Automated Process Control for the Reflow Process

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ABSTRACT

This paper will focus on recent advances in thermal process control and detail new methods for continuous automated process control.

The status quo method of process control for the reflow process is to set the oven to previously determined temperature setpoints and conveyor speed, and when the oven says that the control points have reached setpoint value, begin running production. The user must assume that the temperature setpoints and conveyor speed that gave an in-spec profile yesterday will give an in-spec profile today. The longer it has been since the oven was profiled, the less likely it is that the profile will still be in spec. Most users are aware that they are essentially "flying blind". Because of this the profile is "checked" on a regular basis, say once a month, once a week, once a day, or even as often as once a shift (every 8 hours). The problem with this method is that if the profile has drifted out-of-spec, every product manufactured since the last in-spec profile is suspect. Another problem is that if there is a catastrophic change in the process, it is extremely unlikely that periodic profiling will catch this change. Instead, catastrophes are discovered at final inspection, which of course is too late, and inevitably some product must be reworked or scrapped.

This issue should be of concern to individuals responsible for quality and productivity in electronics assembly. What is needed is a means of monitoring the thermal profile for every board processed. New hardware and software technology will make it possible to both optimize and automatically monitor the reflow portion of the SMT line at a previously unimagined level. This technology includes a statistical method for quantifying reflow process performance, which allows a simple and efficient application of Statistical Process Control to the reflow process.

This paper will include a description of new technology to manage the thermal process and a discussion of potential applications of the technology.

INTRODUCTION

A recent Electronics Industry roadmap stated, "Electronics Manufacturers need control of their processes, products, and product costs." This quote is followed by a statement that identifies the need for technology to "collect and report information on individual production units or provide instructions to, monitoring of, or control of production operations."

For most sections of the SMT assembly line, process data and control is readily available. Until now, however, this has not been true for the reflow process. There have been systems available for many years that are capable of delivering real-time reflow process data, but these systems have been configured as engineering tools. An engineering tool captures all available data on a given process, and then a process engineer analyzes that data to determine the process status. In the current economic climate, where an electronic assembler must realize every possible efficiency, this allocation of scarce engineering resources is not acceptable. Technology that gives users complete control of their processes, minimizing the need for human resources, is required. This need can be met by automatically monitoring the thermal profile for every board processed. New hardware and software technology now makes it possible to both optimize and automatically monitor the reflow portion of the SMT line. This technology allows users to maximize efficiency, minimize costs, improve yields, and improve product quality.

THE STATUS QUO

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TECHNOLOGY REVIEW

The status quo method of thermal process control relies on two basic technologies: pass-through profilers and real-time thermal monitoring systems. Pass-through profilers have evolved into sophisticated process setup tools, some of them nearly completely automated, but still only offer a "snap shot" of the process. One work-around that has been tried with limited success is the use of a pass-through profiler with a fixture that characterizes the equipment (oven) rather than the actual process. This method provides some data for tracking equipment performance, but because the sampling is by nature intermittent, the method does not yield adequate process data or true control. Real-time thermal monitors, with sensors embedded in the oven, offer continuous data, (in essence, a video of the process) and the opportunity for "true" process control. However, because currently available real-time thermal monitors are configured as engineering tools, true process control is resource intensive.

AUTOMATED REFLOW MANAGEMENT SYSTEM

Hardware

Automated reflow management systems that combine continuous SPC charting, line balancing, documentation, and production traceability into one software package have recently been introduced. These systems are designed to feed real-time process data to engineers and managers, allowing them to make critical decisions affecting production costs and quality. They are capable of providing and recording real-time thermal process data for every product, as opposed to the conventional practice of only periodically checking oven performance. This allows the system to automatically catch potential defects before they happen, rather than discovering actual defects in "Inspection".

