Accuracy of the Prophet Thermal Manager Virtual Profiling Tool

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Background

The closed-loop temperature control system on a modern conveyor oven uses thermocouples to monitor oven temperature. These thermocouples are typically located close to the heating mediums to allow quick response to temperature changes. Placement of the control thermocouples near the heat source is a necessary design feature which ensures that the process control response does not lag and "hunt" for the target temperatures, which would ultimately result in an inherently unstable and ineffective control loop. However, because of the placement of the control thermocouples, the oven will not necessarily effectively control the temperature along the conveyor. The result is that the product thermal profile can vary significantly while the oven control thermocouples change very little. Thus, even though the oven controller shows that the process is stable, the product thermal profile must be checked regularly.

Measuring the product thermal profile involves attaching thermocouples to a product and recording the thermal profile as the product passes through the conveyor oven. Temperature profiling is typically employed intermittently as a method of sampling the process status. The underlying assumption is that in-between each successful temperature profile conducted, all processed product meets the quality specifications. This methodology has generally received industry wide acceptance.

While the product thermal profile is typically only measured once a week, once a day, or once a shift, the ideal would be to measure the thermal profile for every board. However, to actively monitor the temperature profile of the product without encumbering production would necessitate a means of measuring the thermal profile without attaching thermocouples to each board. KIC Thermal Profiling has developed a means of monitoring the oven temperature along the conveyor and has designed a computer simulation capable of predicting the changes to the product thermal profile based on process temperature changes.

The widespread implications of employing computer simulations are very apparent in everyday life. With recent advances in technology, computer simulation has taken on a more active role as an engineering tool in everything from the development of new aircraft, car and building designs (CAD/CAM) to cult-like status in the latest computer games.

A means of acquiring the thermal process temperature data in the vicinity of the product was needed in order to provide the model with the raw data needed to create the simulated environment. To create such a means that could effectively and continuously monitor the oven temperatures entailed the development of a special device that:

- Can be placed in a close vicinity to the product
- Avoids interfering with the heat transfer to the product
- Is rigid enough to be handled without damage
- Houses a maximum amount of thermocouples in a minimum amount of area

Called a KICProbe, these devices can accommodate most conveyorized thermal process equipment and is the means by which the thermal process temperature data is acquired and input into the computer model.

KIC Thermal Profiling manufactures a product called the "Prophet Thermal Manager". The Prophet Thermal Manager is designed to be installed in a conveyorized thermal process and claims to be able to monitor and record a "virtual thermal profile" for every product that is processed. If it can be shown that this Virtual Profile closely approximates the true product thermal profile, the Prophet could eliminate the defects caused by incorrect thermal processing and could provide solid documentation showing that every product was processed properly. The goal of this paper is to measure the accuracy of the Virtual Profiling Tool in three common conveyorized thermal processes.

How does Virtual Profiling work?

The Prophet Thermal Manager monitors process temperature along the oven conveyor with 30 permanently installed thermocouples. A SlimKIC Thermal Profiler is used to record a "baseline" thermal profile at up to 12 locations on a sample product. The relationship between process temperature and product temperature is calculated and used to generate a "Virtual Profile".

During production, every 30 seconds, process temperature is measured and a Virtual Profile is calculated and displayed. This Virtual Profile predicts what the thermal profile will be for a product currently entering the oven. As process temperature drifts over hours, days, or weeks, the Virtual Profile calculates how the changes will affect the product thermal profile. *Virtual Profiling is as close as you can get to attaching thermocouples to every product.*

How will the accuracy of the Virtual Profile be measured?

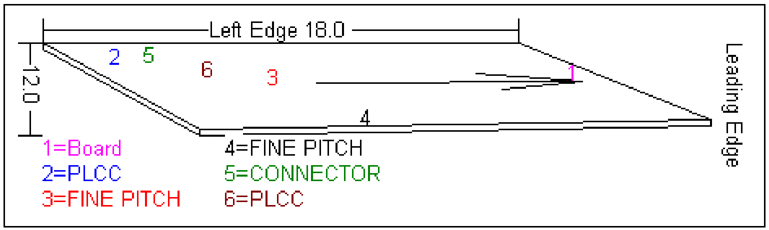
Virtual Profiling can be a very powerful tool, if the Virtual Profile closely resembles the actual product profile. This paper offers some insight into the reliability of the Virtual Profiling tool by comparing the Virtual Profile with actual thermal profiles in three different ovens over 4 to 12 week periods. In each case a "Baseline Profile" was run at the beginning of the testing period, and then verification profiles were run at one week to one month intervals.

Before presenting the data, it is important to understand that the product thermal profile is a function of four parameters: initial product temperature, conveyor speed, process temperature, and heat transfer rate. The initial product temperature and conveyor speed were measured for each profile and held constant through out the testing period. The process temperature is measured by the Prophet Thermal Manager and is used to update the Virtual Profile. The heat transfer rate is not measured, but we were careful not to change the air flow/fan speed setting on the ovens. Significant changes in heat transfer rate can cause inaccuracies in the Virtual Profile.

