Accuracy of the WinKIC Prediction Tool in a Forced Convection Solder Reflow Oven

By Philip C. Kazmierowicz, 10-23-96

WinKIC creates a mathematical model of conveyorized processes which allows you to perform "what if" analysis. For example, "If I raise the first zone by 20 degrees and slow the conveyor by 2%, how will the product profile change?" The changes can be typed into your computer and WinKIC will instantly display a predicted profile. At KIC Thermal Profiling, we are often asked about the accuracy of this WinKIC feature called the "Prediction Tool". Since we developed the feature in 1989, our standard answer has been that most users are able to profile most boards in three passes or less. The goal of this paper is to document the use of the WinKIC Prediction Tool and give you some idea of the accuracy and usefulness of the system. A 20 zone forced convection solder reflow oven with a nitrogen atmosphere and active cooling was chosen for this example.

The accuracy of the Prediction Tool will depend somewhat on the type of conveyor oven you are using, but more so on the accuracy of the information about the process that is input by the user. In order to develop an accurate model of the process, the following information must be correctly input:

1. Oven tunnel length and position of temperature controlled zones and zone control thermocouples.
2. Product length and width and position of thermocouples attached to the product.
3. Zone setpoint temperatures and actual conveyor speed. The oven controller must be "in control" and able to maintain control throughout the profile. Conveyor speed should be measured using WinKIC's conveyor speed measurement tool.
4. If this is a Prophet system, then the position of the KICprobe thermocouples is also necessary.

The following is a typical scenario for determining the process setpoints and conveyor speed necessary to generate the desired product thermal profile:

1. Attach thermocouples to the product to be profiled.
2. Set the oven setpoints and conveyor speed to some "best guess".
3. Run the product through the process recording the thermal profile with either a trailing wire or the SlimKIC or SideKIC.
4. Analyze the results of the first profile and if a change is necessary, go to step 5, otherwise you are done.
5. Use the Profile Prediction tool to adjust the process zone setpoints and conveyor speed on the computer until the predicted profile meets the defined specifications.
6. Change the oven setpoints and conveyor speed to match those used in the predicted profile and go to step 3.

The following example will show how the WinKIC Profile Prediction tool was used in a real-world application to determine the setpoints and conveyor speed that would correctly reflow a new printed circuit board in a forced convection solder reflow oven.

First the oven was measurement was checked for accuracy (figure 1) then the product was measured properly, and checked for accuracy (figure 2).

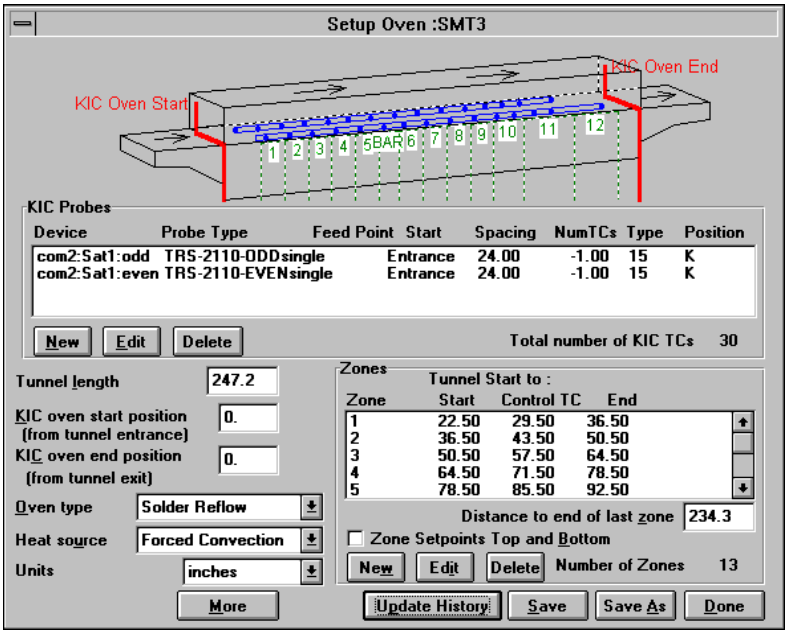


Figure 1: *Notice that the zone positions are measured to 0.5 inch and the KICprobe position and tunnel length is measured to 0.1 inch.*

