AUTOMATIC REFLOW PROFILING
&
DATA ANALYTICS

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ABSTRACT
With the advent of i4.0 and Smart Factory, there has been a great deal of technology put into SMT lines that are manufacturing the very technologies we use today. Data analytics has become paramount and anyone that is collecting the correct data will have proper process control to support SPC, Cpk, and Ppk data to suffice customer requirements. There has also been a great deal of focus on the front end and the backend data for the SMT process. We are concerned about the printing process for precise volumetric printing to the point where Solder Paste Inspection (SPI) equipment has almost become a standard on the surface mount line. We have even put a great deal of technology into the back end of the process with (AOI and X-Ray) to look at every solder joint and void the board may have. This paper will talk about the reflow oven and how automatic profiling has also become a necessary tool for data analytics and troubleshooting as well as taking the guess work out of oven profiling. An automatic profiling system (reflow process inspection) will automatically collect the thermal data at the board level for precise process control and allow traceability for every board that has been through reflow with the actual Thermal Profile, SPC, and Cpk stored for every board. Ask any CQE or Quality Engineer, they need data to support any process changes or customer complaint.
Key words: Automatic Profiling, Solder Reflow, Smart Factory, Process Control.

INTRODUCTION
Data is the foundation of a smart factory. Useful data is imperative to clear insight, correct decisions and optimization. This does not mean the collection of all data that becomes a mass of space but rather the product and process data that can be easily analyzed, and often live for fast reaction. One area of the manufacturing process that is often overlooked is the reflow process. Existing technology can be used to monitor, track, document and react to production during the reflow process. Use of this information in real time is used for quality assurance, quality improvement and process control. This is done via automatic profiling, a technology that is >40 years old and used by manufacturers around the world who produce product from commercial/consumable electronics, cellular, automotive, medical, mil-aero, and more. This data was the 'black hole' in manufacturing data collection and therefore true process control, troubleshooting, traceability and optimization was incomplete. Data analytics is being collected at the print process and then nothing for the reflow. Some use AOI post reflow but then you're too late, requiring rework or scrap. However, implementation of this technology completes the data collection protocol.

DATA COLLECTION
Data is being collected in factories now from incoming inspection, inventory and throughout the manufacturing process and further to product reliability in the field. The manufacturer, and most importantly the customer requires complete product information. Now traceability has become a requirement, especially for customers who inquire about the systems that were used for their product assembly and any problems associated with them, particularly for liability requirements. Mentor, a Siemens business, states that 'The key to avoiding problems is to analyze all available data intelligently, particularly in critical areas.' Having the ability to identify each step of the manufacturing process allows for fast troubleshooting should a problem occur, whether during production or in the field. The analysis of the data provides deep insight into the process, shows where problems occur, why and how often, managing the product's quality. Again, analysis then leads the way to corrective action and improvements, a more efficient process with less scrap, rework and times savings, bottom line, save money.

BENEFITS
Real time data collection allows for immediate action for defect prevention and troubleshooting, thereby saving time and money for rework, trash or field failures. Supplying the highest quality products is a competitive advantage along with a cost savings.
Data analytics facilitates process improvements, optimization and process control. Once again, an optimized process saves money and most importantly the real-time information assures complete process control. Automatic collection and centralization of this data, or connectivity, is a significant step to Smart Factory implementation and is critical to have data from all the manufacturing processes throughout the factory, including the reflow process, an often ignored yet crucial process. Previously it was done via a 'Traveler'. Now it's automated so the information is both continuous and at your fingertips. Using various forms of connectivity from

machines to computers, all the data is stored and can be accessed for the data analytics. But most importantly the information is LIVE which means immediate action can be taken should a problem arise, or an improvement is implemented. Defect prevention.
Data analytics has become paramount and anyone that is collecting the correct data will have proper process control to support SPC, Cpk and PWI data to suffice customer requirements. Complete and useful data allows companies to make better, accurate decisions.

AUTOMATIC PROFILING METHODOLOGY

There is a great deal of companies that overlook the reflow oven and thermal data, possibly the biggest 'black hole' in the manufacturing process. The referenced 'black hole' refers to the profile for each PCB manufactured in the reflow oven. While oven (machine) data may be monitored and collected it is not recording, documenting and/or representing the profile for the products. Data analytics is being collected at the print process and then nothing for the reflow. Some use AOI post reflow but then you're too late, requiring rework or scrap.
An automatic profiling system produces product data throughout the reflow oven in real-time, making this data actionable and traceable. Via data analytics improvements may be made easily and quickly to save defects and money.
An automatic reflow profiling system or Reflow Process Inspection (RPI), is an automatic reflow profiling system that combines continuous SPC/Cpk charting, line balancing, automated documentation and production traceability into an integrated software package. These systems automatically calculate a real-time profile, feed real-time process data to engineers and managers, permitting them to make critical decisions affecting production costs and quality. (See Figure 1.) The systems can provide and record real-time thermal process data for every product vs. the conventional practice of only periodically checking oven performance. One is then automatically assisted in catching potential defects before they happen rather than exposing them during "inspection."

