Thermal profiling: A key element of process control

How can manufacturers ensure process control and still achieve speed of throughput in the electronics industry? Thermal profiling, as an element of process control, provides many solutions.

by Paul Austen and Mark Waterman, ECD

There is no doubt that in today's more sophisticated electronics market, with boards populated with everything from BGAs to SiPs (System in Package), process control is more important than ever. At the center of achieving that control, you will find thermal management. And since thermal management cannot be achieved, or documented, without thermal profiling, thermal profiling brings us to the heart of the matter.

There are basically two ways to achieve successful thermal profiling: profiling the board, or profiling the oven. We will discuss both, and compare the two. Two things are essential to both of them. The first is the target profile. It is this profile, correctly established and achieved, that determines the success or failure of the board's solder joints, as well as safety of or damage to the components. Thus, it is important to develop the target profile correctly, and then ensure it is repeatedly achieved in the most time- and cost-effective manner.

The second thing essential to both board and oven profiling is the use of the prototype. Even in oven profiling, there must be at least one board prototyped to show that OEM target profiles are met. Without measurements from the thermal profile of the prototype, you can neither determine if it meets the required specifications, nor prove that your process is in control. But once you have a successful profile, you can duplicate it run after run, whether through board or oven profiling.

Preparing/running the prototype

Board profiling (which must be done for the prototype in either the board- or oven-profiling method) entails placing the thermocouples (T/Cs) on the crucial components or solder joints and measuring them throughout the oven to make sure their thermal profile meets the target profile. With mixed and complex boards, the use of a shield or barrier to protect more heat-sensitive components from the excessive heat needed by larger (thermal mass) components may be required. When that is the case, profiling will prove, or disprove, that the shielding is sufficient and effective.

When boards are populated on both sides, the boards may be reflowed twice, requiring a larger number of thermocouples. Multiple placements would also be needed if there is a mix of lead and lead free on the same board, each having different maximum/minimum thermal requirements. If there is a component that is much larger than the others, typically a BGA or other large array component, it may take two or more thermocouples to understand and prove thermal conformance to the target profile. Stacked, 3D, or SiP components also present challenges, since they contain multiple layers of functionality and require fast thermal saturation.

Perfecting the profile

When a prototype run has been completed and evaluated as to meeting the target profile parameters, adjustments can be made to bring any variance to within specified limits, typically 3-5 degrees. BGAs often come into play again here, since the BGA with its larger thermal mass may require a higher and longer-held temperature to reach the specified temperature than will its smaller counterpart components.

Perfecting the profile is done by adjusting according to the constraints of the components, and taking into account

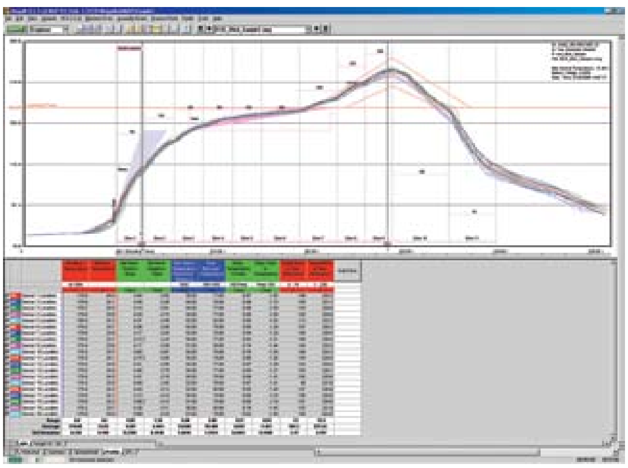


Figure 1: *Typical board profile*

the particular oven's capabilities. Again, software plays an important role. The more data-rich it is, the more it can automatically adjust – based on the results of the prototype run – and thus determine the "new" profile that will now definitively meet the target profile. This frees the engineer from the task of manually extracting data from the profile, and allows him to focus on the oven and its recipe settings. A second prototype run using the new recipe should be done to assure compliance. Only then can production begin. Thus the profile remains key, along with robust software, to streamlining the engineering effort to "dial-in" the optimal recipe.