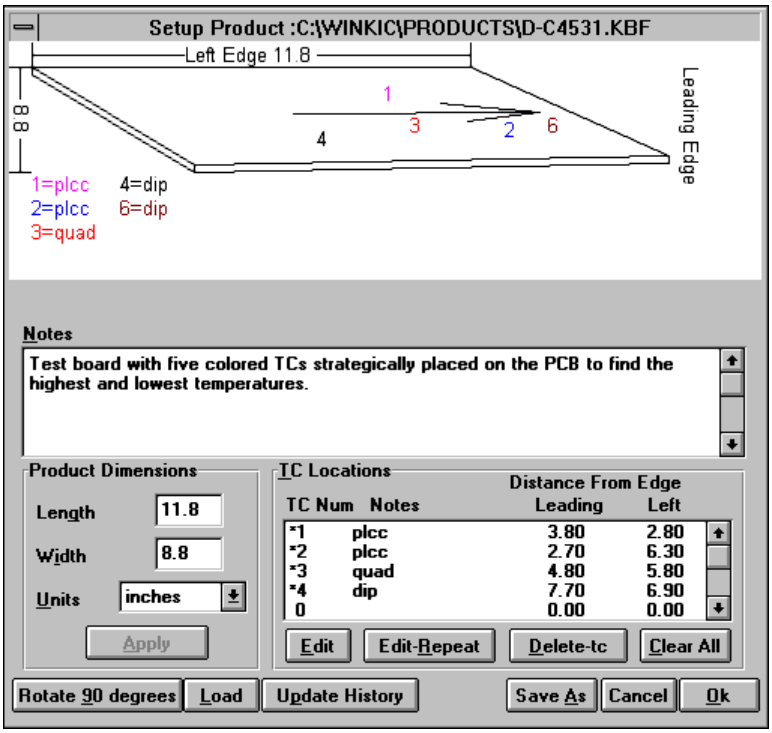
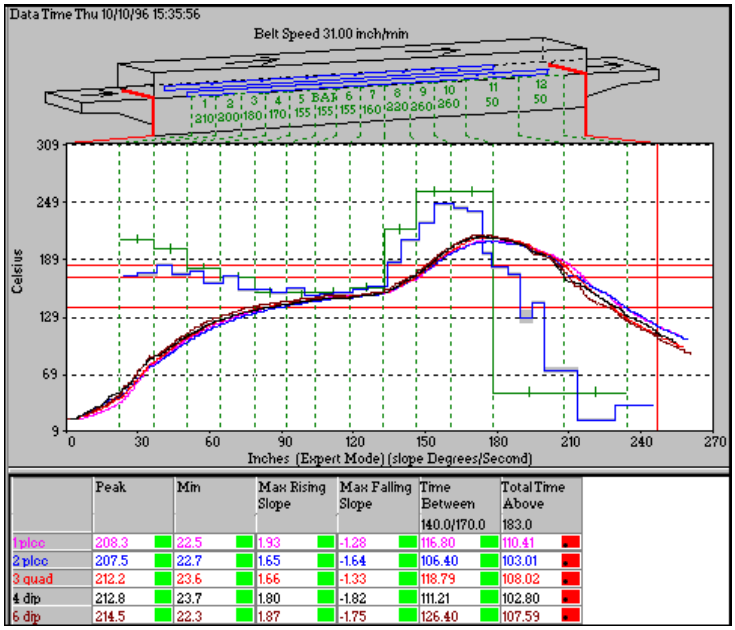


Figure 2: *All product measurements are to within 0.1 inch.*

Then the oven was set to setpoints and conveyor speed that are used for boards similar to this one. Once the oven controller showed "process ready" and the KICprobes showed that the oven had stabilized (Max Change in Last 2.0 minutes < 3.0 degrees), the test board and SlimKIC were run through the oven. The profile was started just as the leading edge of the board crossed the tunnel entrance and the conveyor speed check button was pressed just as the leading edge of the board crossed the tunnel exit. WinKIC indicated that the conveyor speed was within 1%. The Statistics command was then used to analyze the profile (figure 3). All the Statistics with a green box next to them are within the required specification, however the Total Time Above 183C field is in an alarm condition. Figure 4 shows that the statistic limits were set to display a warning (yellow) when the board exceeds 95 seconds above 183C, and an alarm (red) when the board exceeds 100 seconds. The board is spending about 15 seconds more over 183C than was specified.

