a print process, we need to have the paste at the correct viscosity to enable the material to transfer correctly. Today's printers all have a knead paste function available. To eliminate delays in startup and to improve overall yields, using the knead is key.

To understand the importance of the knead function we need to understand the physics behind printing. When the squeegees apply force to the stencil, we produce a sheer force to the paste. Paste is a non-Newtonian fluid that when sheer forces are applied, results in sheer thinning where the viscosity of the paste will decrease. Paste viscosity is measured using either Brookfield or Malcom method. The difference is in the spindle used and RPMS when measuring. This is outlined in IPC-J-STD-005 and IPC-TM-650. For this paper we will use the Brookfield method which is measured in Centipoise X 1000 or KCps.

Typical recommended viscosity ranges are as follows:

- Dispensing: 200-400 KCps
- Screen Printing: 400–600 KCps
- Stencil Printing: 600-1400 KCps

The most common solder paste is around 900 KCps. Changes in powder size and metal content used in small aperture applications can influence viscosities and how they perform. Each paste has its own reaction to sheer force. Pastes are designed to work at a designated viscosity that promotes flow and material transfer. This sweet spot depends on how much sheer force, or in this case, strokes it takes to get the paste at the correct viscosity. In other words, how many boards does it take until the SPI passes and add one and you have the amount of knead strokes required. Remember that non-Newtonian fluids are thixotropic by nature which means that if we stop printing, the paste will return to its static state, and we need to repeat the knead process.

Develop the master recipe

Once the parameter settings are reviewed the product should be verified in a production run. Offsets should be verified with a SPI, if available, added to the recipe offsets during setup. These offsets are associated with the stencil to board where this should be minimal. This value may change when stencils are replaced, or when a different board vendor is used. Once the recipe has been approved it should be given a revision name and uploaded to the network file. It would be wise to back that up at another location in case of issues. The file on the machine should be deleted as well. The machine should be reset to put the axis back in the home position. The stencil and blades can remain, but you may want to simulate a start cold start and replace the paste and clean the stencil. The file download procedure can then be invoked to retrieve the recipe on to the machine. Load recipe and perform startup procedure. Run product and observe results.

Results: If all the procedures have been implemented correctly, then the product should start up with no intervention to the machine or the recipe. This procedure should be repeated with each machine designated for this recipe to test each machine's capability to transfer, set up and run the master recipe with no intervention.

Once the synchronization has been verified, the next step is the hard part. Once we changed the global offsets, all the recipes existing in your library are now affected. Also, some of the printer parameter settings may now need to adjust now that we have addressed issues on the machine. Depending on the size of your product library, it can be done in a batch mode or on a "as needed basis". It is recommended that recipes are created from scratch and not adapted to existing recipes. This way subtle errors can't escape, and the recipe can later be used as a template for subsequent programing. Developing the master recipes in batch mode would require a dedicated machine and the availability of the materials. As painful as setting up the product and printing boards, this is the best way to address high running products and not interrupt production. Once the production needs are met, then the remaining recipes can be addressed when the build becomes available. Working with the production scheduling to get advanced notice will facilitate the process. This is the pain threshold that one must pass to implement this recipe with the rewards worth the effort.

Operator Procedure: Once the library is in place, the procedure for the operator must be developed. All recipes should be removed and put in a folder on the network once the library and backups are in place. The operator should be trained in how to access the folder and download the recipe to the machine. Procedures should be in place to verify recipes revision and how to proceed in the event a matching recipe is not found. The key to making this process work is when the product run is completed the procedure is to delete the recipe. If any changes were made to the recipe, they should be reviewed and documented prior to being uploaded to the network by the designated Engineer who has access. Machines should be reviewed to make sure this procedure is being performed. The operator should alert them of any changes or issues during the startup routine as changes to the state of the machine or material will need to be investigated. Remember process rule 101 before you make changes to the recipe: you built thousands of boards on these parameter settings – what changed? *Avoid the easy fix and address the root cause.*

Maintaining the process:

Once the recipe has been implemented, maintaining the machines' preventive maintenance schedule as well as adding options that can further support the recipe will allow the process to continue with minimal intervention. These options can keep the equipment at consistent operating levels, implement safeguards that eliminate waste and allow for flexibility to adjust to changes beyond the printer's control. Going forward one should consider the following:

Preventive Maintenance – Each machine will have their recommendations for PM. The age-old issue of the dilemma of whether to do PM or to run production has been and continues to be an issue. Studies have shown that overall uptime is increased by taking the time to maintain equipment; however, when a deadline is being faced, PM in most cases loses. For this recipe to work, it will require that all the equipment be at the same level of capability. Over time the process will fail due to encroaching variations in machines. I cannot stress enough of how important PM will have in keeping the line running consistently and reliably. Using software that indicates that a PM procedure needs to be performed and a verification that it has been performed will keep this important function visible.