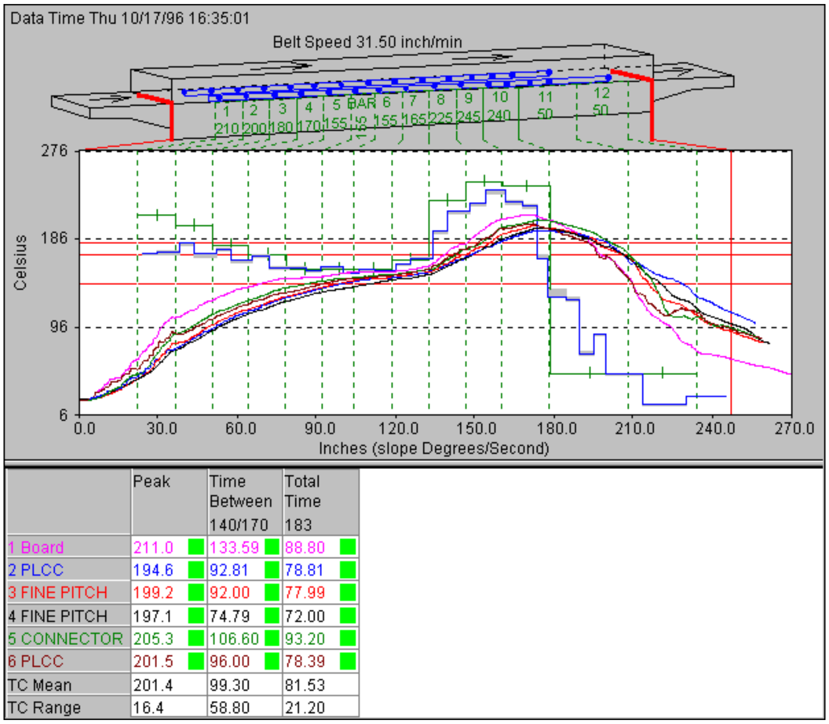
The process temperature at the start of the Baseline profile is referred to as the "Target" process temperature. The amount that process temperature deviates from the Target is referred to as the "Average Deviation" or AD. As the Average Deviation increases, it becomes more likely that the heat transfer rate has also changed, thus lowering our confidence in the accuracy of the Virtual Profile. The AD was recorded for each profile.

Test 1

The first set of profiles were run in a 20 zone (10 top, 10 bottom) forced convection reflow oven with a 247 inch long tunnel. The oven uses air amplifiers to move the air and has an active cooling section. The test product was an 18" x 12" Printed Circuit Board (PCB) with six thermocouples attached at various locations (figure 1). Figure 2 shows a plot of the Baseline profile run on 10-17-96.



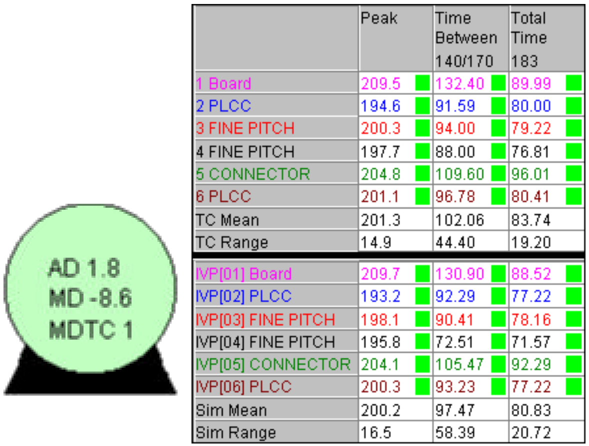
Test 1, Figure 1: *This is a map of the location of the thermocouples on the PCB. The TCs are soldered down with 10-88-2 solder (Utectic 268C).*



	Peak		Time Between 140/170		Total Time 183	
1 Board	211.0	🟩	133.59	🟩	88.80	🟩
2 PLCC	194.6	🟩	92.81	🟩	78.81	🟩
3 FINE PITCH	199.2	🟩	92.00	🟩	77.99	🟩
4 FINE PITCH	197.1	🟩	74.79	🟩	72.00	🟩
5 CONNECTOR	205.3	🟩	106.60	🟩	93.20	🟩
6 PLCC	201.5	🟩	96.00	🟩	78.39	🟩
TC Mean	201.4		99.30		81.53	
TC Range	16.4		58.80		21.20	

Test 1, Figure 2: *This is the first profile of the test run on 10-17-96. This test was used to calculate the relationship between process temperature and product temperature and is referred to as the "Baseline Profile".*

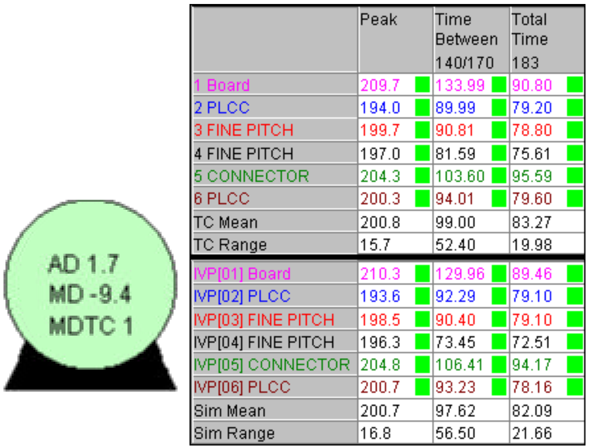
Figure 3 shows the Statistics for the second profile, run on 11-7-96. On average, the 30 thermocouples measuring process temperature only deviated by 1.8 degrees C from the target process temperature. Remember, the target is the process temperature at the start of the Baseline Profile (the Baseline Profile was run almost three weeks earlier). The bottom row of Statistics shows what the Virtual Profile predicted the PCB would see, the top row of the Statistics is what was actually recorded with the SlimKIC Thermal Profiler. The process temperatures didn't change much, and if you compare figure 3 with figure 2, you will see that the product thermal profile did not change much either.



	Peak		Time Between 140/170		Total Time 183	
1 Board	209.5	🟩	132.40	🟩	89.99	🟩
2 PLCC	194.6	🟩	91.59	🟩	80.00	🟩
3 FINE PITCH	200.3	🟩	94.00	🟩	79.22	🟩
4 FINE PITCH	197.7	🟩	88.00	🟩	76.81	🟩
5 CONNECTOR	204.8	🟩	109.60	🟩	96.01	🟩
6 PLCC	201.1	🟩	96.78	🟩	80.41	🟩
TC Mean	201.3		102.06		83.74	
TC Range	14.9		44.40		19.20	
IVP[01] Board	209.7	🟩	130.90	🟩	88.52	🟩
IVP[02] PLCC	193.2	🟩	92.29	🟩	77.22	🟩
IVP[03] FINE PITCH	198.1	🟩	90.41	🟩	78.16	🟩
IVP[04] FINE PITCH	195.8	🟩	72.51	🟩	71.57	🟩
IVP[05] CONNECTOR	204.1	🟩	105.47	🟩	92.29	🟩
IVP[06] PLCC	200.3	🟩	93.23	🟩	77.22	🟩
Sim Mean	200.2		97.47		80.83	
Sim Range	16.5		58.39		20.72	