The goal is to reduce the time above 183C while changing the other statistics as little as possible. The Prediction Tool was used to see what changes to the oven setpoints and conveyor speed would be necessary to achieve this goal.

Before reviewing the oven changes necessary to improve this profile, it might be helpful to examine the cause & effect relationship of oven setpoint changes on the product thermal profile. Figure 5 shows how the profile is affected when the conveyor speed is significantly reduced. In this case it dropped from 31 to 24 inches per minute. When the conveyor moves more slowly, the product has more time to reach the process temperature. If the conveyor were to move infinitely slowly, the product profile would approximate the process temperature profile.



	Peak	Min	Max Rising Slope	Max Falling Slope	Time Between 140.0/170.0	Total Time Above 183.0
1ploc	208.3	22.5	1.93	-1.28	116.80	110.41
2 ploc	207.5	22.7	1.65	-1.64	106.40	103.01
3 quad	212.2	23.6	1.66	-1.33	118.79	108.02
4 dip	212.8	23.7	1.80	-1.82	111.21	102.80
6 dip	214.5	22.3	1.87	-1.75	126.40	107.59

Figure 3: The first profile.

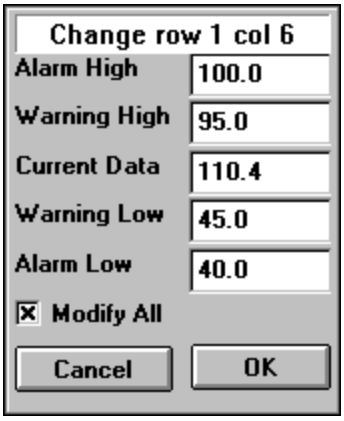
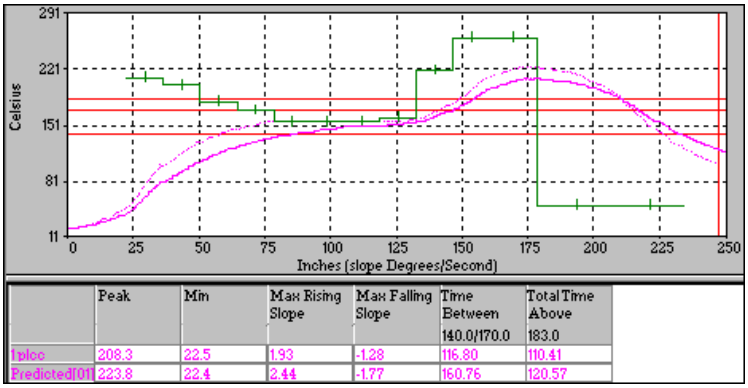


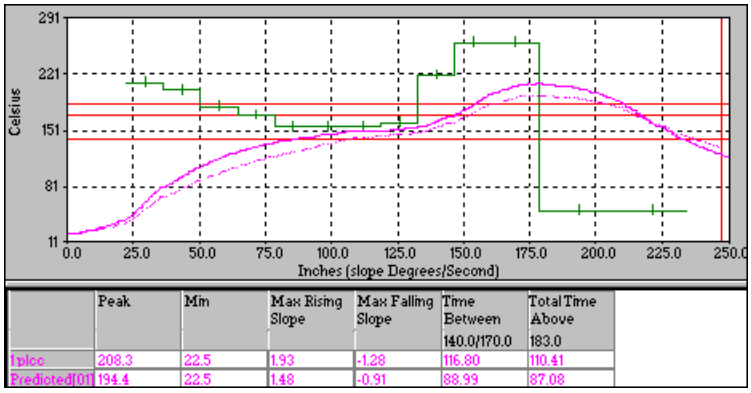
Figure 4: Limits on the "Time Above 183C".



