Introducing SPC to the Reflow Process

By Dennis Ishler and Robert Sheahan

Screen Printers and Pick & Place machines have had real time SPC capability for several years, but until recently, reflow ovens, vertical ovens, and wave solder machines have been difficult to include in an SPC program. New 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.

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.

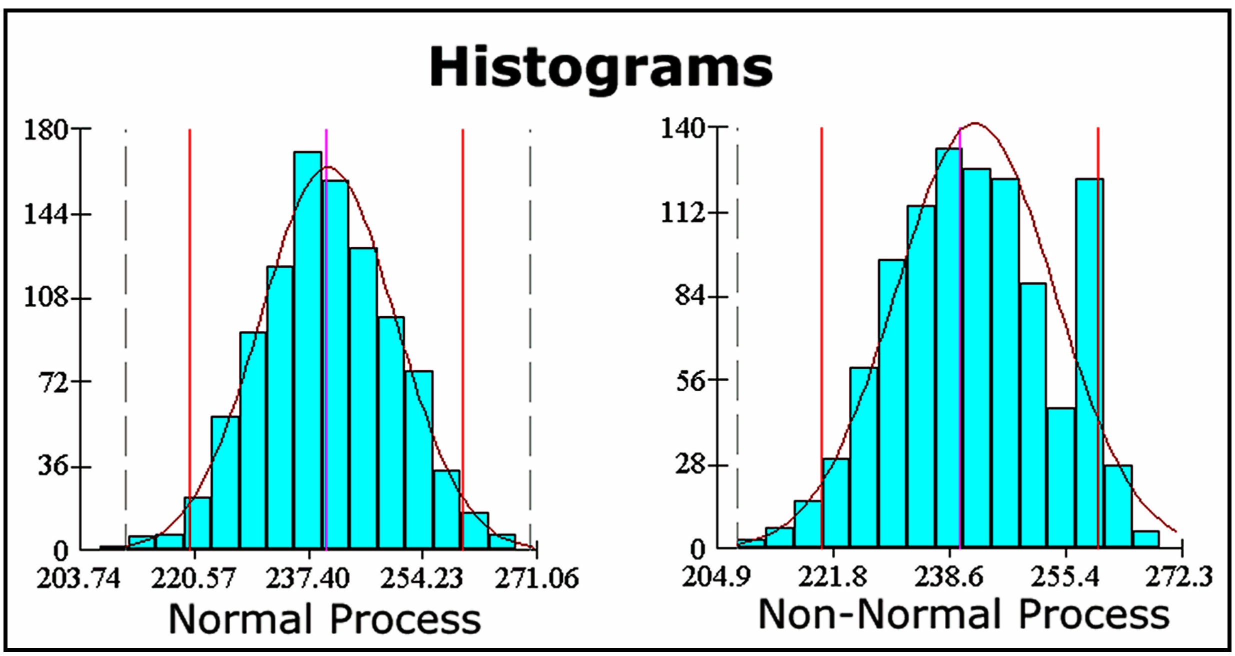

***Figure 1**: Frequency Histograms—normal and non-normal*

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.

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 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.

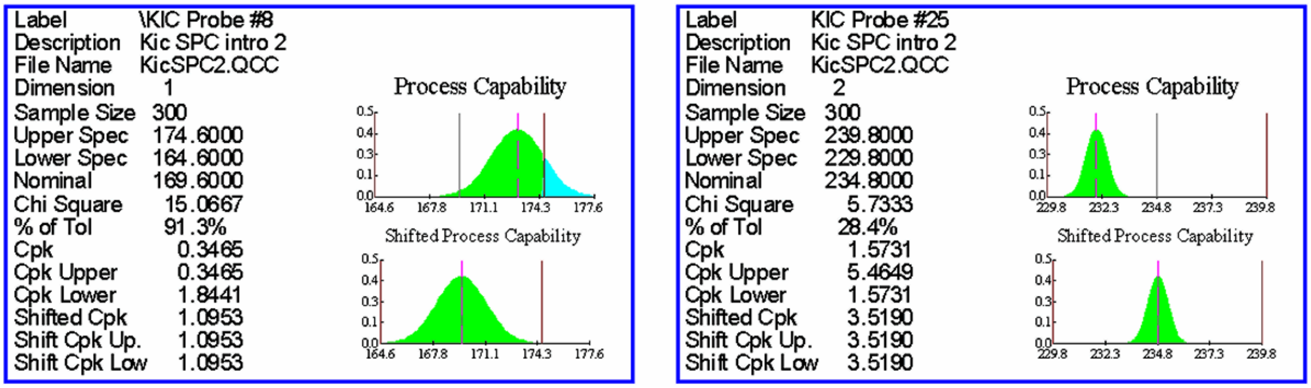

***Figure 2**: Process Capability Analysis*

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 TC 8 is monitoring may be draftier than the one monitored by TC 25, or may be suffering from a mechanical problem in its convection fans.