Test 1, Figure 3: *This profile was run on 11-7-96. The top box shows the Statistics for the actual Profile, the bottom box shows the Statistics for the Virtual profile. AD=1.8 for this profile.*

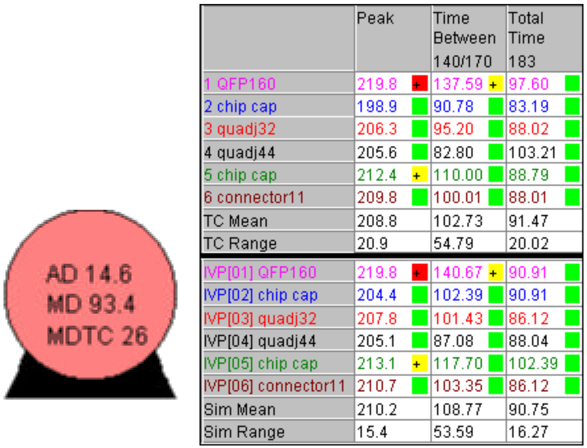
Figure 4 shows the results of the profile run on 11-21-96. The AD was still a low 1.7. Figure 5 shows the results from 1-23-97 where the Average Deviation increased to 14.6C. Unfortunately we did not run any profiles for the two months between November 21 and Jan 21. However, with the AD increasing from 1.7 to 14.6, we can see that the process temperature changed significantly. If we compare the Statistics from figure 4 and figure 5, we can see that the product temperature changed significantly as well. Notice that the mean peak temperature jumped up 8C, and the time above 183C increased by 8 seconds. The interesting thing is how accurately the Virtual Profile predicted the product thermal profile. The Virtual Profile peak temperature for TC# 2 was off by 5.5C, but the average peak temperature for all six TCs was within 1.4C and four of the peaks were within 1.0C. The other virtual profile statistics, while not as accurate as the peak temperature, were fairly accurate as well.



AD 1.7
MD -9.4
MDTC 1

	Peak	Time Between 140/170	Total Time 183
1 Board	209.7 🟩	133.99 🟩	90.80 🟩
2 PLCC	194.0 🟩	89.99 🟩	79.20 🟩
3 FINE PITCH	199.7 🟩	90.81 🟩	78.80 🟩
4 FINE PITCH	197.0 🟩	81.59 🟩	75.61 🟩
5 CONNECTOR	204.3 🟩	103.60 🟩	95.59 🟩
6 PLCC	200.3 🟩	94.01 🟩	79.60 🟩
TC Mean	200.8	99.00	83.27
TC Range	15.7	52.40	19.98
IVP[01] Board	210.3 🟩	129.96 🟩	89.46 🟩
IVP[02] PLCC	193.6 🟩	92.29 🟩	79.10 🟩
IVP[03] FINE PITCH	198.5 🟩	90.40 🟩	79.10 🟩
IVP[04] FINE PITCH	196.3 🟩	73.45 🟩	72.51 🟩
IVP[05] CONNECTOR	204.8 🟩	106.41 🟩	94.17 🟩
IVP[06] PLCC	200.7 🟩	93.23 🟩	78.16 🟩
Sim Mean	200.7	97.62	82.09
Sim Range	16.8	56.50	21.66

Test 1, Figure 4: *These are the Statistics from a profile run on 11-21-96. The Average Deviation was only 1.7C.*

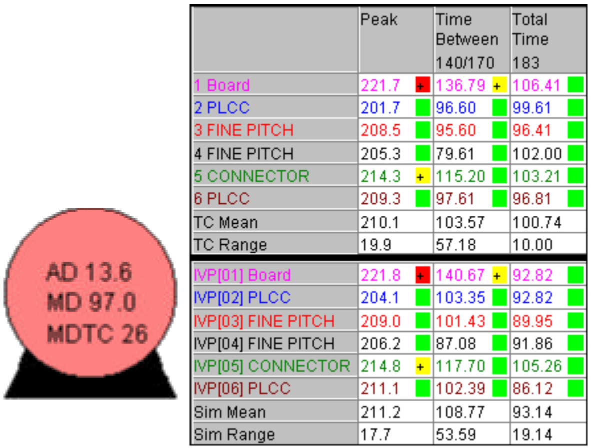


AD 14.6
MD 93.4
MDTC 26

	Peak	Time Between 140/170	Total Time 183
1 QFP160	219.8 🟥+	137.59 🟨+	97.60 🟩
2 chip cap	198.9 🟩	90.78 🟩	83.19 🟩
3 quadj32	206.3 🟩	95.20 🟩	88.02 🟩
4 quadj44	205.6 🟩	82.80 🟩	103.21 🟩
5 chip cap	212.4 🟨+	110.00 🟩	88.79 🟩
6 connector11	209.8 🟩	100.01 🟩	88.01 🟩
TC Mean	208.8	102.73	91.47
TC Range	20.9	54.79	20.02
IVP[01] QFP160	219.8 🟥+	140.67 🟨+	90.91 🟩
IVP[02] chip cap	204.4 🟩	102.39 🟩	90.91 🟩
IVP[03] quadj32	207.8 🟩	101.43 🟩	86.12 🟩
IVP[04] quadj44	205.1 🟩	87.08 🟩	88.04 🟩
IVP[05] chip cap	213.1 🟨+	117.70 🟩	102.39 🟩
IVP[06] connector11	210.7 🟩	103.35 🟩	86.12 🟩
Sim Mean	210.2	108.77	90.75
Sim Range	15.4	53.59	16.27

Test 1, Figure 5: *These are the Statistics from a profile run on 1-21-97. On Average, process temperature has changed by 14.6C and this has had a significant affect on product temperature.*

Figure 6 shows the results of a profile run on 1-30-97. The accuracy of the prediction is similar to that shown in Figure 5.