	Peak	Min	Max Rising Slope	Max Falling Slope	Time Between 140.0/170.0	Total Time Above 183.0
1ploc	208.3	22.5	1.93	-1.28	116.80	110.41
Predicted[01]	223.8	22.4	2.44	-1.77	160.76	120.57

Figure 5: *Solid line is at 31 inches/min, dotted line is at 24 inches/min.*

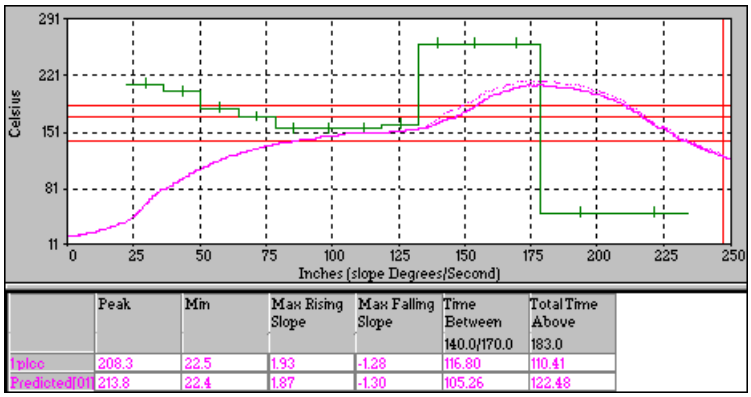
Figure 6 shows how the profile is affected when the conveyor speed is increased, in this case from 31 to 38 inches/minute. It's important to notice that any change in conveyor speed will affect the entire profile.



	Peak	Min	Max Rising Slope	Max Falling Slope	Time Between 140.0/170.0	Total Time Above 183.0
1plcc	208.3	22.5	1.93	-1.28	116.80	110.41
Predicted[01]	194.4	22.5	1.48	-0.91	88.99	87.08

Figure 6: *Solid line is at 31 inches/minute, dotted line is at 38 inches/minute.*

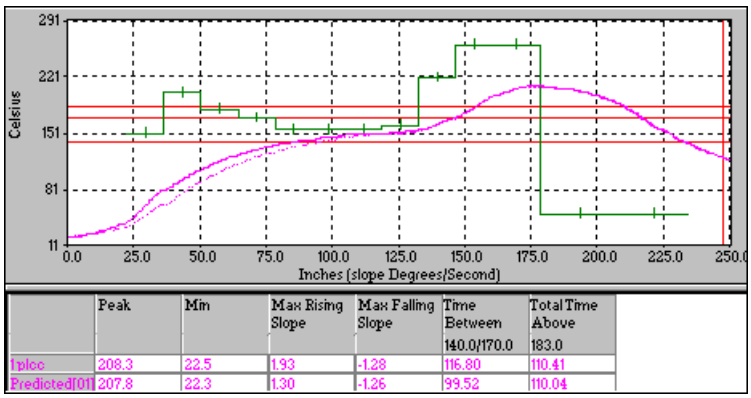
Figure 7 shows the change to the profile when a single zone near the end of the heated zones is raised. In this case zone 8 is raised from 220C to 260C. Notice how the profile before zone 8 is not affected at all.



	Peak	Min	Max Rising Slope	Max Falling Slope	Time Between 140.0/170.0	Total Time Above 183.0
1plcc	208.3	22.5	1.93	-1.28	116.80	110.41
Predicted[01]	213.8	22.4	1.87	-1.30	105.26	122.48

Figure 7: *Zone 8 is raised from 220 to 260 C.*

Figure 8 shows the how a profile is affected when the first zone is lowered. In this case we lowered zone 1 from 210C to 150C. Notice that the profile is only affected up to about the middle of the soak zone where the product profile is at equilibrium with the process. A rule to remember is that any change in zone setpoint temperature will affect the product profile up to the point that it is at equilibrium with the process. If the product profile is never at equilibrium with the process, a change in zone temp, even the first zone, will affect the entire profile including the peak temperature.