SPC is like the warning squeal of automobile brakes when the brake pad is almost worn out. The warning gives the driver plenty of time to get to a garage and avoid costly accidents. 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. With continuous thermal profiling and SPC, a failure will be detected within 30 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 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 much product has been affected. All production between the first bad profile and the last good profile becomes suspect.

The solution to the problem of pass-through profilers' failure 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 completely self contained 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.

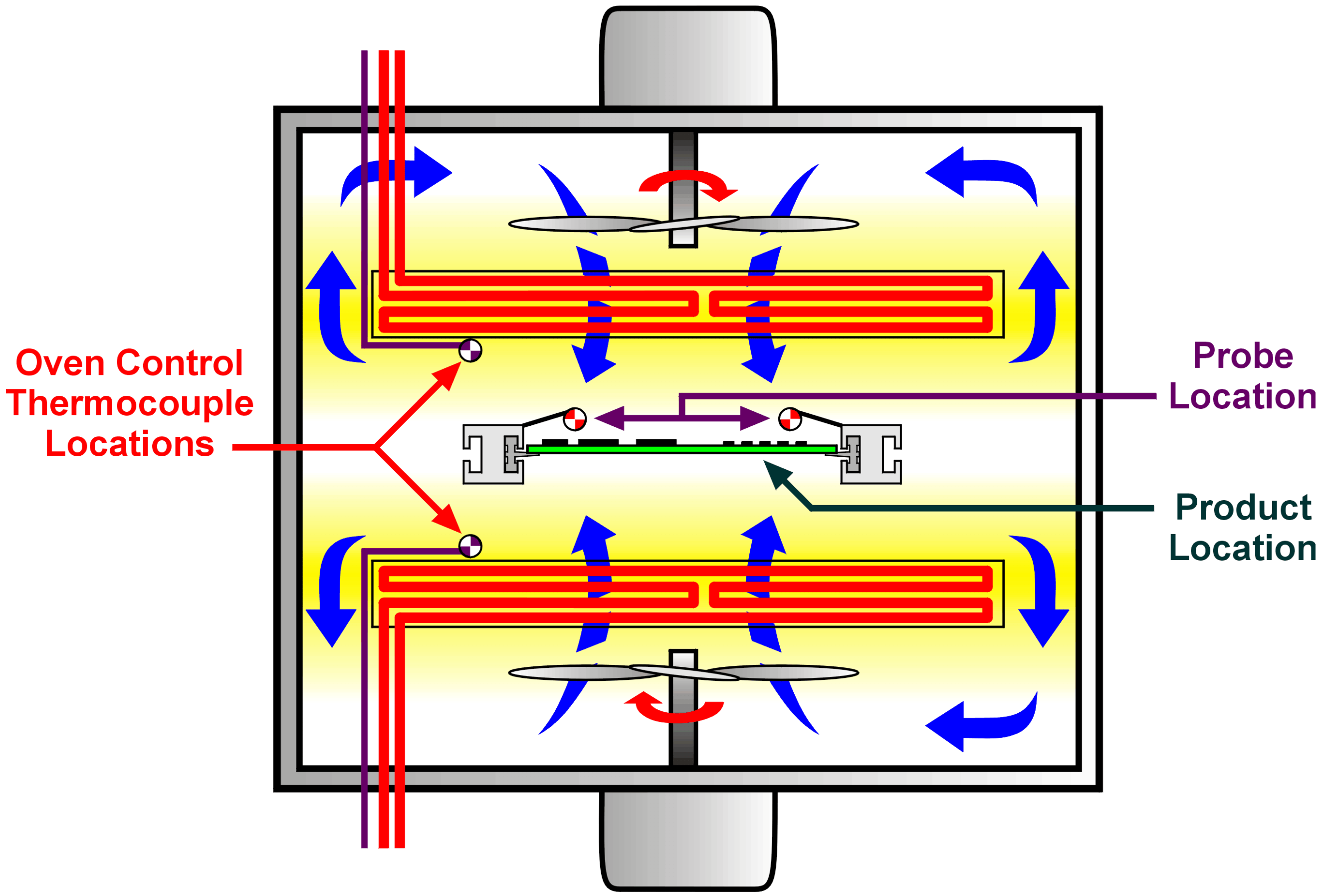

***Figure 3**: Oven Cross Section showing probe orientation*

Temperatures at the conveyor are continuously displayed as "Oven 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. The thermocouple probes are outside of the oven control loop, which enables them to reveal critical temperature deviations at the conveyor that are often hidden from the oven control thermocouples. This system can typically be installed in a standard convection oven, vertical oven, or wave solder machine in less than a day.