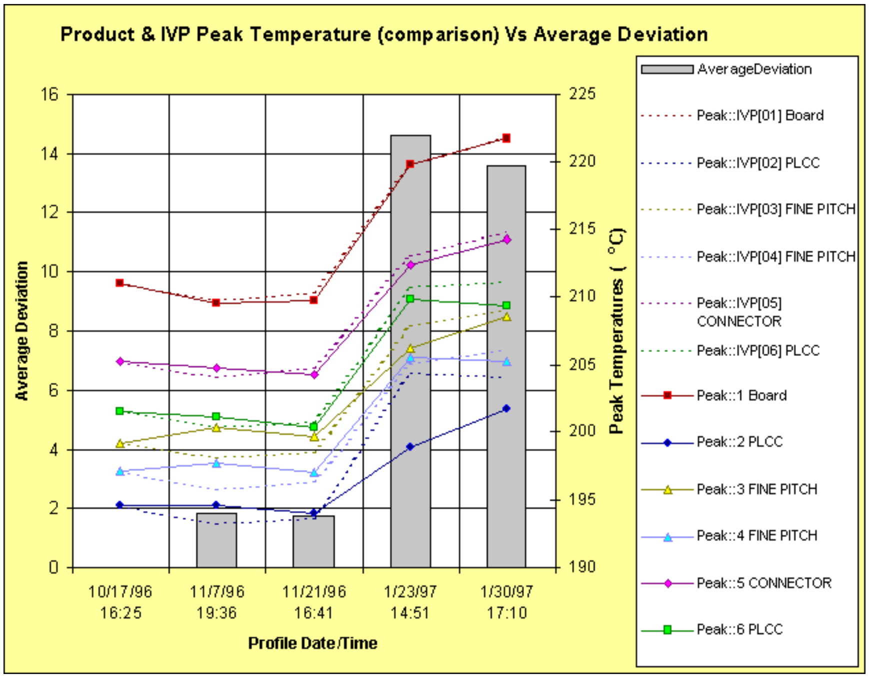


AD 13.6
MD 97.0
MDTC 26

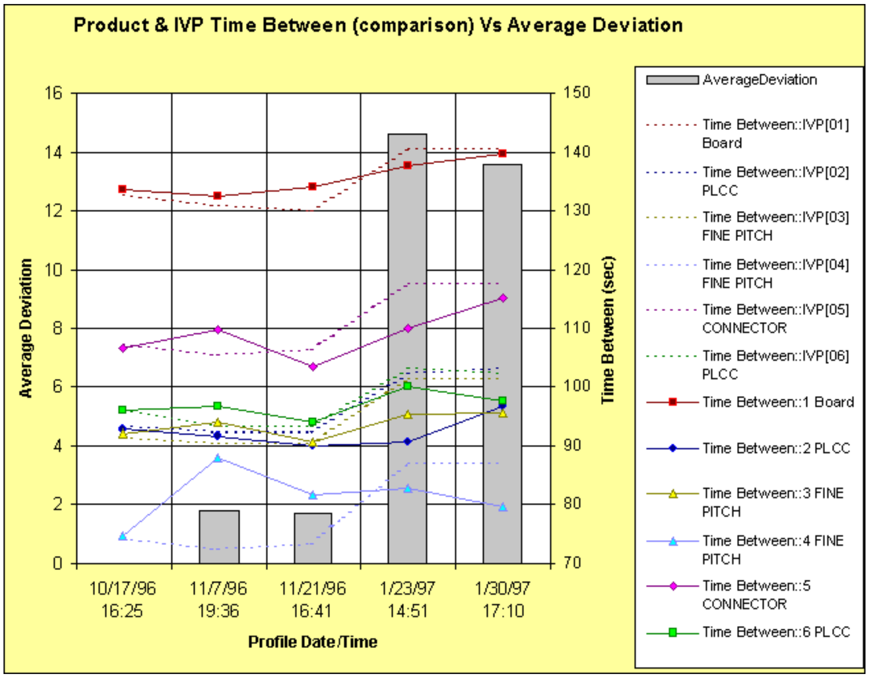
	Peak	Time Between 140/170	Total Time 183
1 Board	221.7 🟥+	136.79 🟨+	106.41 🟩
2 PLCC	201.7 🟩	96.60 🟩	99.61 🟩
3 FINE PITCH	208.5 🟩	95.60 🟩	96.41 🟩
4 FINE PITCH	205.3 🟩	79.61 🟩	102.00 🟩
5 CONNECTOR	214.3 🟨+	115.20 🟩	103.21 🟩
6 PLCC	209.3 🟩	97.61 🟩	96.81 🟩
TC Mean	210.1	103.57	100.74
TC Range	19.9	57.18	10.00
IVP[01] Board	221.8 🟥+	140.67 🟨+	92.82 🟩
IVP[02] PLCC	204.1 🟩	103.35 🟩	92.82 🟩
IVP[03] FINE PITCH	209.0 🟩	101.43 🟩	89.95 🟩
IVP[04] FINE PITCH	206.2 🟩	87.08 🟩	91.86 🟩
IVP[05] CONNECTOR	214.8 🟨+	117.70 🟩	105.26 🟩
IVP[06] PLCC	211.1 🟩	102.39 🟩	86.12 🟩
Sim Mean	211.2	108.77	93.14
Sim Range	17.7	53.59	19.14

Test 1, Figure 6: *This profile was run on 1-30-97. From 10-17-96 to 1-30-97 the average peak temperature on the PCB went from 201.4C to 210.1C. The Virtual Profile predicted the average peak would rise to 211.2C.*

Figure 7 is a chart created with Microsoft Excel that plots the peak temperature for both the actual thermal profile (solid line) and the Virtual Profile (dotted line). For each profile a bar indicates the Average Deviation. Figure 8 is a similar chart for the Time Between 140C and 170C.