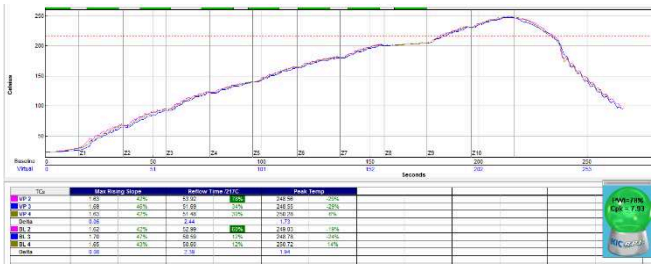

Figure 1. Real-time calculated reflow profile

The RPI automatic profiling system will automatically collect the thermal data at the board level for precise process control and allow traceability for every board that has been through reflow with the actual thermal profile, SPC, and Cpk stored for every board. Ask any CQE or Quality Engineer, they need data to support any process changes or customer complaint. Traceability of board specific reflow profile is also done automatically. Every board is married with a profile instead of a profile/week, profile/day, or profile/shift plus SPC Cpk data analytics of every board/run/shift/week/month. The data may show that oven temperatures and process specifications vary more than expected.
As the means for verifying the profile of every board produced, the virtual profile is established by running a baseline profile of the product with a real-time profiler while simultaneously collecting real-time data from thermocouple probes and additional installed sensors in the oven such as board sensor and conveyor speed encoder. The mathematical correlation between the temperatures at product level and those on the product itself permits the software to calculate changes in the product profile accurately. Once a virtual profile has been established, the system goes into monitoring mode with a real-time calculation of how the product profile is changing, based on probe readings. Process temperature or airflow cannot change without affecting the product temperature, and the software's algorithms accurately calculates changes in process temperature to changes in the product profile. I don't like this sentence.
Once a profile has been established within a user-defined process window, an RPI system monitors production for that product. In the monitoring mode, the system produces a real-time profile chart and a table of data selected based on the process window. Other screens display SPC and Cpk control charts (See Figure 2.) for each statistic as well as a control chart for the product's overall process window index (PWI). Data are updated and saved for each board as it exits the oven.

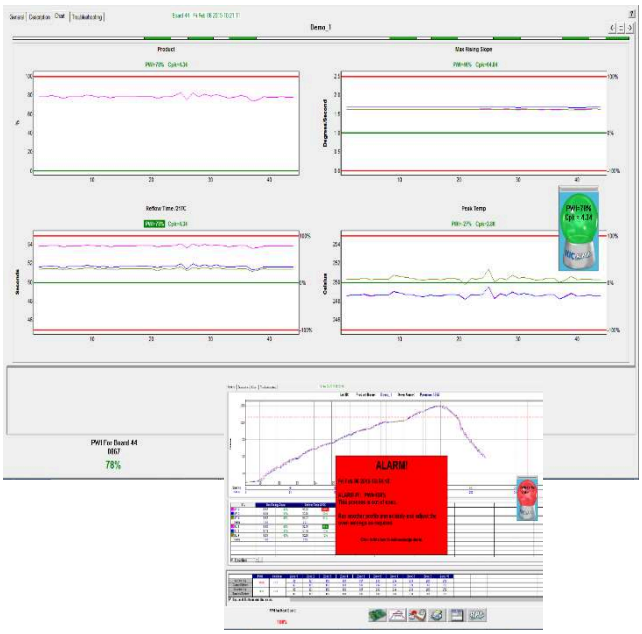

Figure 2. Live SPC/Cpk control charts. Alarm notification on computer screen

AUTOMATIC PROFILING & DATA ANALYTICS

For each calculated profile that has been established, the system will automatically begin to generate SPC data. When a board exits the oven, the data set is plotted on frequency histograms. Process data are charted for all critical process specs: peak temperature, soak time, time above liquidus, etc. The data are plotted on real-time control charts and Cpk is

calculated for each spec. Finally, the overall Process Window Index or PWI is charted, providing a real-time Cpk for the entire process. Any process drift outside control limits will bring an immediate alarm.

The PWI, a statistical method for ranking process performance, measures how well a process fits within user-defined limits.

Data collection is automated and Windows-based. The system's filing system permits users to examine the profile for every board produced, thus providing valuable process documentation. The file system is product name-based, making all data, profiles, production data and alarm events accessible. All events and profiles are time and date stamped as well. The alarm record shows when alarms both occurred and were acknowledged, permitting supervisors to monitor operator performance. Alarms are triggered whenever the virtual profile statistics or the PWI exceed user-defined limits. The system will also alarm Cpk variations so that the situation can be corrected before the process goes out of spec. A third alarm function acts as a fail-safe and alerts to significant change in process temperatures.

With this collection of data and the use of a barcode or lot ID a company can achieve traceability to each board throughout the reflow process.

Automated data collection and the use of centralized data storage makes it fast and easy to search historic data, analyze trends, research problems and optimize recipes and processes in the reflow process. Data sharing and data mining, a key aspect of smart factory and Industry 4.0 are possible with this system. This flexible software and data collection system also satisfies auditors for both process and documentation control and is recommended by auditors globally.

CONCLUSION

An automated reflow process inspection system offers benefits including SPC charting and real-time process information, resulting in reduced training costs, product traceability, verification profile elimination and zero-defect thermal processing. One can fine-tune the reflow process by centering it in the process window while determining that the oven is not as stable as once thought. The RPI, however, permits a process to be verified as good before it is run, to help prevent defects and to build in rather than inspect in the level of quality required.

The basic functionality of an automatic profiling system, is to accurately and automatically monitor and collect data on products passing through the reflow oven, a process that provides several significant benefits:

- Reflow data is being automatically generated live, continuously
- Manual periodic profiles are eliminated
- Data analytics is being performed with real-time profiles
- Continuous SPC control charts alerts to variances in process capability (Cpk).
- The real time feedback captures process drift with warnings and alarms, preventing defects.
    - Cost reduction
    - Highest quality standards
    - Process control
- Improved automation and data for analytics supports increased flexibility, lower overhead and higher quality standards