	Peak	Min	Max Rising Slope	Max Falling Slope	Time Between 140.0/170.0	Total Time Above 183.0
1plcc	208.3	22.5	1.93	-1.28	116.80	110.41
Predicted[01]	207.8	22.3	1.30	-1.26	99.52	110.04

Figure 8: *Zone 1 lowered from 210C to 150C.*

Looking back at figure 3, you can see that the product profile was spending too much time above 183C. From the previous discussion of the effects of conveyor speed on the product profile, you know that increasing the conveyor speed will lower the peak temperature and reduce the amount of time it spends above a given temperature. In this case the conveyor speed was increased from 31 to 33 inches/min. Figure 9 shows how WinKIC predicted the statistics would change.

	Peak	Min	Max Rising Slope	Max Falling Slope	Time Between 140.0/170.0	Total Time Above 183.0
Predicted[01]	205.3	22.4	1.87	-1.23	97.98	101.58
Predicted[02	204.1	22.6	1.61	-1.58	88.99	93.49
Predicted[03	209.5	23.7	1.62	-1.29	97.08	100.68
Predicted[04	209.3	23.7	1.75	-1.74	90.79	94.39
Predicted[06	211.3	22.3	1.77	-1.67	103.37	99.78

Figure 9: *Conveyor speed increased from 31 to 33 inches/minute.*

To further reduce the time above 183C, the setpoint temperature was lowered for zones 8 & 9 and raised for zone 10. The idea was to get more of a sharp peak instead of the plateau we have now. The Prediction Dialog Box depicted in Figure 10 shows the changes to the oven settings. WinKIC predicted that these changes would lower the time above 183C without lowering the peak very far below the lower limit of 200C (figure 11).

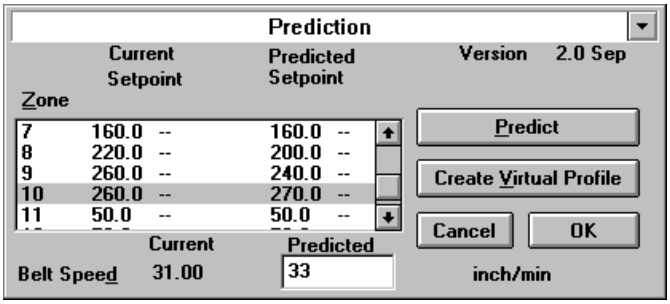
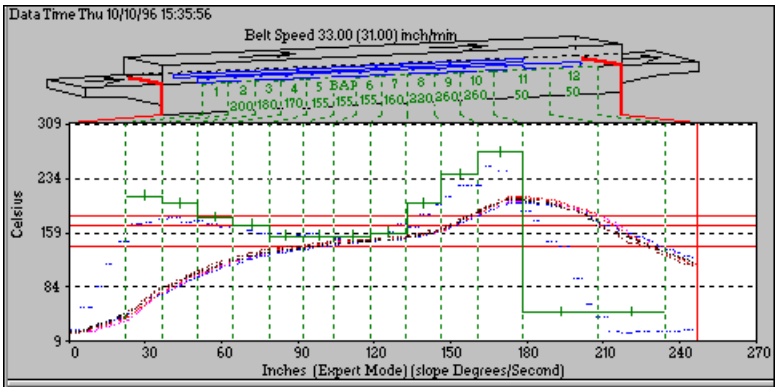


