Applying Real-time SPC to Thermal Process Management

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Until recently, reflow ovens, vertical ovens, and wave solder machines, have been difficult to include in an SPC program. Screen printers and pick & place machines have had the capability to output valid SPC data for years. Developments in both thermal monitoring hardware and Statistical Process Control software now make it possible to automatically gather data on the thermal portions of the SMT process in real-time; automatically output data to an off-site software program; and automatically store, manage, and analyze that data for SPC purposes. These developments make it possible for SMT manufacturers to apply Statistical Process Control to the entire production line. This paper will focus on new technology that makes thermal process data from any SMT reflow or solder wave conveyor oven available in real-time for SPC analysis.

Following a brief introduction to SPC, thermal process management, and conventional methods of thermal data collection, the paper will focus on new tools for the collection of continuous thermal process data in real-time and the application of SPC to the thermal portion of the SMT production process. The advantages of these new tools will be covered in detail, with the final portion of the presentation focusing on efficient and cost-effective methods for applying continuous real-time SPC to thermal management. This presentation will provide PCB manufacturers with practical information for filling the current gap in gathering SPC data on thermal processes and give them the opportunity to apply SPC analysis to the entire SMT production line.

Statistical Process Control

Statistical Process Control (SPC), is a method that utilizes a set of statistical tools to optimize and maintain quality in manufacturing processes. The key to understanding SPC is predictability. If a predictable process produces good parts, then deviations from process predictions can be read as indicators that the process is changing and may soon produce bad parts. The first step in implementing an SPC program is finding the critical process measurement(s) and gathering data from a selected sample of production. Once a set number of samples has been gathered the data is plotted on one or several SPC charts—generally on X-bar charts and then on a frequency histogram.

Variation in a process that is "In Control" will fall into a normal "frequency distribution", which resembles a "bell curve" when displayed on a histogram (see Figure 1—Normal Curve). If the data does not fall into a standard frequency distribution, it means that there is an "assignable cause" present in the process. An assignable cause is something in a process that will cause it to behave erratically and develop a "non-normal" curve (see Figure 1). Examples of assignable causes would be consistently faulty material, a machine incapable of meeting process specifications, or an operator using a machine incorrectly. The assignable cause in Figure 1 (Non-normal) is a faulty thermostat.

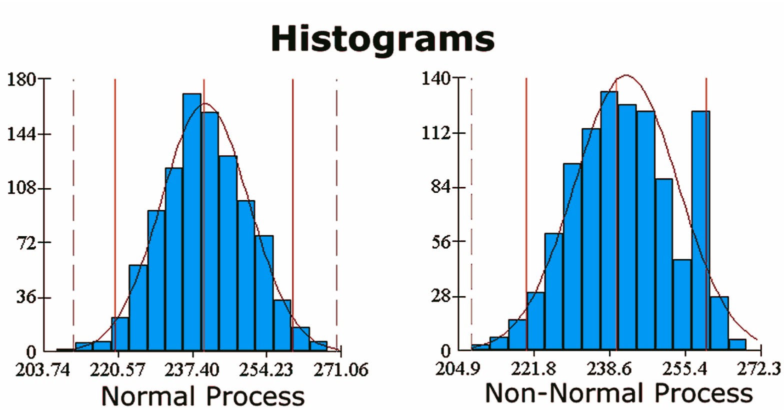

Figure 1: Normal and Non-normal Histograms

After assignable causes have been removed, statistics can be used to develop an accurate overview of the process. Pareto charts can show what features need the most work by displaying them in the order of most defects to

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fewest. Correlation and regression analysis can answer questions like "Is minimum conductivity more closely linked to peak temperature or to soak temperature?" Process capability charts can show how well different zones of the furnace maintain their desired temperatures (see Figure 2). Analyzing a process in this way concentrates process improvement efforts on the areas where they are essential.