The oven profile

Oven profiling demands you measure information about the oven such as temperature change (delta) zone to zone. This is a measure of the zone's ability to heat, or to cool. If this changes as the oven changes, or if settings are inadvertently changed, you can be sure your product's profile will change. If constant, then your product profiles will be consistent.

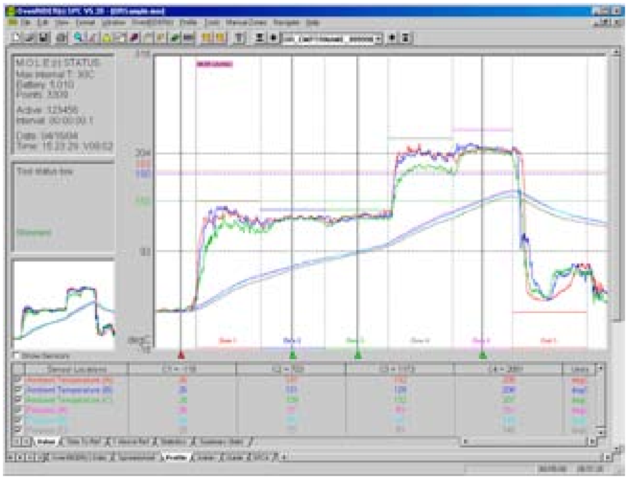
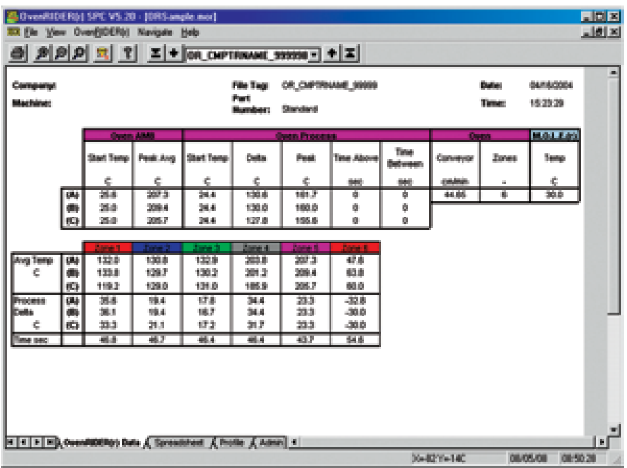


Figure 2A: *Oven profile*



	Oven AMB Start Temp C	Oven AMB Peak Avg C	Oven Process Start Temp C	Oven Process Delta C	Oven Process Peak C	Oven Process Time Above sec	Oven Process Time Between sec	Oven Conveyor cm/min	Oven Zones -	M.O.L.E.(r) Temp C
(A)	25.6	207.3	24.4	130.6	161.7	0	0	44.65	6	30.0
(B)	25.0	209.4	24.4	130.0	160.0	0	0			
(C)	25.0	205.7	24.4	127.8	155.6	0	0			

		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Avg Temp C	(A)	132.0	130.8	132.9	203.8	207.3	47.8
	(B)	133.8	129.7	130.2	201.2	209.4	63.8
	(C)	119.2	129.0	131.0	185.9	205.7	60.0
Process Delta C	(A)	35.6	19.4	17.8	34.4	23.3	-32.8
	(B)	36.1	19.4	16.7	34.4	23.3	-30.0
	(C)	33.3	21.1	17.2	31.7	23.3	-30.0
Time sec		46.8	46.7	46.4	46.4	43.7	54.6

Figure 2B: *Oven profile documentation*

Oven profiling's role

"Oven" profiling means using a fixed, robust, durable fixture to measure the oven's performance at the SAME settings (recipe) that produced a "good" board profile (one which met the target profile specifications). The target profile assumes more importance than ever.

It should be stressed that process repeatability is critical; and profiles of "real" boards are essential to confirming they are meeting OEM needs. Once that is done, however, oven profiling provides a way to prove the process remains in control without having to re-profile the same board repeatedly.