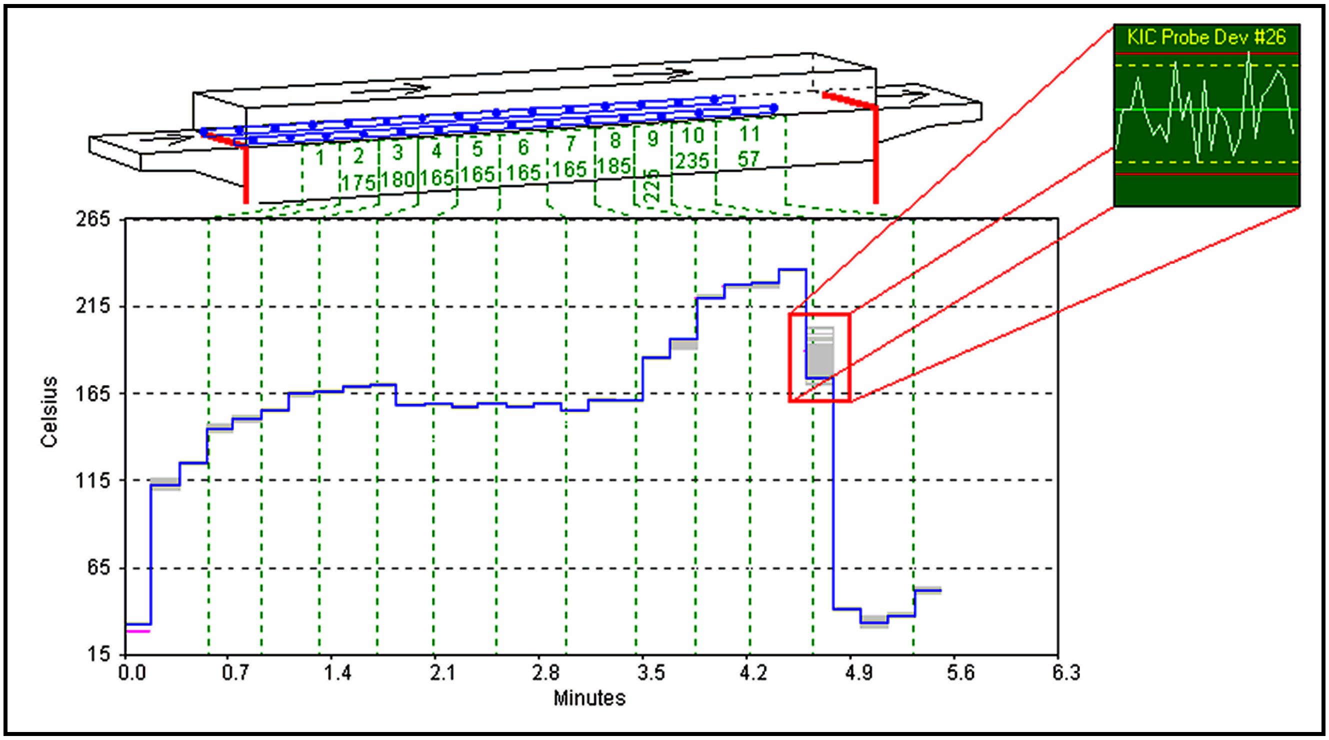

Figure 4: *The temperature data collected from the probe thermocouples forms the "Oven Profile" and the measured temperature variations from each TC (shown in gray) can be plotted on a control chart.*