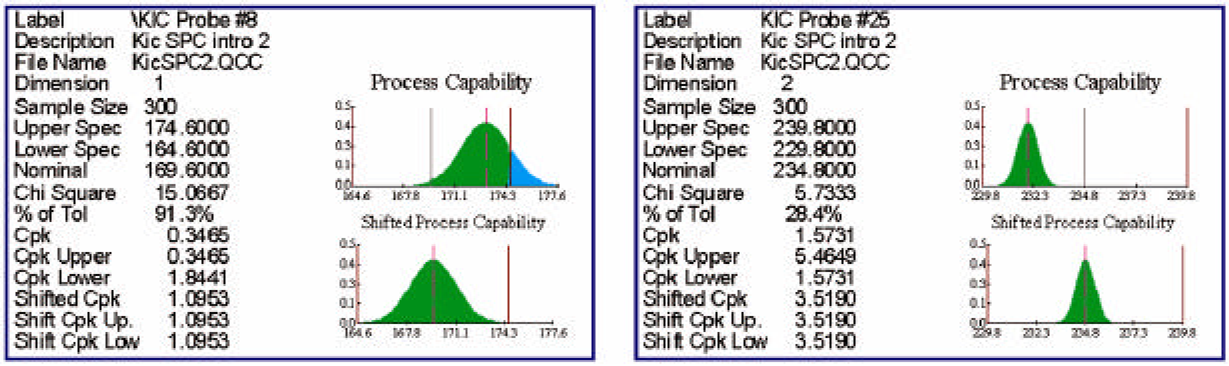

Figure 2: Process Capability Analysis

The Cpk charts in Figure 2 indicate that Thermocouple 8 is fluctuating significantly and well above the nominal, while Thermocouple 25 is well below nominal with very few parts outside the specification limits. The oven zone T\C 8 is monitoring may be draftier than the one monitored by T\C 25, or may be suffering from a mechanical problem in its convection fans.

Even in a "perfect" process, machinery is subject to normal wear and failures, and the results of these process shifts may not be immediately apparent. SPC can spot a process drift too subtle for direct observation, giving operators time to repair the process before defective parts are produced. If a predictable process produces good parts, then deviations from process predictions can be read as indicators that the process is changing and may soon produce bad parts. With continuous thermal profiling and real-time SPC, a failure can be detected within seconds. Without these tools, the failure might not be detected until the next scheduled profiling, or when the electrical test reports a high percentage of failed boards, resulting in hours or days of bad parts.

The Reflow Process

Solder Reflow is a process for connecting electrical components and assemblies to printed circuit boards. The purpose of the reflow oven is to heat the product to a precise temperature at a precise rate for a precise period of time. When this combination of time and temperature are plotted, the result is a "Thermal Profile". Maintaining a proper profile is critical: if the PCB does not get hot enough the solder will not bond the components to the solder pads properly; if the PCB gets too hot or is heated too quickly, the board and components will be damaged.

Monitoring the Reflow Process

Until recently, the Reflow Process has been the most difficult portion of SMT production to monitor for quality control. For many years the conventional method of monitoring conveyorized thermal processes has been to attach thermocouples to a product, and using a wireless profiler, run the product and profiler through the oven to record the thermal profile. This is called "profiling the oven," and is typically done on a regular basis: monthly, weekly, or as often as once a shift, to verify that the oven can successfully produce a product with the correct solder joint quality attributes. The oven capability must be verified regularly because it has been shown that even in modern forced air convection ovens, there are times when the product thermal profile can drift beyond acceptable specifications, even though the oven controller indicates that nothing has changed. The other time it is necessary to verify the product profile is when a problem exists on the production line. When there is a decrease in yield, the oven must be profiled to determine whether it is the source of the problem. There are three problems with the conventional method of profiling:

1. Using a product profiler is time consuming and often results in production downtime.
2. Each profile run is the equivalent of a snapshot taken with a still camera, and the oven user is forced to assume that the oven is not changing in between "snapshots." These "snapshots" will rarely catch an intermittent problem in the oven.
3. If regular profiling uncovers a problem, there is generally no way to tell precisely how many products have been affected. All production between the first bad profile and the last good profile becomes suspect.

