# Reflow Process Control Monitoring, and Data Logging

Rita Mohanty, Marc C. Apell, Rich Burke
Speedline Technologies

**Abstract**
With the introduction of lead free electronics assembly worldwide, greater concerns are raised over factory control of materials and processes. Due to the mix of both leaded and lead free production, greater care must be introduced to ensure proper reflow process control along with data logging for product traceability. Reflow profiles must be more precise in a lead free process since the reflow temperatures of the lead free materials can approach the temperature tolerance of some of the components.

This paper evaluates the introduction of automatic reflow process control in both leaded and lead free environments by the use of bar code readers and redundant process monitoring. The use of the latest automation technology in reflow will generate the ability to ensure assemblies are reflowed with the proper profile with minimal or no operator intervention along with redundant process monitoring for process control. All data generated can be gathered for individual product traceability and integration of statistical process control. Data will be presented on the implementation, operation, and control of introducing these technologies into a reflow environment.

**Introduction:**
More than 15 years ago the SMT industry migrated from organic acid-based solder pastes and rosin to the far less-forgiving realm of low-solids, no-clean formulations. Right about the same time, inert nitrogen was also introduced as an alternative to air atmosphere. This helped in expanding the reflow process window, allowing a wider process window for critical reflow parameters such as Time Above Liquidous (TAL), Peak Temperature (PT), and Soak Time (ST). In addition to the two above mentioned changes, another new heating technology was also introduced to the reflow process; convection heating.

Up until this time, IR heating was the choice of heat transfer medium. SMT industry realized the growing importance of the thermal profile, and saw immediate gains in stability, overall throughput and process quality by switching to convection heating. the primary reason being the efficiency of heat transfer from the heating element to the product boards. The benefit of convection heat transfer is a near 1 to 1 relationship between heater set points and product temperature vs. nearly a 3 or 4 to 1 relationship of IR heat transfer.

As a result of these industry-wide changes, other important advances like flux management systems and variable-speed convection were born. These new advances have improved refow efficiency in current reflow systems considerable.

Reflow process, which is one of the most critical step in a SMT process is highly impacted by the lead free migration process. The importance of flexibility, process control and stability simply can't be overstated as operations worldwide race to beat competitors and expectations. But as this process window closes, a number of enabling technologies are opening doors in our brave, new, lead-free world

**Effect of Thermal Profile:**
Thermal profile is probably the most important factor in any reflow soldering process. It has the most direct effect on the quality of solder joints. Due to the higher temperature requirements of lead free reflow process, new thermal profiles are required for reliable product. In addition to that, the process window for lead free alloy is considerably narrow because the liquidous temperature has increased from 183°C (eutectic SnPb) to 217°C - 221°C (lead-free SnAgCu or commonly referred to as SAC alloy).

This increase of 34°C - 38°C in liquidous temperature means that the required peak temperature range must also increase. Current lead-free solder pastes require peak temperatures in the range of 230°C - 250°C, these peak temperatures can come very close to the maximum temperature limits of many components. Board laminates are also often stressed even further with these peak temperatures much higher above the glass transition state of the laminate.

Table 1 shows the NIC Components table. These higher peak temperatures approach the uppermost limit for many SMT components. The time of the exposure is, of course, a great criterion in whether these temperatures will prove a factor in decreasing process quality.

**Table 1 - NIC component**

TEMPERATURE LIMITS

| *Peak Temperature* | *Max. Duration* |
|---|---|
| +260°C | 5 SECONDS |
| +250°C | 15 SECONDS |
| +240°C | 25 SECONDS |
| +230°C | 40 SECONDS |

The above reflow soldering profile and temperature limits applies to the following NIC surface mount products:

- **NMC** series… Ceramic Chip Capacitors
- **NRC** and **NRSN** series… Thick Film Chip Resistors and Resistor Arrays
- **NTC** series… Tantalum Chip Capacitors
- **NTHC** series… NTC Chip Thermistors
- **NIS** series… 0402/0603 Chip Inductors
- **NCB** series… Ferrite Chip Beads
- **NRD** and **NSD** series… Silicon and Schottky Barrier Rectifier Diodes

This makes thermal control and stability of reflow ovens more critical than ever. How much does it close your reflow process window? As opposed to SnPb alloys, which maintain a 30°C - 40°C margin within this "component danger zone", the peak temperatures for lead-free alloys will generally shave that margin to within 10°C.