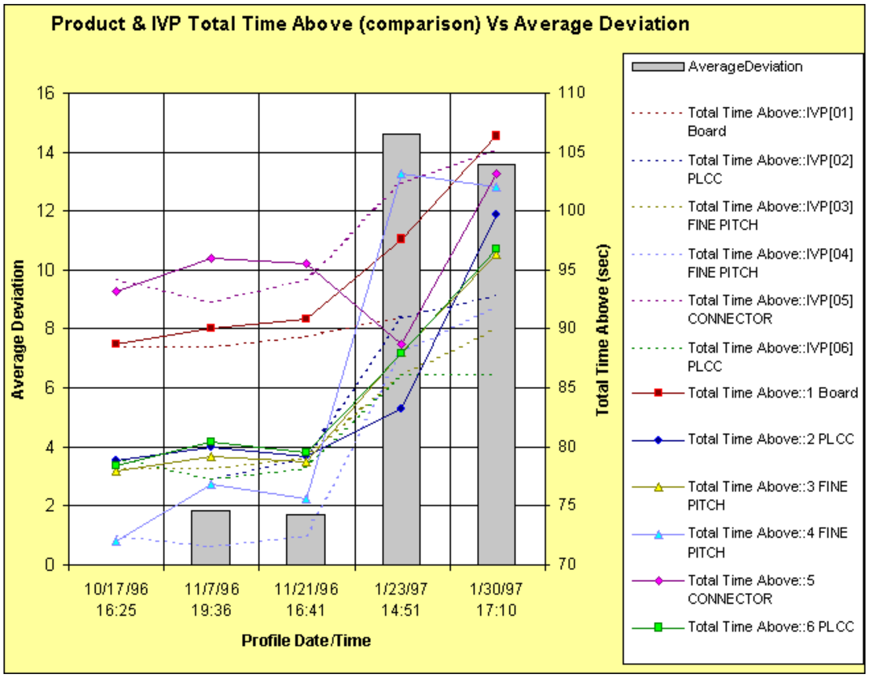


Test 1, Figure 7



Test 1, Figure 8

Figure 9 shows how the Time Above 183C changed over the three month testing period and it shows how accurately the Virtual Profile predicted the changes.



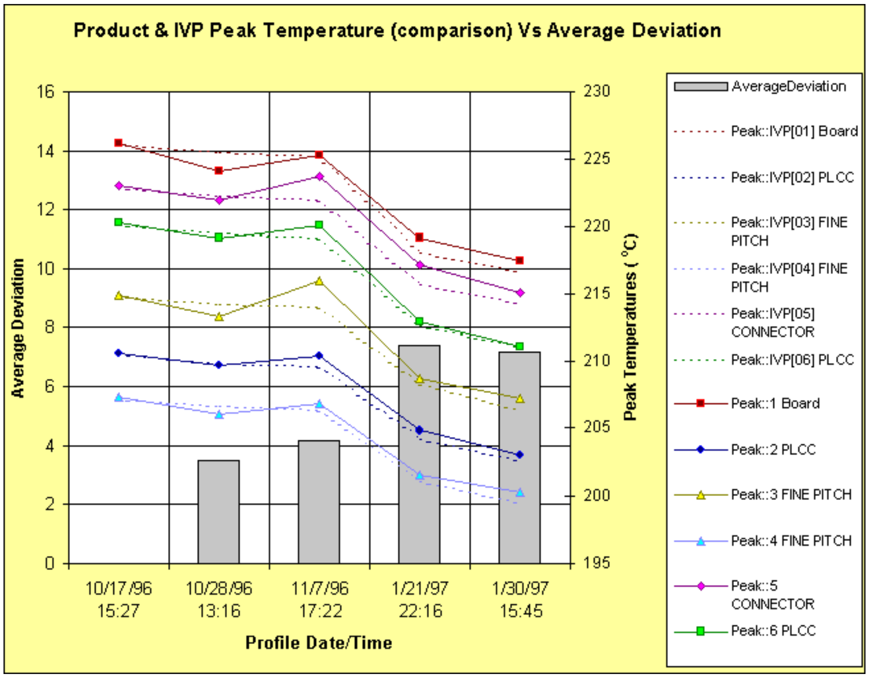
Test 1, Figure 9

Test 2

For the second test we used the same PCB as was used in Test 1. This test uses a different reflow oven, however it is the same manufacturer and model as was used in Test 1. For the sake of brevity, the statistics for each experiment are not shown, instead only the Excel charts. This series of profiles was run at the same time as those for Test 1 (10-17-96 to 1-30-97).

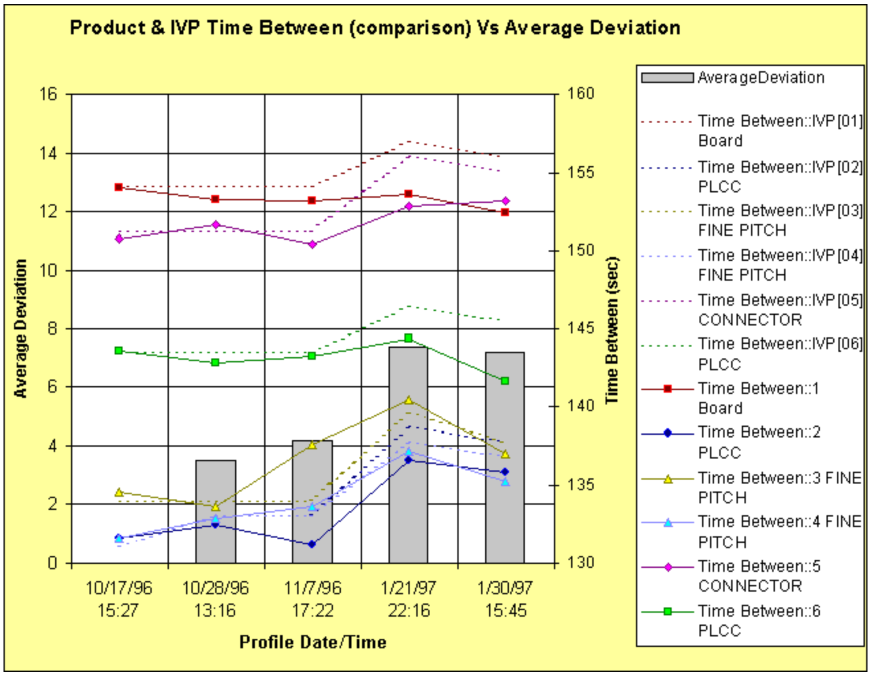
In Test 1 we saw the PCB peak temperature rise an average of 8C over the course of the test (Test 1, Figure 7). Test 2, Figure 1 shows that the mean peak temperature dropped 8C. Figure 1 also shows that the Virtual Profile was just as adept at predicting the actual profile as it was in Test 1.