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The solution to the failure of pass-through profilers' to provide a continuous product profile and their disruption of production is a system that is the equivalent of having a video camera running twenty-four hours a day in the oven. In its standard form, this system consists of two 1\4" diameter stainless steel probes containing fifteen internal thermocouples each that are mounted along the conveyor in close proximity to the product; a thermocouple processing unit (TPU) that sends the probe data to a computer; and a Windows based software package. The key difference between this system and conventional product profilers is that the thirty thermocouples inside the probes (see Figure 3) are continuously monitoring the process temperatures.

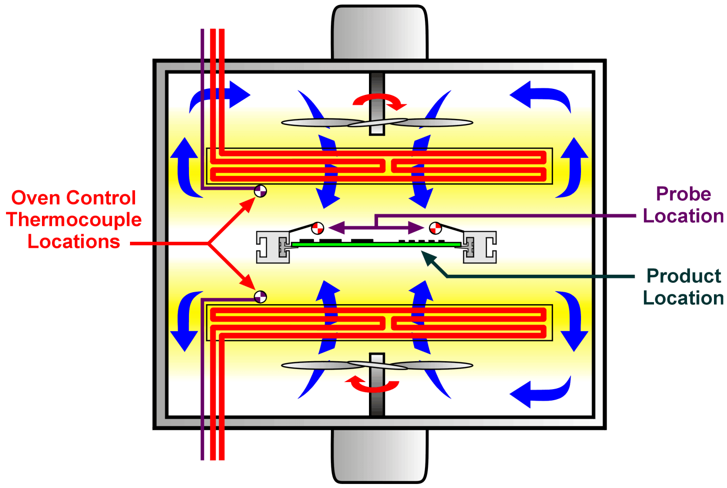

Figure 3: Oven Cross Section Showing Probe Location

Temperatures at the conveyor are continuously displayed as "Process Profiles" on a computer screen and data is permanently recorded on the hard disk. During production, any temperature drift and its location are instantly visible to the user (See Fig. 4). The thermocouple probes are outside of the oven control loop, which enables them to reveal critical temperature deviations at the product level that are often hidden from the oven control thermocouples.

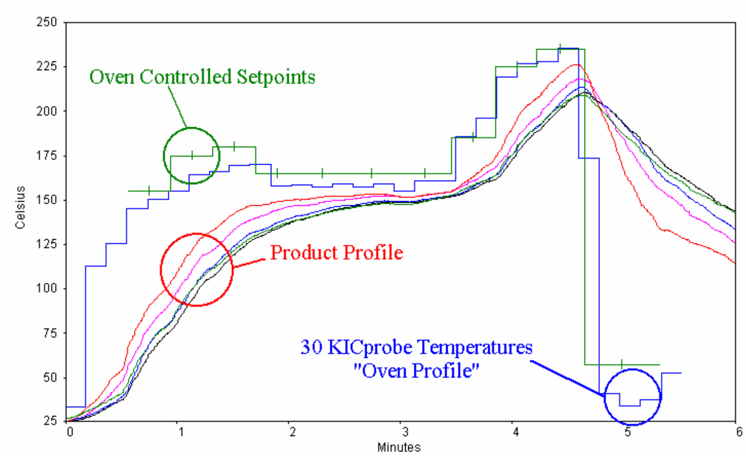

Figure 4: KIC Graph - Setpoints and Process Profile w/Product Profile

The Virtual Profile

Users of the world's most advanced technology, including the aviation industry, NASA, and biomedical researchers, have long recognized the value of computer simulations. The thermal manager software, using a sophisticated algorithm reflecting the laws of physics and thermodynamics, correlates real-time process data to an actual product profile, with the final output being a simulated product profile continually updated during production. Positioning the thermal manager probes in close proximity to the product establishes a direct correlation between the product profile and the oven (or process) profile, making it possible during production for changes in the probe thermocouple temperatures to be utilized to simulate product profiles. This simulated profile is referred to as a "Virtual Profile".