Several of ECD's larger customers in Asia report that once the target profile has been established, they save tremendous amounts of production time by profiling the oven rather than the board. They profile several times a week or even once per day where appropriate, and have achieved success using this procedure.

This type of thermal profiling proves especially useful if an EMS provider is switching his line from Product A to Product B. If the oven recipe does not change between A and B, then oven profiling can remain as proof that the boards are meeting the target profile. If the oven recipe changes, then one must prove the oven is good (oven profile) compared to older oven profiles at the same recipe. Or, lacking an oven recipe with which to compare, one must run a board profile of the new Product B and confirm it meets specs. Then the process engineer can capture the oven profile at the new recipe and forever use it as a standard of comparison of oven profiles taken for that recipe in the future

Oven profiling also proves ideal when repetitive runs are done to complete large orders. If the engineer can verify that the oven is at the same specs that the OEM specified for the target profile, profiling the boards will not be necessary on every single run. Any product profile they were required to match, and indeed match in the beginning, will be consistent. This will save the time and cost of connecting T/Cs to the product and minimize risk of damage to the customer's boards. Even a moderate decrease in the number of profiles saves hours of production time, resulting in increased throughput, reduced engineer time, and a reduction in the need for product boards to be sacrificed to the profiling process.

Any given zone's "ability" can be affected by loss of convection efficiency due to buildup of flux and other contaminants, such as dirt and dust, on fan blades. In such a case, even though zone temperatures may not change, the convection rate is reduced and, as a result, the zone's ability to change the temperature of the product will be reduced. Thus, the oven is NOT as capable, and product profiles will be in question.

The ambient temperature should also be taken in each zone. This is a "product level" measurement of each zone's temperature in order to make sure it remains consistent. Both these measurements (ambient and delta) should be taken in several locations across the width of the conveyor to assure zones are even and consistent across the width of the conveyor rails.

Finally, measuring conveyor speed to make sure it is calibrated is essential, since changes in the speed will affect all zones, and thus the entire profile.

SPC requirements/documentation

Statistical process control (SPC) cannot be effective without large amounts of data. In thermal management, it requires that the same parameters be measured through repeated production runs, evaluating each as to how well it meets a target profile, indicating whether it is "in" or "out of spec. It thus provides a way to predict if future runs risk being out of spec.

We've said that depending on the configuration and size of the board, the number of thermocouples required to secure adequate data during board profiling may vary. One thing is certain, however. In all subsequent runs, the thermocouples must be placed in the same locations as on the prototype to show that the same parameters are being measured, and the same result are being met. Otherwise, the results will be skewed.

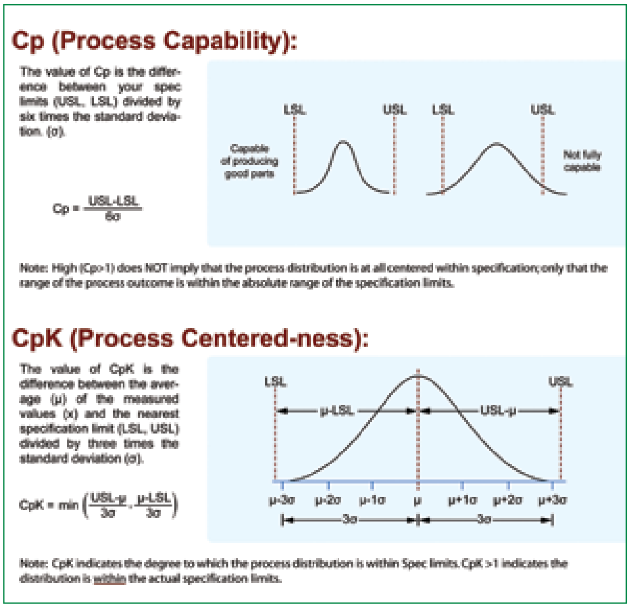


Figure 3: *Cp-CpK*

Interpreting profiles

When teaching the art of thermal profiling through ECD-U (ECD's online university), instructors point out that when looking at the profile report generated by a run, you will be looking at results of spec limits vs. actual measurements for that run. Ideally, the process can operate within upper spec limits (USL) and lower-spec limits (LSL). Cp is a measure of how well the process variation compares to the range of your spec limits.