Another difference between Test 1 and Test 2 is that the process temperatures did not change as much over the course of Test 2 as they did during Test 1. The Average Deviation stayed below 8C during Test 2, where as in Test 1 it exceeded 14C for one of the profiles.

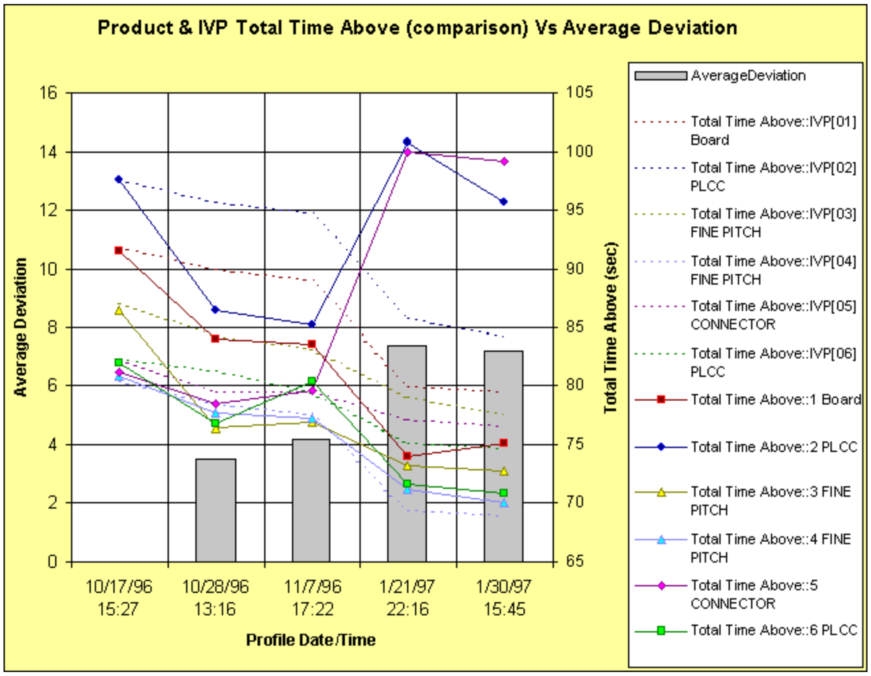


Test 2, Figure 1

Figure 2 plots the Time Between 140C and 170C. Figure 3 plots the Time Above 183C.



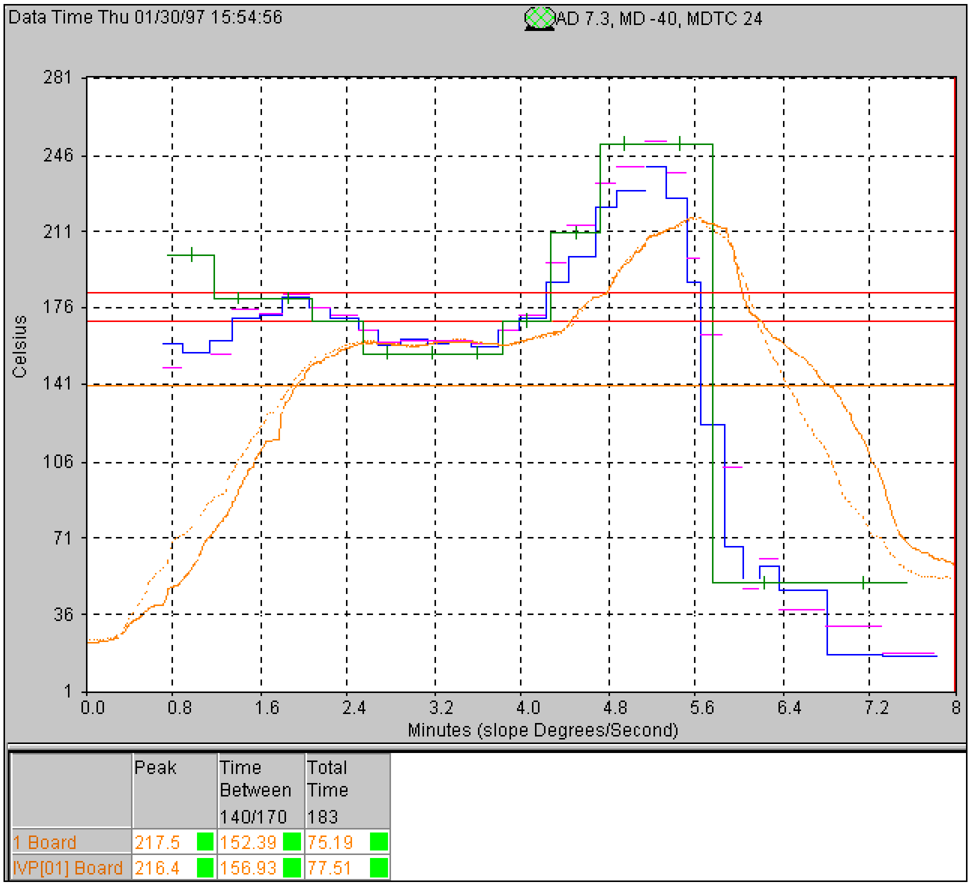
Test 2, Figure 2



Test 2, Figure 3

If you look closely at Figure 3, you will notice that thermocouples #2 and #5 spend a significantly longer number of seconds above 183C than was predicted by the Virtual Profile. The Virtual Profile was able to predict within about 5 seconds for all the other TCs.

Figure 4 shows the Prophet screen with the Virtual and actual profile for TC #1 displayed (orange). The blue step curve shows the current process temperature and the red steps show the process temperature at the time of the baseline profile (10-17-96). We can see that process temperature in the last two heated zones has dropped somewhat, and it should come as no surprise that the product peak temperature has dropped as well. What is even more significant is the drop in temperature between the last heated zone and the cooling zone. This cooling zone was cleaned in December which caused a significant change in process temperature.