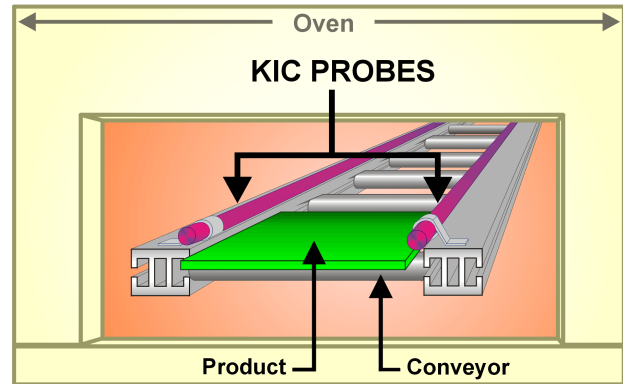

Figure 1: Thermocouple probe location in oven

The automated reflow management system utilizes thirty thermocouples permanently embedded inside the conveyorized oven/furnace at the process level. The thermocouples are configured in two probes 15 internal thermocouples inside a flexible stainless steel weave. The probes are installed along the conveyor at product level and run the length of the process. The probes are connected to a Thermocouple Processing Unit (TPU), which sends the probe data to a PC. The TPU monitors the temperature of two 15-thermocouple probes as well as input from product sensors installed at the entrance and exit of the oven.

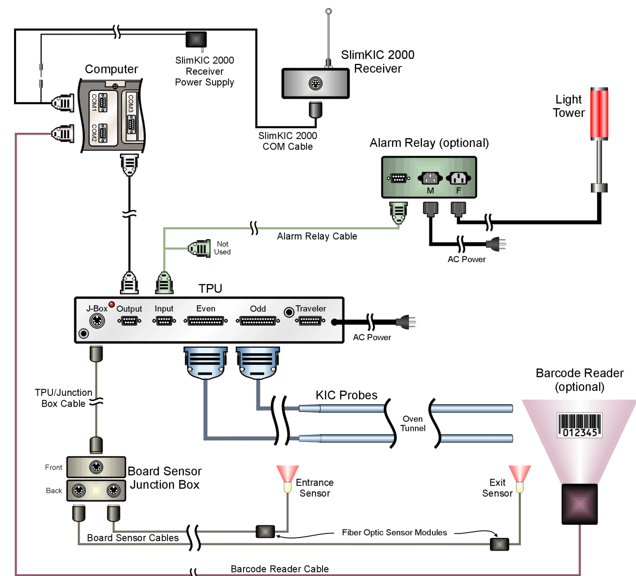

Figure 2: Hardware configuration

The automated reflow management system includes two significant hardware improvements for more accurate process measurement: more responsive probes than previous systems, as well more reliable product sensors. The thermocouple probes need to react quickly to changes in airflow and temperature, which are indicative of changes in temperature experienced by the product. Increasing the sensitivity of the probes makes changes in airflow and temperature in the oven easier to detect and reduces response time, which allows the system to more precisely monitor the changes to the

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process as a product passes through the oven. The other hardware improvement was developing reliable product sensors. To track board position accurately required state of the art product sensors that would not only indicate when the product enters and exits the oven, but do it in such a way that outside influences were eliminated. These two hardware upgrades improve the accuracy of the *Virtual Profile* (see *Virtual Profile* below).

Software

The basic functionality of the automated reflow management system is to accurately and automatically monitor and collect data on product passing through the reflow oven. This functionality allows the system to provide significant benefits:

1. Eliminate the need for process verification profiles.
2. Provide real-time feedback and alarms for zero defect production.
3. Completely automate reflow process data collection.
4. Provide automated SPC charting of the reflow process, and the capability to alarm off variances in process CpK.

Figure 3: Automated Reflow Management System Software Main Screen

One of the most significant differences between the automated reflow management system and previous real-time thermal monitors is that the new system is a production solution rather than an engineering tool. The system software has been designed to be completely intuitive for maximum ease of use. The system's ease of use means that the process can be monitored with a minimum of human resources and training costs can be significantly reduced. The automated reflow management system's ability to interface directly with the oven controller on selected models from leading manufacturers offers additional process efficiencies. When setpoints are changed in the software, (e.g. changing over to a previously profiled product), the data can be downloaded automatically to the oven, eliminating the need for separate data entry.

