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How to Properly Calculate Reflow Temperature Gradients

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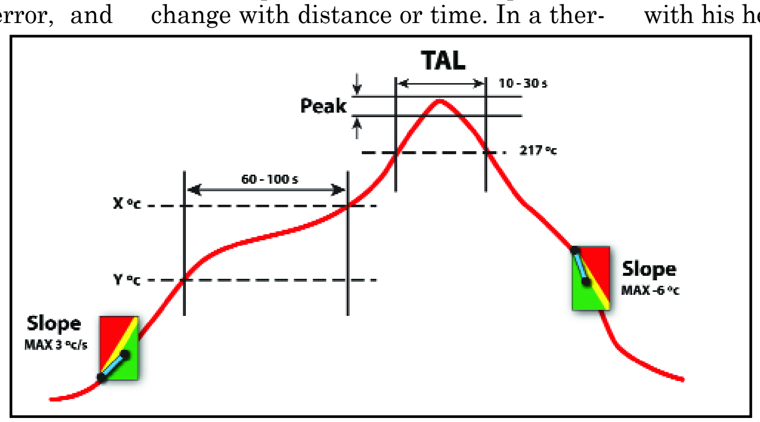
The theory is simple: Process electronic assemblies in spec every time and the result is a quality product. In practice, however, this is much more difficult for numerous reasons, including normal and abnormal process variations, human error, and many other factors.

First, let's be clear about what the process specifications actually are. Critical components such as LEDs, crystals, bottom-terminated components (BTC), including micro-BGAs and others, have very specific process limits that can be challenging to achieve and can be devastating when ignored. Electronics manufacturers must fully understand the nomenclature and process window definitions before setting up their assembly machines. For example, max rising and falling slope limits during PCB reflow are a common source of misunderstanding and process failure.

The Devil's in the Details

Take an LED component for example, and note that the terms slope and gradient may be used interchangeably. A typical reflow process window or process limits for such a component may appear relatively straightforward, but the downside of getting it wrong is significant. First, a definition of a temperature slope: the rate of temperature change with distance or time. In a thermal profile, this will be measured in degrees Celsius or Kelvin (°C or K) per second.



Example of thermal process specifications for an LED component.

A common mistake is to calculate max rising and falling temperature gradients as a linear measurement from the start of the profile to the peak temperature, and from the peak temperature to the end of the profile. These calculations are misleading and result in slope profile inaccuracies because they average together all of the various slope calculations along the entire profile. This brings to mind an old joke about a statistician, with his head in the oven and feet in the refrigerator, who stated that the average temperature was comfortable.

To find the correct measurement of a slope we need one more specification, the distance or time over which the slope will be measured. Reading the fine print in the LED component spec limits we might find something like the following: Max rising slope to be measured over 10-second intervals.

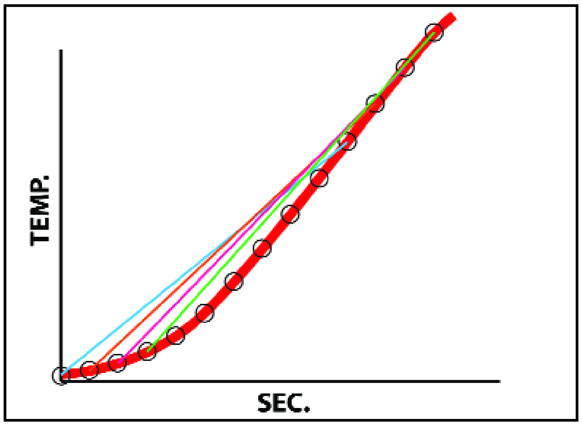
To calculate the max rising slope for the LED component we need to measure each 10-second slope along the profile from the beginning to peak temperature. To do that we select the profile temperature at 10 seconds, subtract the temperature at 0 seconds, and divide by 10 seconds. Next, we calculate the profile temperature at 11 seconds, subtracting the temperature at 1 second and divide by 10 seconds and so forth. The calculations will continue in one-second increments until the peak.

Finally, the highest number of all these calculations represents max rising slope. You will find that the 10-second max gradient measurement is significantly higher than the average gradient. Similar calculations will be made on the falling slope, but the component supplier will likely specify a different acceptable limit along with new calculation guidelines. The cooling section of the profile has a shorter duration and may be susceptible to more volatile temperature variations. The component specifications may call for max falling slope measurements over a 5-second interval instead.

Approaches to Slope Calculation

The use of average instead of max slope calculations will be misleading, and it risks component damage. What makes this particularly worrisome is that stressing LEDs or other optoelectronic and electronic components may introduce latent defects that enable the PCB to pass the factory's quality inspection, but go on to fail prematurely when in use.

This may seem very complicated, but with today's profiling software it is straightforward. The calculations are made in just a fraction a second. You need only to study the specs and set the profiling software to perform slope calculations at the component and solder paste supplier's specifications for time interval. Just make sure that the profiling software is capable of measuring the max slope over any duration limit.



10-second slope measurements in increments of 1 second.

If there are several temperature-sensitive components with different specs, there are two approaches. First, use the most stringent specification for all components. Second, if the profiler supports different specs for each thermocouple (TC), you can attach the TCs to the critical components, making sure all of them are within their individual specs. This will be easier to achieve than the "lowest common denominator" approach of the first method.

The larger challenge will be to set up the reflow oven to achieve a profile that accommodates the more demanding slope specs when using the correct calculations. Again, today's profiling software with prediction algorithms will do a good job of automatically selecting the appropriate oven recipe.

If, however, the slope specifications are defined by the client, and your reflow oven is not capable of achieving them even with a powerful prediction software, then you may need to investigate further. Ensure that everybody involved is clear on the full definition of the thermal process window and the correct methods to calculate it.

This is not a discussion of semantics but whether you are running your production in or out of spec, with all the risk entailed.

Being careful to calculate the reflow profile correctly will help ensure that the final electronic assemblies are of the best quality.

With today's advanced technology enabling higher process efficiencies across the board, paying close attention to the method of temperature slope calculation is no longer an option, it is an imperative.

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