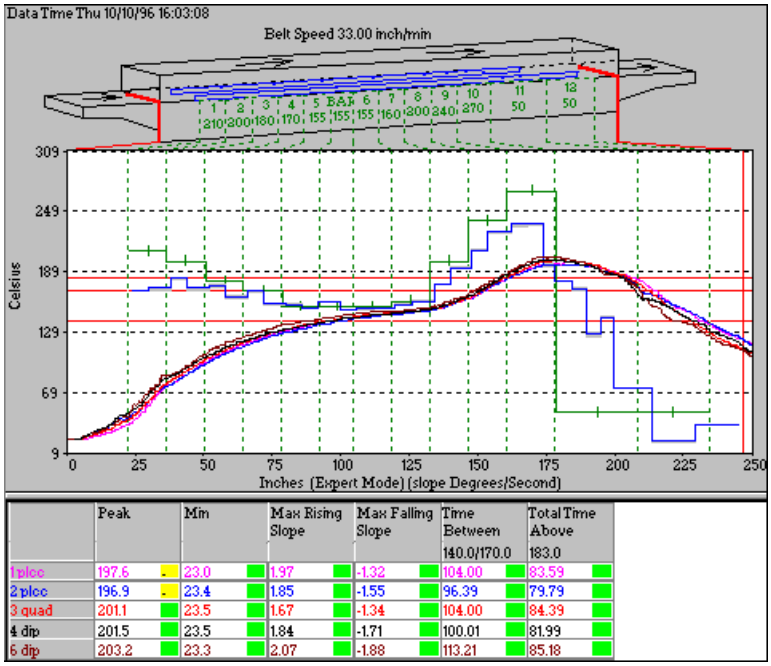
Figure 10: *Prediction box showing current and predicted setpoints.*



	Peak	Min	Max Rising Slope	Max Falling Slope	Time Between 140.0/170.0	Total Time Above 183.0
1 ploc	208.3	22.5	1.93	-1.28	116.80	110.41
2 ploc	207.5	22.7	1.65	-1.64	106.40	103.01
3 quad	212.2	23.6	1.66	-1.33	118.79	108.02
4 dip	212.8	23.7	1.80	-1.82	111.21	102.80
6 dip	214.5	22.3	1.87	-1.75	126.40	107.59
Predicted[01]	202.5	22.4	1.87	-1.22	106.07	88.99
Predicted[02	199.8	22.6	1.61	-1.53	97.98	80.00
Predicted[03	208.6	23.7	1.62	-1.28	105.17	88.09
Predicted[04	203.8	23.7	1.75	-1.70	99.78	83.60
Predicted[06	207.2	22.3	1.77	-1.65	113.26	88.09

Figure 11: *The first prediction. Notice how the time above 183C has dropped significantly. Even though one peak temp is slightly below the warning limit, we decided to run a profile with these settings and see what happens.*

Figure 12 shows the actual results of the profile run with the new oven settings. The peak temperatures and time above 183C are a little lower than WinKIC predicted. Figure 13 shows a comparison of the predicted (dotted line) Vs actual for thermocouple #1. As you can see, the prediction was extremely accurate until zone 10. If you go back and look at how WinKIC predicted the KICprobe temperatures would change in zone 10, you can see that while zone 10 was raised from 260C to 270C, the actual zone temperature, as measured by the KICprobes, dropped from 240C to 235C.



	Peak	Min	Max Rising Slope	Max Falling Slope	Time Between 140.0/170.0	Total Time Above 183.0
1plcc	197.6	23.0	1.97	-1.32	104.00	83.59
2plcc	196.9	23.4	1.85	-1.55	96.39	79.79
3 quad	201.1	23.5	1.67	-1.34	104.00	84.39
4 dip	201.5	23.5	1.84	-1.71	100.01	81.99
6 dip	203.2	23.3	2.07	-1.88	113.21	85.18

Figure 12: *The Second Pass.*

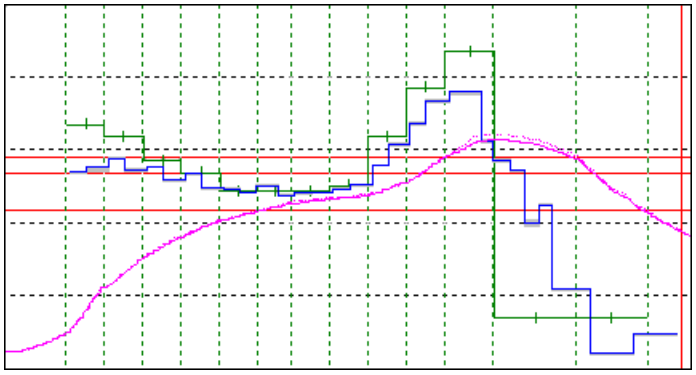


Figure 13: *Predicted Vs Actual profiles for TC #1.*

Since the oven did not seem to be responding the anticipated way, we went back to the first profile and looked for a solution that did not involve significantly changing the setpoint temperatures in the "reflow zones" (zones 9 & 10). First the conveyor speed was increased from 31 to 34 inches/min. WinKIC predicted that while this would lower the time above 183C significantly, it was not enough to meet the specifications (figure 14).