Always important, the heat transfer efficiency of modern reflow operations has more impact than ever on operating costs. Given the higher operating temperatures of lead-free alloys, the heat transfer efficiency also requires strict temperature variation reduction across the entire assembly. Carefully consider the upper temperature limit of your components against the peak temperatures of lead-free alloys, and you see the value of the smallest possible thermal differential. Today's reflow soldering systems simply must transfer thermal energy across the assembly's varying thermal masses with smallest variation between the low and high thermal mass components. Otherwise, the small thermal mass component is at risk of overheating, and the large thermal mass component is at risk of not reflowing.

**Process Control**

As mentioned above, Thermal efficiency is critical to lead free process. There are many different ways thermal efficiencies can be achieved in lead free process, which includes technologies such as variable-speed convection, controlled convection rate, heat-on-intake design and diffusers with 'nozzle-like-flow' capability. These technologies clearly improve the thermal efficiency but do nothing to the process control. Process control is essential to a successful, repeatable, and reliable lead free reflow process.

One process control technology worth mentioning is the recipe-driven, closed-loop, blower-speed control. These systems work by monitoring and controlling the RPM of an individual blower through a feedback loop. Figure 1 shows a closed loop blower speed control system. Without this control, any variation in blower speed (RPM) will almost certainly affect the thermal profile, compromising process control and operational stability.

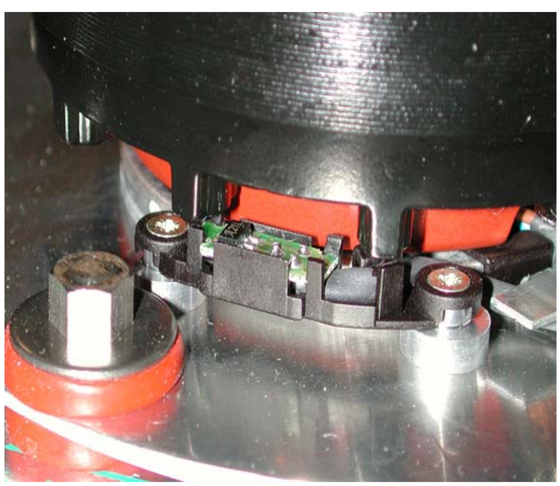

**Figure 1 - Closed-loop blower speed control system.**

There are measurable and significant effects of a convection-rate reduction in just one blower on the sustainable peak temperature of an assembly. Figure 2 shows a ramp profile that minimizes this differential; however, a ramp-soak-peak profile would look quite different. In any case, precise control over convection speed, and careful adherence to operational specifications throughout the profile, will provide unparalleled process control.

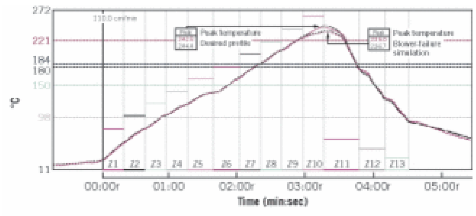


**Figure 2 - Effect of cooling slopes in lead free reflows**

This more complete thermal control also provides numerous benefits during the cooling portion of the reflow process. Solder paste suppliers typically recommend aggressive cooling slopes (2°C/sec. to 4°C/sec.) for lead-free alloys. Some studies have shown an aggressive cooling slope can provide optimal diffusion of material and fine eutectic grain structures. Figure 3 shows the effect of an aggressive cooling slope. It is important to note that the desired fine dendrite size is a result of the tin-rich forms being more random in size and shape, and therefore, more diffused within the solder joint. Figure 4 depicts tin-rich forms that are longer and more layered, the results of which can be a discernible grainy solder joint structure.

**Figure 3 - Effect of an aggressive cooling slope of 6.31$^{0}$C/sec**

**Figure 4 - Tin reached forms are longer and more layered with cooling slope of 1.27$^{0}$C/sec**

In past cooling zones it sufficed to provide some level of variable convection; however, current ovens integrate features and functions that focus on more complex control issues. While closed-loop convection powers repeatability, cooling-zone convection variability ensures flexible cooling-slope development. Add to that closed-loop temperature control, and the power of this combination becomes apparent in cooling-zone profile flexibility, repeatability, and overall process control.