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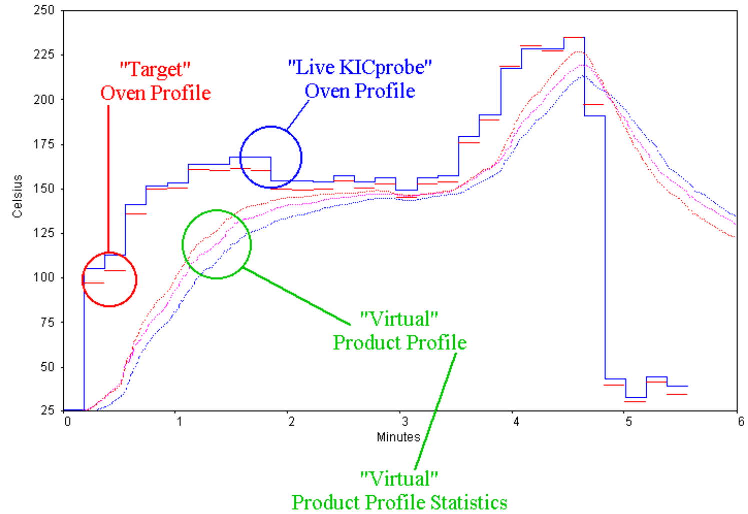
Once an initial product profile has been run with a conventional pass-through profiler, the thermal manager software calculates the relationship between process temperature as read by the probes and product temperature, establishing a "baseline profile" and “Target” process temperatures. During production, the software continuously calculates how this profile has changed based on measured changes in process temperatures from the “Target” temperatures. The virtual profile is calculated and displayed every thirty seconds, effectively predicting the thermal profile for product currently entering the oven. (See Fig. 5). As process temperature drifts over hours, days, or weeks, the Virtual Profile calculates how the changes will affect the product thermal profile. If at any point the product profile falls outside user defined limits, an alarm will sound. If a closed loop system is integrated, the alarm feature can be used to shut down the feed conveyor. *Virtual Profiling is as close as you can get to attaching thermocouples to every product.*



	Peak	Max Rising Slope	Total Time Above 183
VP[01] U8B1	219.6	2.80	61.74
VP[02] U7H1	213.2	2.69	60.63
VP[03] BOARD	226.8	3.20	61.51

Figure 5: The Virtual Profile, (Probes, Targets, and Statistics)

SPC for the Reflow Process

The virtual profile data output from the thermal manager is available to any software application via live data output from the system software. This provides real-time data on the thermal process that can be used in a number of ways. Perhaps the most valuable way this data can be utilized is for real-time Statistical Process Control. The thermal monitoring output interfaces directly with an SPC software package that automates data collection, management, and analysis. This software package is also capable of monitoring Screen Printers, Solder Paste Inspection Machines, and Pick & Place machines, which makes it possible to apply SPC to the entire SMT line.

Conventional methods of gathering data for SPC analysis are time-consuming and generally rely on a single statistic. Real-time data collection allows users to automatically chart multiple critical statistics, including:

- Raw data from the thirty thermocouples in the probes
- Maximum and average deviation from the “target” profile for each probe thermocouple
- Belt speed.
- Thermal Manager Statistics output, including peak temp, time above reflow; ramp or slope rate, and slope or temperature at any point in the process.

Traditionally, SPC has required the collection of twenty-five sets of data before points can be plotted on a chart and analysis can begin. Data collection has always been the most daunting task associated with implementing SPC because of the time and labor required, and also because manually collecting the data can cause an excessive amount of time to pass before charting can begin. Another issue in implementing an SPC program is the questions that sampling only a small percentage of production raise. All three of these issues have been resolved. The thermal manager outputs data every thirty seconds, allowing adequate data for a initial charting to be gathered

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in under an hour. The data is gathered automatically, removing labor and cost issues. Because the data is continuously collected in real-time, sampling issues are minimized.

Once data collection has begun, and the initial control charts have been created by the software package, the user can determine if the process is in control. An X-bar chart showing a process within specifications and a histogram showing a standard frequency distribution, or bell curve, indicates a process that is "in control". If the histogram curve is multi-modal, it indicates the presence of special causes that must be removed from the process. Once an SPC program has been initiated, users identify their worst trait, access the impact, develop and employ long-term countermeasures to improve the process, and then move on to identifying the next problem. The SPC software can indicate where these problems are and includes tools such as Pareto and Process Capability charts for trouble shooting.