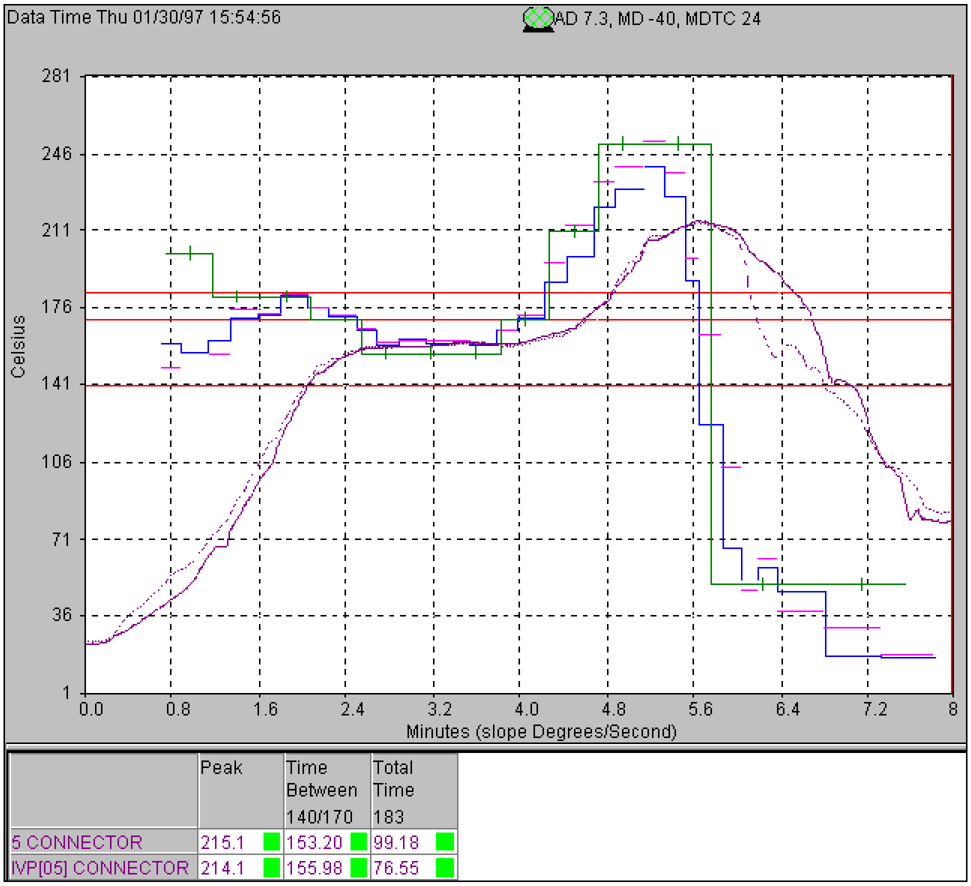
Data Time Thu 01/30/97 15:54:56

AD 7.3, MD -40, MDTC 24

	Peak	Time Between 140/170	Total Time 183
1 Board	217.5 🟩	152.39 🟩	75.19 🟩
IVP[01] Board	216.4 🟩	156.93 🟩	77.51 🟩

Test 2, Figure 4: *The dotted orange line is the Virtual Profile for TC #1, the solid orange line is the actual profile for TC #1.*

In Figure 4 we see that the Virtual Profile predicted TC #1 very accurately. However, Figure 5 shows a similar plot for TC# 5. We can see that, for some reason, the TC did not cool as quickly as the Virtual Profile predicted.



Data Time Thu 01/30/97 15:54:56

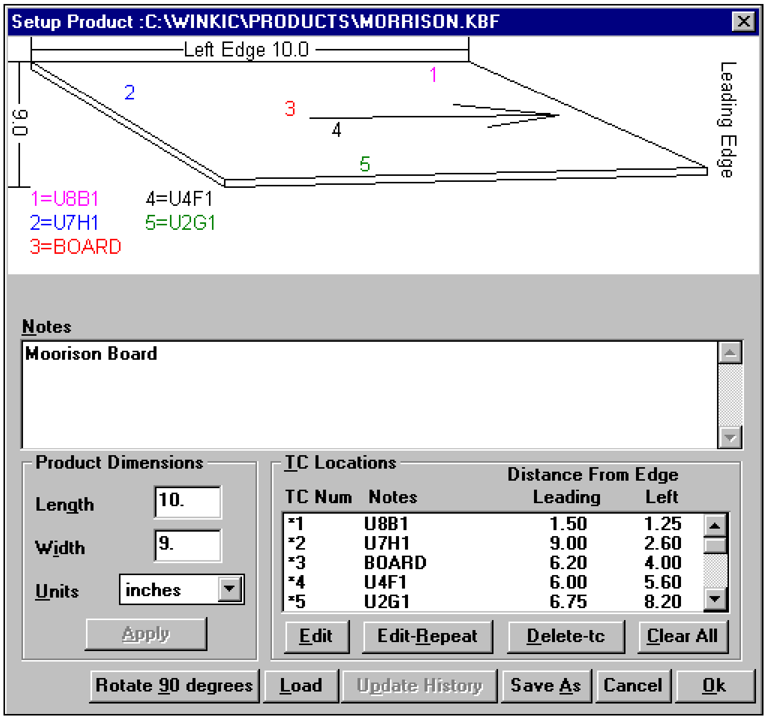
AD 7.3, MD -40, MDTC 24

	Peak		Time Between 140/170		Total Time 183	
5 CONNECTOR	215.1	🟩	153.20	🟩	99.18	🟩
IVP[05] CONNECTOR	214.1	🟩	155.98	🟩	76.55	🟩

Test 2, Figure 5: *The dotted purple line is the Virtual Profile for TC #5, the solid purple line is the actual profile for TC #5.*

Test 3

For the third test we used a different 20 zone (10 top and 10 bottom) forced convection reflow oven. This particular oven uses fans instead of air amplifiers. The test board was a 10" x 9" populated PCB (figure 1). For the sake of brevity, the statistics for each experiment are not shown, instead only the Excel charts.