The value of Cp is the difference between your specification limits (USL-LSL, or the Tolerance) divided by six times the standard deviation of the data, and is an indication of the consistency of your board profiles. A Cp value greater than 1.0 means your board profile variations in readings are more consistent than (within) your tolerance, but does not mean that the process is operating within the specification limits, only that it's within the range of the limits. In other words, it can show that your process data is "tight" compared to the tolerance; but it cannot tell you if you are within your tolerance. So we need another measurement: CpK.

The value of CpK is the difference between the average of the data and the nearest specification limit (LSL or USL) divided by three times the standard deviation of the data, and is a comparison of your board profile data consistency to the center of your specification. CpK values greater than 1.0 mean the measure of your board profile's consistency is within your specification (tolerance).

Compliance and liability

Profiling documentation, whether of the board or of the oven, is not only helpful as boards become more complex, it is increasingly mandatory as both governments and OEMs impose more requirements – not only for traceability, but also for verification of process control. EMS providers and OEMs both need to guarantee, and verify with written reports, that their processes met all government regulations, as well as any hi-rel or other standards demanded for the product.

They both also face additional challenges when they provide critical products such as medical equipment. Medical device manufacturers must often prove their devices were not defective and did not contribute to death or injury. Automobile manufacturers/suppliers can also utilize the profile documentation to prove that parts were manufactured in spec, and not likely to have caused brake failure, started fires, or otherwise been responsible for litigation-provoking incidents. This is another instance where the more robust the software, the more valuable. ECD addressed this issue with MAP, which allows hundreds of customizable data extractions and reports suitable for documentation of the machine, assembly, and process, to show proof of process specification and control.

Training, accuracy, diagnoses

One of the additional benefits that accrue from thermal profiling with good documentation is the ease of cross training engineers. It enables them to set up a profile in cases where they have no prior experience with the specific makeup of a board.

Accuracy among operators can also be increased with an easy-to-use thermal profiler. Clear indicators as to profile readiness: e.g. thermocouples are in place on the board, and/or all parameters for the oven recipe are met, enable the operator to start run without first checking with an engineer. This increases accuracy while reducing downtime.

Finally, thermal profiling can be a diagnostic tool. When a board is returned with problems, a review of its actual original profile can help pinpoint or rule out process issues, saving engineering staff valuable time otherwise needed to manually diagnose. Not only will that enable the "fix" for those and future boards of the same type, but it will do so in a manner that generates written reports, giving documentation to the problem and its solution.

Conclusion

Process control through thermal profiling is a "must" for both semiconductor manufacturing and board assembly. While this article has focused on board assembly; many of these same principles apply in the semiconductor sector as well, especially in wafer level packaging. Heat tolerance must be observed for most vulnerable devices; the wafers, like the boards, must be able to pass safely through the ramp-up, soak, time-above-liquidus, and cool-down zones of the oven, spending neither too little nor too much time in each and emerging unscathed. Semiconductor manufacturers and board assemblers will both be looking to maximize yields and eliminate rework. A perfect assignment for thermal profiling – in whatever form – saving time and ensuring thermal process control toward more reliable end-user products. **EM**

Reference

[1]ECD-U, Profiling 301, www.ecd.com
[2]Eissinger, Rick, "Thermal Profiling in Reflow Soldering," www.ecd.com
[3]www.ecd.com

About the authors

Paul Austen is a twenty-year veteran Senior Project Engineer with ECD, in Milwaukie, OR, USA, and holds a degree in Electrical Engineering from Portland University. Paul can be reached at paul.austen@ecd.com. Mark Waterman is a Field Service Engineer and Trainer with ECD, in Milaukie, OR, USA, and has over 20 years experience in the field of electronics. Mark can be reached at mark.waterman@ecd.com.