As mentioned earlier, introduction of nitrogen to reflow process definitely increased the process window. It pushed open the reflow process window by improving paste spreading, preventing re-oxidation, and reducing wetting times (with peak temperature reductions up to 10°C). It has also led to more aesthetically pleasing solder joints.
Despite the benefit of nitrogen environment, the change over has been slow throughout the industry. This is mainly due to the high cost of capital equipment and consumable. Today, majority of the reflow process uses air rather than nitrogen. These are some of the important reasons manufacturer remain focused on process control and expect quality improvement opportunities in technologies such as process verification and product traceability. Advancements in both are providing detailed data logging and redundant monitoring of critical process parameters. Product-level traceability - taking the shape of barcode scanning devices - is experiencing wide adoption within operations and industries requiring high reliability, such as the automotive, medical, aerospace, and military markets.

**Barcode Scanning:**
The addition of barcode scanning in reflow will offer two distinct capabilities. These capabilities include automatic recipe verification and changeover along with serial lot tracking of specific machine performance for process control and verification.

The addition of barcode scanning will add the ability to the reflow oven to enable automatic recipe verification and/or loading based on an incoming boards scanned barcode. Scenarios are shown below based on a recipe being matched with the scanned barcode and a recipe not being matched with the incoming scanned barcode. The assumption here is the oven is in the processing mode, boards are already in the oven, and a board has just been scanned on the in-coming input conveyor.

**Scenario #1** Recipe Available
- Oven will force upstream SMEMA busy to stop incoming boards.
- All existing boards in oven will complete processing and will exit
- Oven will be soft stopped to allow loading of new recipe
- Automatically load matching recipe
- Oven will be automatically restarted with newly loaded recipe.
- When oven "Ready" mode is reached upstream SMEMA busy will be turned off and boards will be allowed to reenter oven

**Scenario #2** Recipe Not Available
- Oven will force upstream SMEMA busy to stop incoming boards.
- All existing boards in oven will complete processing and will exit
- An alarm will be generated and the light tower will alert, indicating a message to the user that the incoming boards barcode does not match currently available oven recipes.
- A dialog will be presented to the user allowing them to associate the incoming boards scan code to an existing machine recipe.
- If the user associates the incoming board with an existing recipe the user can then press restart and the oven will prepare for the new boards entry.
- If no association is created the user must manually remove the board from the conveyor and then press board removed to ready for the next board to be scanned

**Conclusion**
While the mandate for lead-free alloys has complicated reflow soldering systems, it also has yielded advanced technologies that enable higher reliability, greater yields, and lower total costs of ownership. As the lead-free future unfolds, new challenges will likely present themselves, and the industry will pull together to meet them. On the horizon, we can see the fast-approaching implementation of 01005s, and their requisite assembly issues. As the prevalence of more challenging 0201 and 01005 components grows, it will result in a decline of traditional 0603 and 0402 components. This trend will place more importance on tight process control, operational stability, and repeatability as shown in Figure 5.

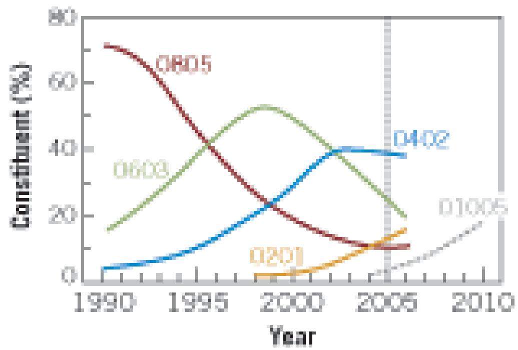


**Figure 5 - LCR passive component size trends. Courtesy of Prismark**

The reflow soldering process continues to show solid growth and provides incremental process improvements - even in the face of the well-publicized challenges of lead-free conversion. Manufacturers continue to commit to the next level of reflow, and prove that reflow process optimization is alive and opening windows worldwide.