A fully implemented SPC program can be used in two ways: for real-time process control by machine operators on the production floor; and for tracking machine performance and troubleshooting machine failures. Charting the virtual profile statistics output allows machine operators to track process status, to spot process drifts too small to be noticed by the naked eye, and correct them before they can cause a defect or affect yield (See Fig.6)

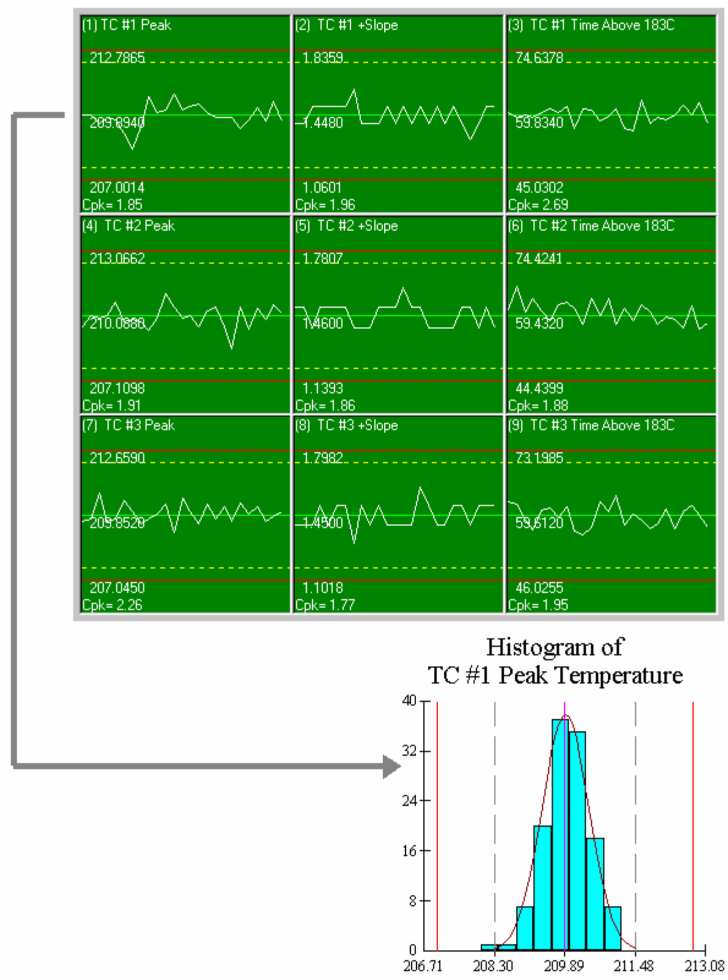

Figure 6: Charts of VP Statistics

When the virtual profile statistics charts indicate process drift, an SPC Program configured to also track probe temperature deviations can facilitate preventive maintenance, troubleshooting, and repair. By programming the SPC charts tracking probe temperatures to reflect oven sections (Pre-heat, Soak, Reflow, and Cooling), machine performance can be charted in parallel with the charting of process performance (See Fig 7). This will locate and isolate problems, as well as helping to identify potential counter measures, and assist in tracking degradation trends in the heating or cooling zones for Preventative Maintenance (PM). It will also help insure that the oven has been correctly reassembled after PM is completed. This ability to track machine performance on an ongoing basis gives the added benefit that oven PM can be done on an "as needed" basis rather than at scheduled intervals.