	Peak	Min	Max Rising Slope	Max Falling Slope	Time Between 140.0/170.0	Total Time Above 183.0
Predicted[01]	203.9	22.5	1.86	-1.22	92.48	97.72
Predicted[02	202.4	22.6	1.60	-1.55	82.89	88.99
Predicted[03	208.2	23.7	1.61	-1.27	89.86	95.97
Predicted[04	207.6	23.7	1.75	-1.72	83.76	90.74
Predicted[06	209.8	22.3	1.77	-1.66	94.23	95.10

Figure 14: *Conveyor speed increased from 31 to 34 inches/minute.*

Zone 8 was then reduced from 220C to 200C (figure 15). This reduced the time above reflow by making the peak of the profiles more pointed, and less of a plateau.

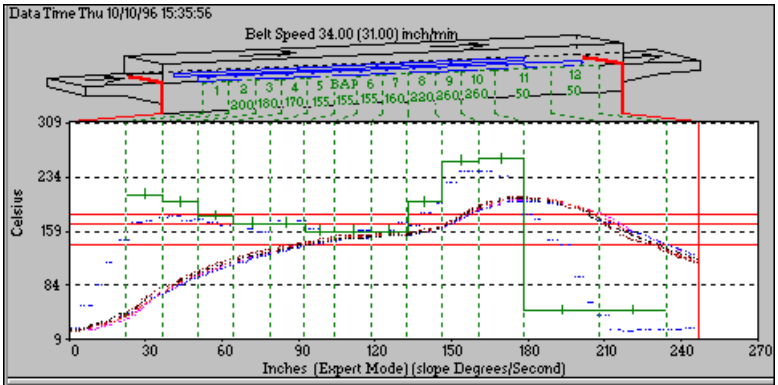
	Peak	Min	Max Rising Slope	Max Falling Slope	Time Between 140.0/170.0	Total Time Above 183.0
Predicted[01]	201.6	22.5	1.86	-1.20	96.84	92.48
Predicted[02	199.7	22.6	1.60	-1.52	88.12	83.76
Predicted[03	206.2	23.7	1.61	-1.26	95.10	89.86
Predicted[04	204.6	23.7	1.75	-1.69	90.74	85.50
Predicted[06	207.0	22.3	1.77	-1.63	99.46	89.86

Figure 15: *Zone 8 lowered 20 degrees.*

Next, the temperatures throughout the soak zone were raised to try to increase the time between 140C & 170C and also raise the peak temperatures slightly. Zone 5 was raised from 155C to 170C, and zone 6 from 155C to 160C (figure 16).

	Peak	Min	Max Rising Slope	Max Falling Slope	Time Between 140.0/170.0	Total Time Above 183.0
Predicted[01]	202.8	22.5	1.86	-1.21	104.70	95.10
Predicted[02	201.0	22.6	1.60	-1.53	98.59	86.38
Predicted[03	207.1	23.7	1.61	-1.26	106.44	92.48
Predicted[04	205.6	23.7	1.75	-1.70	101.21	87.25
Predicted[06	207.9	22.3	1.77	-1.64	109.06	91.61