Setup Product :C:\WINKIC\PRODUCTS\MORRISON.KBF

1=U8B1
2=U7H1
3=BOARD
4=U4F1
5=U2G1

Notes

Moorison Board

Product Dimensions

Length 10.

Width 9.

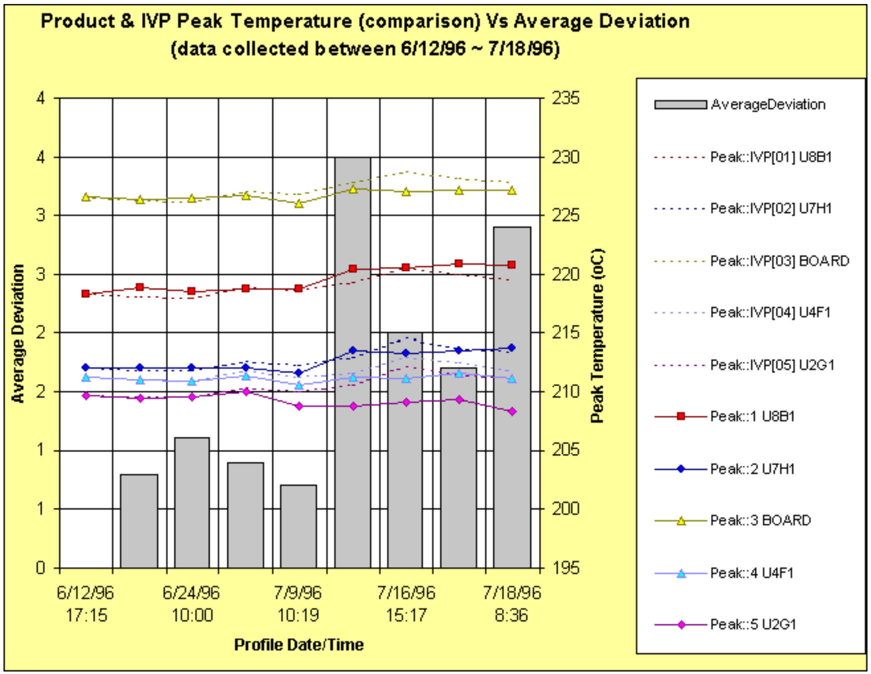
Units inches

TC Locations

TC Num	Notes	Distance From Edge Leading	Distance From Edge Left
*1	U8B1	1.50	1.25
*2	U7H1	9.00	2.60
*3	BOARD	6.20	4.00
*4	U4F1	6.00	5.60
*5	U2G1	6.75	8.20

Test 3, Figure 1: *PCB used for Test 3*

Nine profiles were run from June 12 through July 18. The profile on June 12 was used as the Baseline Profile and by definition has an Average Deviation of 0.0. The process temperature along the oven conveyor was very stable during this test as shown by the fact that the highest Average Deviation recorded was 3.5C. Figure 2 shows how accurately the Virtual Profile predicted the peak temperature, and Figure 3 shows how accurately the Time Above 183C was predicted. As you can see, the Virtual Profile did an excellent job of predicting the actual profile statistics.

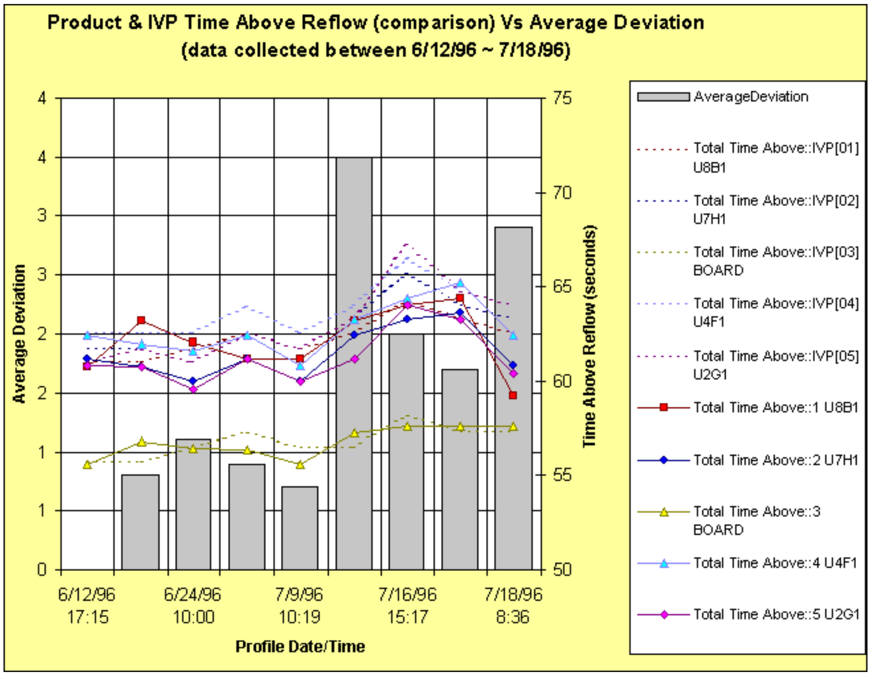


Test 3, Figure 2: *This graph shows how the Virtual Profile peak temperatures (dotted lines) compared with the actual profile peaks (solid lines).*

Conclusion

Virtual Profiling can be a very powerful tool, if the Virtual Profile closely resembles the actual product profile. This paper has shown that in tests in two popular brands of forced convection solder reflow ovens, the Virtual Profile does indeed closely match the profile as recorded by attaching thermocouples directly to the PCB.

Obviously the performance of the Virtual Profiling tool may vary from oven to oven. Upon purchasing a KIC Prophet Thermal Manager you have 30 days to try it. If you are not satisfied, for any reason, please send it back in lieu of payment.



Test 3, Figure 3

If you have any questions regarding this study, or any question about KIC products, please feel free to contact the authors, Philip Kazmierowicz and Dennis Ishler at:

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