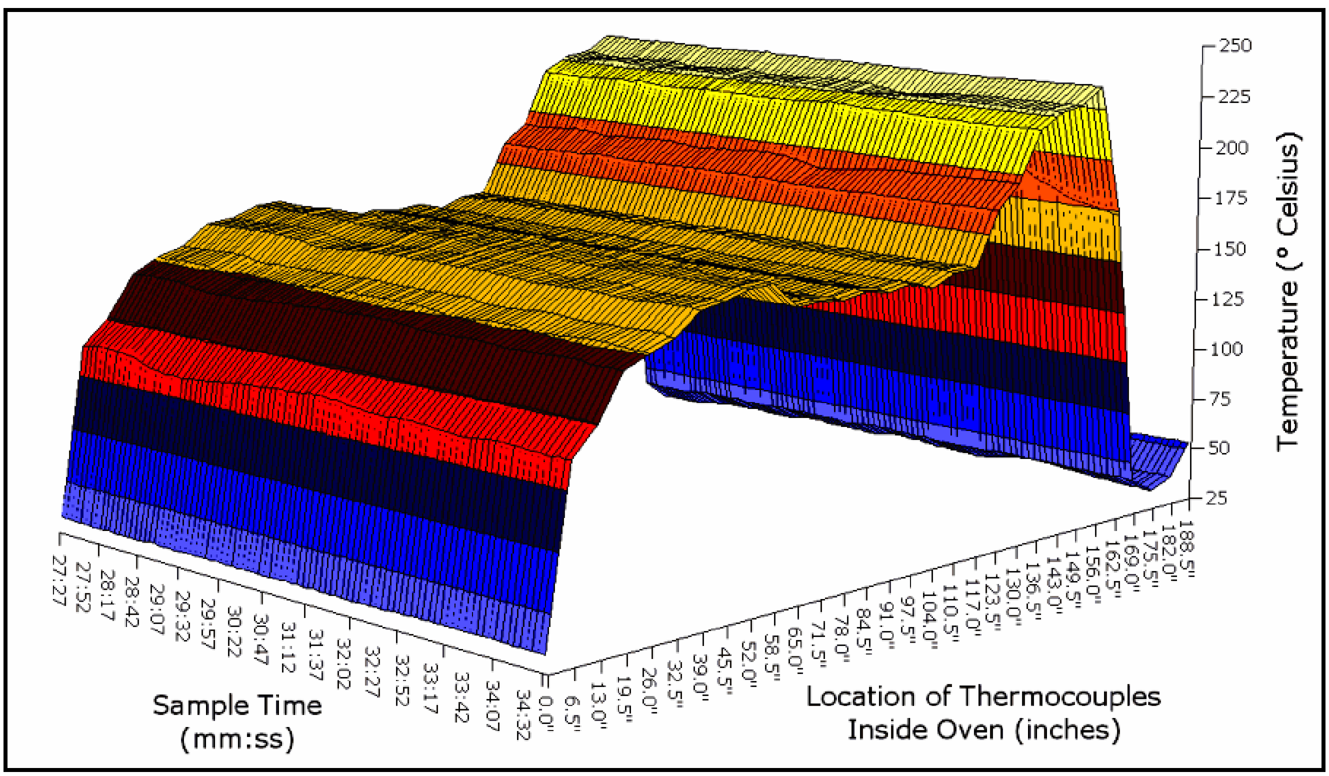

Figure 5: *The Oven Profile's variation over time accumulates as a "footprint". The 3-dimensionalview above was created from the footprint in Figure 4.*

The Oven Profile is updated every thirty seconds and is permanently recorded in a history file on the computer hard drive.

SPC for the Reflow Process

The Oven 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.

The thermal manager is capable of collecting and outputting the following data to the software package: raw data from the thirty thermocouples in the probes, maximum deviation for each probe thermocouple, and belt speed. Up to 50 control charts can be tracked simultaneously by the software package on the computer screen and the chart backgrounds change color according to process conditions: green for normal, gray for warning, and red for alarm. This combination of data options allows the user to custom tailor the SPC application to their process. Some manufacturers have chosen to monitor a single thermocouple at a critical point in their oven profile, while others have identified multiple critical process parameters. (See Figure 6)