Figure 16: *Zone 5 and Zone 6 raised slightly.*

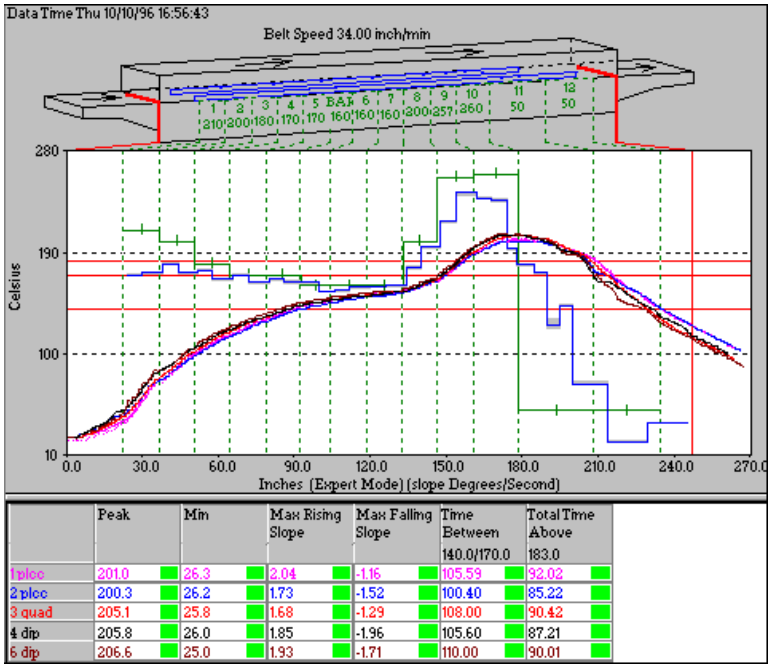


	Peak	Min	Max Rising Slope	Max Falling Slope	Time Between 140.0/170.0	Total Time Above 183.0
1plcc	208.3	22.5	1.93	-1.28	116.80	110.41
2plcc	207.5	22.7	1.65	-1.64	106.40	103.01
3 quad	212.2	23.6	1.66	-1.33	118.79	108.02
4 dip	212.8	23.7	1.80	-1.82	111.21	102.80
6 dip	214.5	22.3	1.87	-1.75	126.40	107.59
Predicted[01	202.2	22.5	1.86	-1.21	105.57	93.36
Predicted[02	200.3	22.6	1.60	-1.52	98.59	84.63
Predicted[03	206.6	23.7	1.61	-1.26	106.44	90.74
Predicted[04	204.8	23.7	1.75	-1.69	101.21	86.38
Predicted[06	207.2	22.3	1.77	-1.63	109.93	89.86

Figure 17: *The predicted results of 4 zone setpoint* changes and a 9% conveyor speed change.

Zone 9 was lowered just slightly, from 260C to 257C. This brought the time above 183C column below 95 seconds without dropping the peak temperature column below 200C. Figure 17 shows the Statistics for both the original profile, and the prediction.

Figure 18 shows the actual profile with the new oven setpoints. As you can see everything is "green" and it's ready to go! Figure 19 shows how close the actual profile matched the predicted profile.



	Peak	Min	Max Rising Slope	Max Falling Slope	Time Between 140.0/170.0	Total Time Above 183.0
1 plcc	201.0	26.3	2.04	-1.16	105.59	92.02
2 plcc	200.3	26.2	1.73	-1.52	100.40	85.22
3 quad	205.1	25.8	1.68	-1.29	108.00	90.42
4 dip	205.8	26.0	1.85	-1.96	105.60	87.21
5 dip	206.6	25.0	1.93	-1.71	110.00	90.01

Figure 18: *Profile #3, all's well that ends well!*

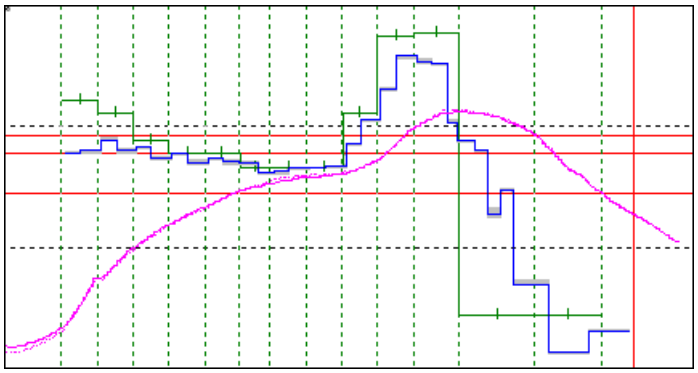


Figure 19: *The actual profile is so close to the predicted profile that it is hard to tell them apart.*

If you have any questions regarding this paper or any KIC products, please feel free to contact us at:

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