Process Verification: This option was first developed on printers for customers who were running lead and unleaded paste in their facility to be RoHS compliant. It is primarily being used now to validate that the correct material and associated revisions are being used in the process. If a mismatch is found, then it prevents the operator from proceeding until the issue is addressed. This option links into the recipe where it uses a hand barcode scanner to identify and confirm the correct paste, stencil, tooling, blades, or pump via an independent barcode for each element.

The PCB can be scanned as well to verify if the correct substrate is being used. This ensures that the correct materials are supplied to the printer and eliminates downtime and waste due to errors.

Paste height monitor – Maintaining the correct amount of paste is critical to maintaining a steady state process. The recommended paste roll diameter is 15mm. Excess paste on the stencil prevents the paste from rolling which affects the aperture fill – insufficient paste contributes to scavenging of the apertures. Using a paste height monitor, where the paste is dispensed manually or automatically, will maintain the correct level of paste and eliminate defects.

Process Parameter Limiting Software – Most security systems available on today's printers have become more sophisticated. Individual groups can be created such as Engineering, Technician, Operator, with each their own level of access. Individual passwords are now used where each movement within the software is tracked and documented in logs files. Locking the operator out of the recipe on paper seems like a good idea, some flexibility needs to be allowed. Changes in environmental conditions, PCB lot differences, paste variability based on stencil life force us to make corrections to maintain production. However, right now it's either all or nothing, where access to parameters have no limit or control. A resent development allows one to set up the security as previously done, then set limit parameters to what range the operator has access to change. For example, if access to the printing pressure is allowed – allow a 20% variance where any changes outside of this range would indicate that something more serious is occurring and should be addressed. Allowing flexibility with limits is recommended.

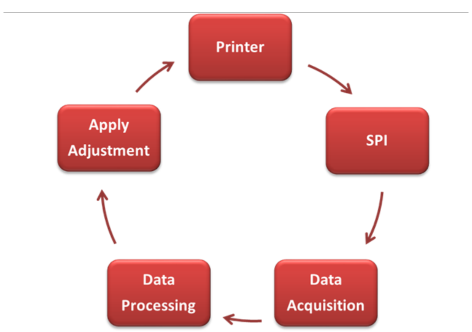
SPI Closed-Loop:

This system is used for analyzing and adjusting the printing process, utilizing measurements from an automated, 3-D Solder Paste Inspection System, or SPI, to adjust the alignment of the board to the stencil using X, Y and Theta corrections. This option will also continuously optimize the print offset correction and monitor the process for print offset creep. The introduction of closed-loop control eliminates operator intervention, or process "tweaking".

By optimizing solder paste deposition and solder joint integrity, product reliability is greatly improved. The closed-loop option that connects the printer to SPI eliminates or reduces operator intervention. The print process becomes more immune to stencil changes, non-linear stretch, environmental and tooling variation.

Key Benefits:

- Produce consistent & accurate print results
- Reduce or eliminate operator "tweaking"
- Prevent defects instead of just identifying them
- Compensates for uncontrollable or difficult to control process variables



This graphic illustrates how the closed-loop works. Instead of operating independently, measurements from the SPI are directed to the printer via the inspection interface for on-the-fly process correction. The printer sends critical information to the SPI like the print direction and fiducial locations and the SPI uses this information to calculate the print offsets and rotation in board space and determines if the board is acceptable. The SPI machine will then feedback these adjustments to the printer. If the board is rejected by the SPI machine, an additional option is to trigger a wipe in the printer to address any stencil issues.

Verification safeguards that the correct material is used where security and process limiting software maintains the recipe integrity while allowing flexibility. Closed Loop communication between the printer and the SPI adjusts minor offsets on the fly without influencing database recipes.

Conclusion:

As we strive for the challenges of implementing the concepts of Factory 4.0, recipe consistency and dependability is key to developing a reliable and predicable process. The flexibility to run a product without startup delays based on machine availability allows an increase in productivity if utilized correctly. Aligning the machine global offsets to a single stencil and board eliminates the machine-to-machine variance in calibration. Going forward, we now have reference point that can be called upon whenever there are questions if alignment issues/repeatability between a product and the machine. The machine can now be verified/eliminated or identified as the source of the issue. In conclusion, the use of a central database and the synchronization of the machine offsets will produce a more flexible and repeatable process.