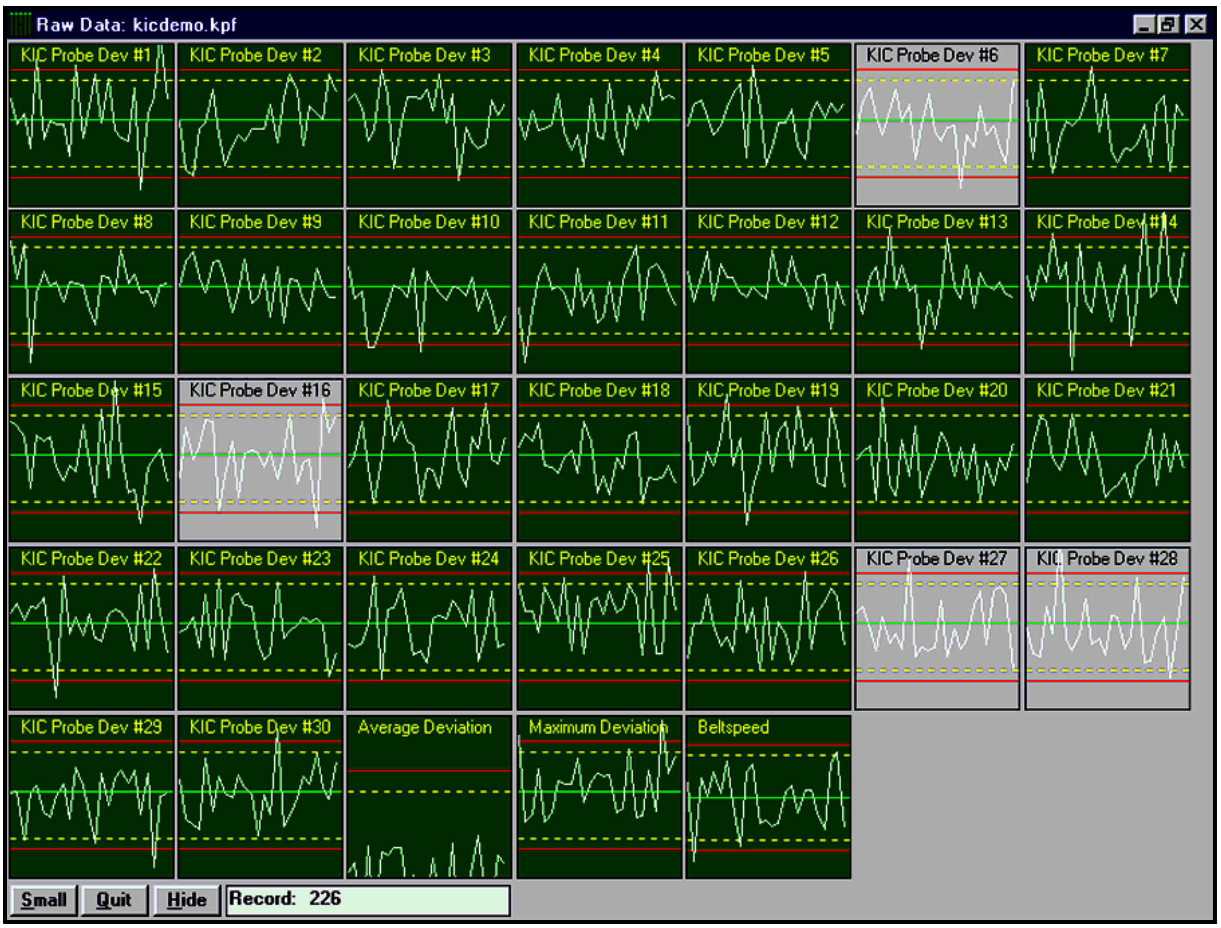

***Figure 6**: QC-CALC Control Charts*

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 can be gathered in under an hour. The data is gathered automatically, removing labor and cost issues, and 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 is used in two ways: for real-time process control by machine operators on the production floor, and for historical analysis by statisticians. The SPC program allows machine operators to track process status, to spot problems while they’re too small to be noticed by the naked eye, and correct them before they can cause a defect or affect yield. Data can also be sent to standard industry databases such as Excel or Access and then analyzed by statisticians at a later date for long term process analysis and improvement.

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.

Along with totally automated data gathering capabilities and real-time output, another critical feature for an SPC program is a user-friendly and flexible report generator. Ideally, the report generator should give the user the ability to customize their report, rather than being forced to rely on a fixed form. Optimal report generators give users the ability to drag and drop fields, including customized bit maps: for example, their company logo. This gives the user the ability to present reports in the form that is most useful to their particular company

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. Users will be quick to recognize the benefits of these powerful production tools, which include:

- Real-time data collection acquires an adequate sample for SPC analysis in hours without disrupting production.
- 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 include several critical statistics, including belt speed, in their SPC program.
- Real-time SPC is collected automatically, providing significant increases in data accuracy, and is available for analysis at any time.
- Real-time SPC simplifies the identification of long-term trends in the production process.
- Real-time SPC is an extremely effective tool for decreasing production defect rates.

Without real-time SPC, a defect or failure is a manufacturers 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.

