

Finding the Best Oven Recipe with the SlimKIC 2000 Using the Auto-Focus Software Option

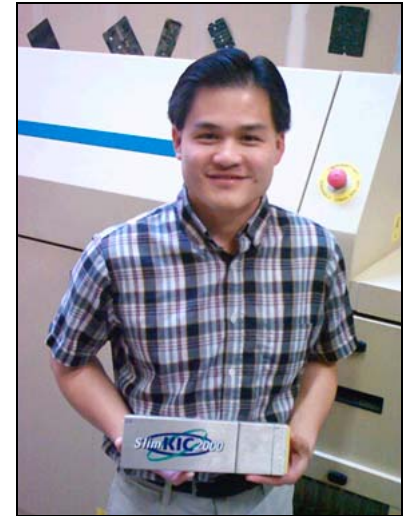
Ronald Chau, KIC 3-20-2003

Introduction

The SlimKIC 2000™ is a tool that records the thermal profile of a product in a conveyerized thermal process such as a solder reflow oven. It also includes software that determines whether or not the profile is in spec, and that helps the user find an oven recipe that will put the profile in spec.

Recently, the KIC R&D department developed a software option to the SlimKIC 2000 called *Auto-Focus*™ that uses the information from previously run products to calculate a good first oven recipe for a new product. The Quality Assurance department at KIC was asked to develop a comprehensive test that would qualitatively show how well the Auto-Focus option with the SlimKIC 2000 finds oven recipes. Specifically, we were asked to answer the following questions:

- On average, how many profiles does it take to find a good oven recipe for a new product?
- How many boards must I profile before Auto-Focus has enough information to give me a useful first pass oven recipe?
- Is Auto-Focus reliable enough to confidently setup the oven for a new product without running a profile?



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This report will describe the test procedure and display the test results.

Equipment Used

Setup and Profiling Tools

The basic SlimKIC 2000 kit includes the SlimKIC, which has either 9 or 12 Type K thermocouple inputs (all of our testing was done with a 9 channel unit). We tested with the optional radio receiver that allows the SlimKIC data to be transferred to the PC without plugging a wire into a hot datalogger at the end of the profile.

With the SlimKIC 2000 you can purchase two software options. The less expensive option is called the *Navigator*™. The Navigator is an “oven recipe search engine” that automatically finds the one best oven recipe after a profile is run. The Navigator has been available for several years. The more complete option is called Auto-Focus which includes all of the capabilities of the Navigator, plus it finds an appropriate oven recipe *before* running the first profile. This option was released in March of 2003. The tests in this paper were performed with the Auto-Focus option (which includes all the Navigator capabilities).



The SlimKIC 2000 System

The SlimKIC 2000 is a tool that is designed to help the user find the ideal oven recipe for a given process window. The process window chosen for these tests is typical for a leaded no-clean solder paste:

Statistic Name	Low Limit	High Limit	Units
Max Rising Slope (Target=2.0) (Calculate Slope over 20 Seconds)	0.0	3.0	Degrees/Second
Soak Time 140-170C	50	90	Seconds
Time Above Reflow - 183C	40	75	Seconds
Peak Temperature	205	225	Degrees Celsius

The process window used for all profiles in this report

Ovens

We tested the SlimKIC 2000 in two different solder reflow ovens:

- 2000 BTU Paragon 150 (10 heated zones, 2 water cooled zones)
- 1995 Vitronics Unitherm II SMR 1200N (12 heated zones, 4 water cooled zones)

We chose these ovens because they are readily accessible to us.



BTU Paragon 150



Vitronics SMR 1200N

Boards

We setup each oven for twenty different printed circuit boards. Between three and eight thermocouples (TCs) were attached to each board. The TCs were attached with aluminum tape, a proven method for attaining accurate and repeatable temperature measurements of printed circuit boards¹. The thermocouples were positioned to read both the highest and lowest peak temperature, and more TCs were used on the larger boards to ensure that the full temperature range was covered. The ovens were setup for each board in the order shown.

Note that the Auto-Focus option requires us to enter the length, width and weight of each board. This information is used by Auto-Focus as it uses the database of previously profiled boards to calculate an appropriate first oven recipe.