Previous tools focused on characterizing the oven, and the software was designed to give engineers the maximum amount of flexibility. Part of this flexibility was the ability to monitor any conveyorized thermal process. This flexibility meant that real-time thermal monitoring offered engineers a valuable tool, but also meant complicated software that only engineers and very senior process technicians had the process knowledge required to use effectively. The automated reflow management system was designed as a dedicated production tool for electronic assembly processes (soldering and curing). Although it does have engineering functionality in the background that can be easily accessed if required, it is designed for ease of use on the production floor. The system automatically and efficiently verifies the profile of every board processed.

Virtual Profile

The means for verifying the profile of every board produced is the *Virtual Profile*. 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 the 30 permanent sensors in oven. The mathematical correlation between the temperatures at product level and the temperatures on the product itself allows the software to accurately simulate changes in the product profile. Once the Virtual Profile has been established, the system goes to monitoring mode with real-time simulation of how the profile of the board is changing based on probe readings. The automated thermal management system monitors and records beltspeed and process temperature variations. Process temperature or airflow cannot change without affecting the product temperature, and the software's algorithms accurately extrapolate changes in process temperature to changes in the product profile. The accuracy of this computer simulation has been established elsewhere[1].

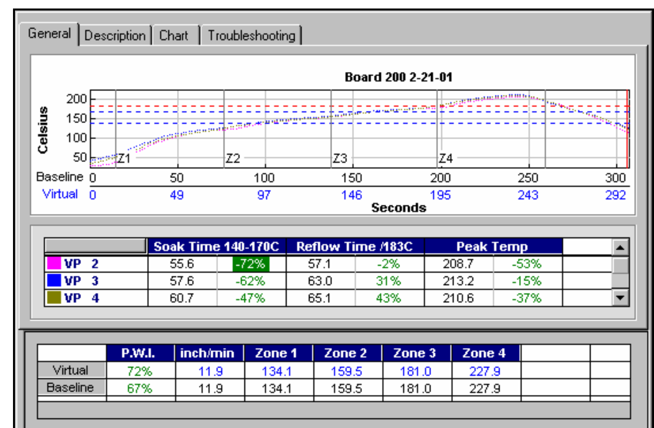

Figure 4: The Virtual Profile

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Once a profile has been established within a user defined process window, the automated reflow management system monitors production for that particular board. Production monitoring is achieved by selecting a product folder and clicking the create Virtual Profile button. In the real-time monitoring mode, the system produces a real-time profile chart and a table of data that has been selected based on the process window. On other screens, available by tabs, there are SPC control charts for each statistic, as well as a control chart for the overall *Process Window Index* (see *Process Window Index* below) of the product itself. Data is updated and saved for each board as it exits the oven. For each production board, based on the profile established and the current probe readings, the system produces a simulated temperature profile.

The Process Window Index

Another feature of the software platform is the *Process Window Index (PWI)*, a statistical method for ranking thermal profile and thermal process performance. The PWI measures how well a profile fits within user defined process limits. This is done by ranking process profiles on the basis of how well a given profile "fits" the critical process statistics. A profile that will process product without exceeding any of the critical process statistics is defined as being inside the Process Window.The center of the Process Window is defined as zero, and the extreme edge of the process window as 99%. A PWI of 100% or more indicates that the profile will not process product within spec. A PWI of 99% indicates that the profile will process product within spec, but it is running at the very edge of the Process Window. A PWI of less than 99% indicates that the profile is in spec and tells users what percentage of the process window they are using: for example, a PWI of 70% indicates a profile that is using 70% of the process spec. Figure 5 illustrates how the Process Window Index is calculated.