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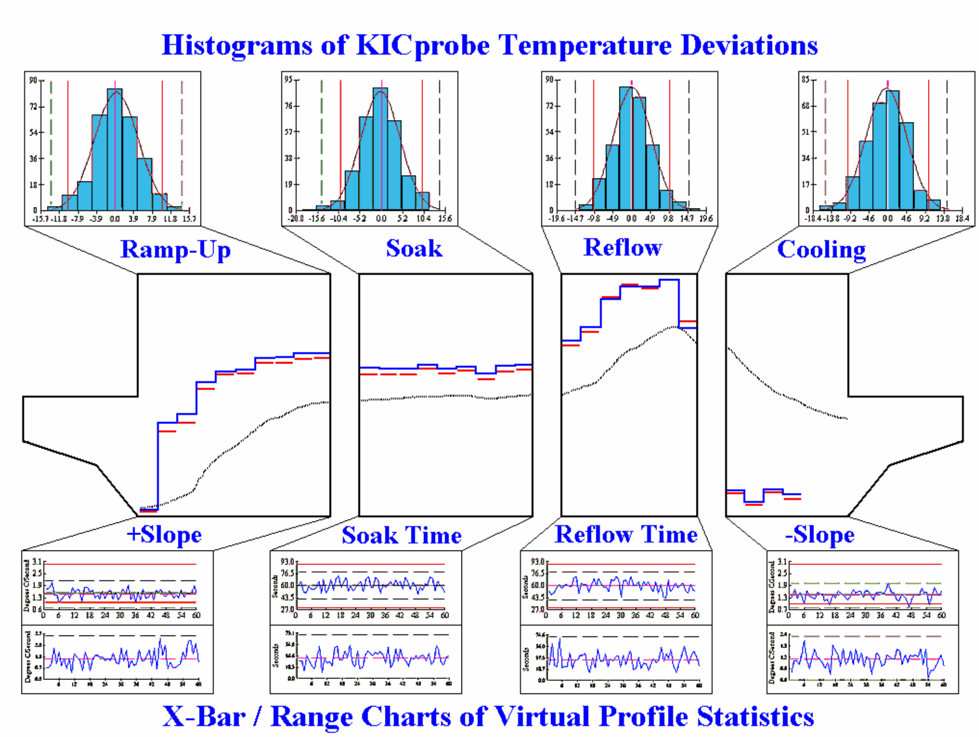

Figure 7: Oven Broken into 4 Sections with Probe Deviation Control Charts for each section.

Simplifying SPC

The key to bringing SPC to the reflow process is simplifying and demystifying it. SPC will never be used if the only person who understands it is a process engineer making bi-weekly visits to the plant floor, and it will never be implemented if it is perceived as being more trouble than it's worth. This makes the capability to gather accurate data about the thermal process critical. This issue has been resolved by the development of the thermal manager, which makes real-time monitoring of the thermal process simple and convenient. The interface with an automated SPC program removes all data gathering chores; completes all calculations, and makes it possible for the thermal process to be tracked from the plant floor.

Benefits of Applying SPC to the Reflow Process

Advances in both hardware and software have made efficient and cost-effective methods for applying continuous real-time Statistical Process Control available to SMT manufacturers. The process of implementing an SPC program for the reflow process has been made simple and painless, filling a significant gap in the application of SPC to the SMT production process. Continuous real-time data collection is essential for maximizing the benefits of SPC analysis. The advantages of continuous automated real-time SPC data collection are:

1. Real-time data collection can acquire an adequate sample for SPC analysis within hours during normal production.
2. Conventional methods of gathering thermal data for SPC analysis generally focuses on a single statistic, for ex: Peak Temperature or Time Above Liquidous. New technology allows the collection of all critical process statistics including belt speed for SPC analysis.
3. Real-time SPC provides significant increases in data accuracy, is collected automatically, and is available for analysis at all times.
4. Real-time SPC simplifies the identification of long-term trends in the production process.
5. Real-time SPC is an extremely effective tool for zero-defect production.

Without real-time SPC, a defect or failure is a manufacturer's first indication that something has gone wrong in their thermal process, and without SPC data, decisions about correcting the problem are simply best guesses. Continuous data collection insures that drift in the thermal process cannot go undetected, and this provides users with the capability to prevent defects caused by failures in their thermal processes before they occur. The advantages of real-time SPC for the reflow process are clear, and advances in both hardware and software technology have given SMT manufacturers the tools to benefit from them.

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