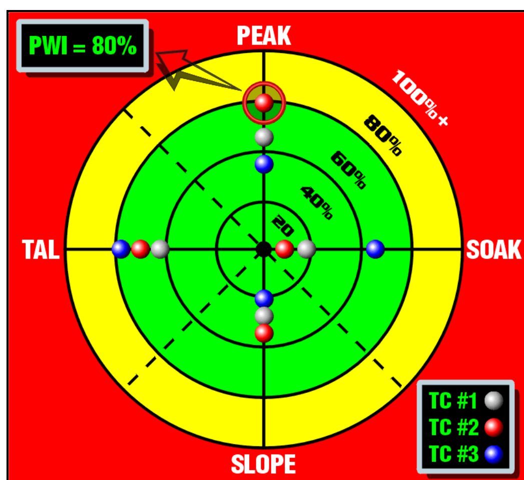

Figure 5: How the PWI is calculated

The simplicity of the Process Window Index makes its validity as a statistical tool readily apparent, and that it clearly offers significant benefits for improving soldering processes. Profiles can be easily compared, and users can be confident that they are using the best profile their process can achieve. The PWI reflects the performance of the whole profile, which provides much better indicator of process capability than tracking a single statistic. The PWI thus provides excellent data for SPC and other QC monitoring programs. The automated reflow management system uses the Process Window Index to calculate the overall process CpK for every board that goes through the oven.

The Heat Transfer Issue

It has recently been asserted that measuring the heat transfer rate in the reflow process is critical. Tools are available that can measure the heat transfer rate in an oven, but only intermittently, and only on a fixture, not on the actual product. Although the option of continuously monitoring the heat transfer rate was investigated during system development, it was determined that this feature offered no improvement to the system's functionality. Research has established what is intuitively obvious: that temperature at the product level will vary significantly if there is a change in process temperature or airflow, e.g. the loss of a fan.

The automated reflow management system does not directly measure the heat transfer rate inside oven. What it does do is take advantage of fact that modern ovens are finely tuned instruments that are highly repeatable and reliable. In a properly functioning oven, the ΔT between the oven setpoints and the conveyor in the controlled zones is extremely stable in normal operation, and temperatures measured at the conveyor are very consistent if the heat transfer rate is consistent. Temperatures at the conveyor may be 15°C lower than the setpoint degree temperature, but the variation between an empty to full oven is generally only 2-3°C.

The automated reflow management system characterizes the oven and determines how stable it is. This means that the system, once it has learned the oven's characteristics, will detect variations in the oven and determine whether they are characteristic. The temperature as measured at the product level is a function of the oven's heat transfer rate, which is determined by the zone setpoint temperature and the velocity of the air in the zone. Thus, any change in zone setpoint temperature or air velocity will cause a change in temperatures at the product level.

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SYSTEM FUNCTIONALITY

Automated Real-time SPC, Data Collection, and Alarms

Once the Virtual Profile is established, the system will automatically begin to gather SPC data when the first board exits the oven. Every time a board exits the oven, the data set is plotted on frequency histograms. Process data is charted for all critical process specs: Peak Temperature, Soak Time, Time Above Liquidus, etc. The data is plotted on *real-time control charts* and *Process Capability* (CpK) is calculated for each spec. The overall Process Window Index is charted, providing a *Real-time CpK for the entire process*. Any process drift outside of control limits will bring an immediate alarm. The process engineer also has the option of setting a warning limit on the CpK. Real-time CpK tracking enables the system to flag an out of control process before the oven/furnace has produced a single defect.

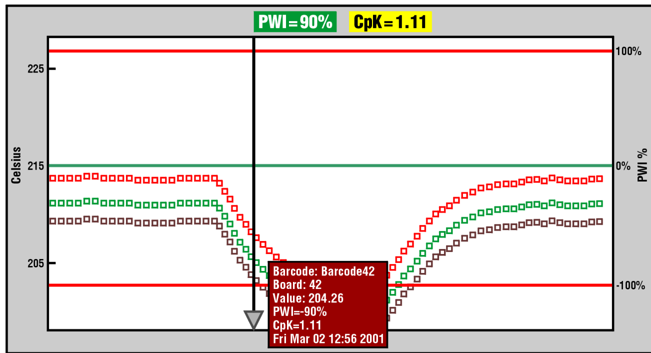

Figure 6: SPC Charts

Data collection is automated and Windows-based. The system's profile explorer allows 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, readily accessible. All events and profiles are time and date stamped as well. The alarm record shows when alarms occurred and when they were acknowledged, allowing supervisors to monitor their operator's performance. Alarms are triggered whenever the Virtual Profile statistics or the Process Window Index exceeds user-defined limits. The system will also alarm variations in process CpK, notifying the user that the process is varying and allowing the situation to be corrected before the process goes out spec. There is a third alarm function that acts as a fail-safe and will alarm any significant change in process temperatures. When there is an alarm, users can go to the Troubleshooting tab in the software. The troubleshooting chart has thirty bars (one for each probe thermocouple), which make it simple to isolate the source of the alarm. The bars track positive and negative deviation for each thermocouple, and a mouse click on the bar will give the user the amount of deviation. The software correlates the probe TC's to the oven zones, so the exact location of the temperature deviation is readily apparent. Belt speed is also tracked.

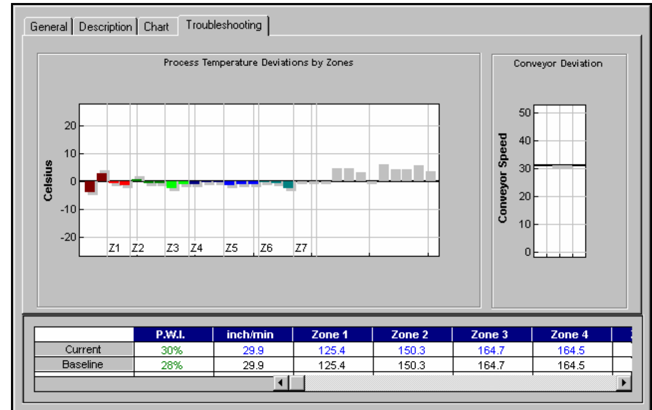

Figure 7: Troubleshooting Screen

System Options

System options include Live Data Output, Barcode capability, and an Alarm Relay. The live data output can send all data for each board in ASCI format to a remote file, for example, an SPC program or archive file. The data string for each board includes barcode or time and date stamp, oven name and product name, process window parameters, oven recipe, overall PWI and CpK, plus thermocouple data. If the Barcode option is used, all data gathered will be tied to the board's number, giving each board a unique data set. There is also an alarm relay option that can activate a light tower or stop the feed conveyor if there is an alarm.

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CONCLUSION: APPLICATIONS AND BENEFITS

The Automated Reflow Management System is currently being evaluated at several sites, and the results of the evaluations will be available for the presentation at SMTA 2001. The benefits the system offers include:

- Automatic SPC charting: CpK and process data for every product
- Real-time process information for improved decision making
- Ease of use means improved staff allocation and reduced training costs
- Oven Controller Interface
- Traceability for every product
- Eliminate verification profiles
- Zero-defect thermal process

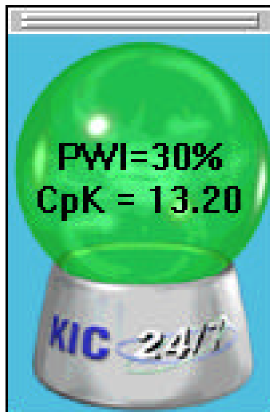

Figure 8: Virtual Profile Crystal Ball

The automated reflow management system offers users many benefits, but the greatest is the simplicity it brings to total reflow process management. Whenever the Virtual Profile is live, a small screen containing a crystal ball is superimposed on the computer screen. If the crystal ball is green as a production board exits oven, that board is guaranteed to have been processed inside the process window. The crystal ball is green when the process is in spec, yellow when it the process has reached a warning limit, and red when it is in an alarm state. The Crystal ball contains the overall process PWI and the process CpK, and in standard production, those two numbers are all a user needs to be assured their process in spec. With the automated reflow management system, users can be assured that their reflow process will be in-spec 24/7. An in-spec process will increase product reliability by ensuring consistent process, a process with which it is impossible to experience reflow related defects.

SOURCES

1. Philip C. Kazmierowicz and Dennis Ishler, “Accuracy of the Prophet Thermal Manager Virtual Profiling Tool,” May 1997
2. Philip C. Kazmierowicz, “Increasing Reflow Process Efficiency and Yield with Automated Reflow Setup Software,” APEX 2001
3. Dr. Wayne Johnson, “Improved Thermal Process Control for Lead-free Assembly,” APEX 2001

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