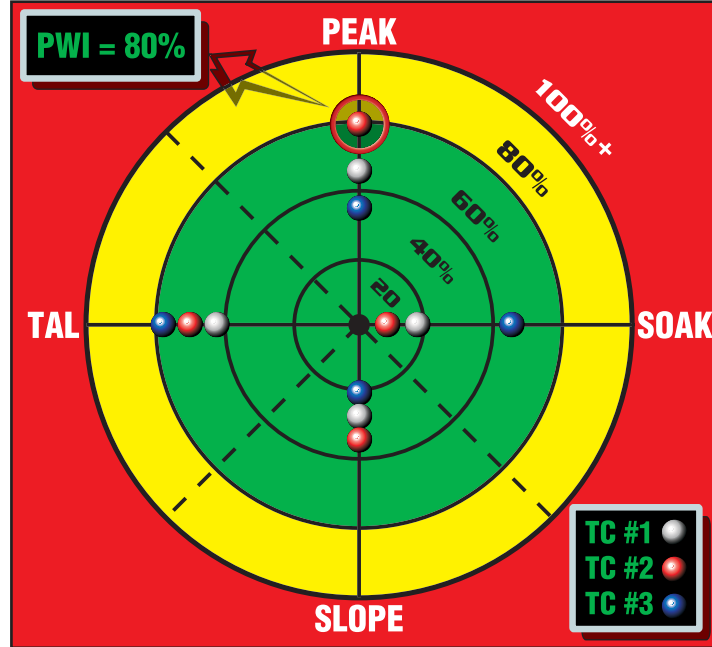
Board #	Length (Inches)	Width (Inches)	Weight (Grams)
1	11.25	8.25	404
2	10.50	7.50	158
3	8.25	11.25	190
4	13.00	10.50	749
5	8.50	6.20	66
6	20.00	7.75	550
7	16.00	6.50	490
8	13.00	9.00	484
9	6.75	4.00	103
10	4.00	12.50	192

Board #	Length (Inches)	Width (Inches)	Weight (Grams)
11	13.35	4.75	304
12	9.00	8.30	319
13	5.20	4.30	22
14	13.50	4.20	290
15	6.10	8.50	142
16	13.60	9.00	485
17	6.60	3.10	106
18	8.70	13.00	676
19	12.30	4.00	191
20	14.20	7.80	423

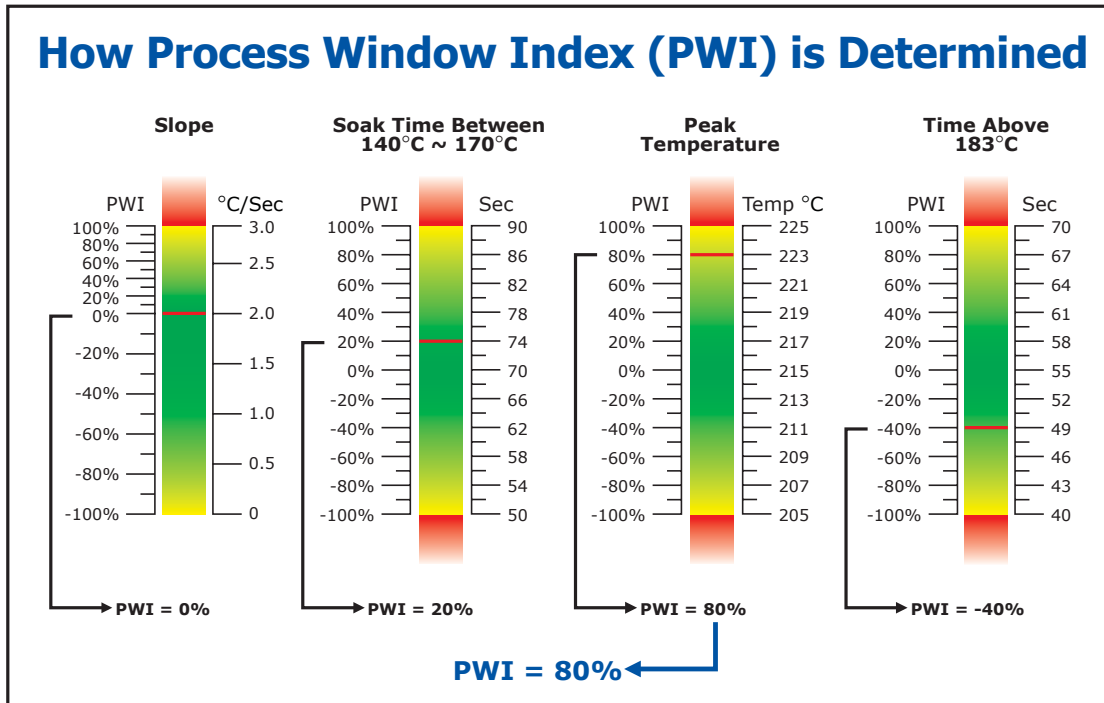


The Process Window Index

The SlimKIC 2000 has a unique method of mathematically measuring profile quality. It calculates a *Process Window Index* or *PWI* that shows whether or not the thermal profile is inside the process window and by how much. A PWI of 100% indicates that the thermal profile is right at the process window limit. A PWI at or above 100% is out of spec, and a PWI below 100% is in spec. A PWI of 0% is the theoretical best. The lower the PWI, the less likely the process will drift out of spec during production².



Every profile gets a PWI, which allows us to compare oven recipes. A PWI is calculated for each statistic, for each TC.



Our custom process window has four Statistics, so if there are three thermocouples attached to the board, there will be a total of 12 PWI's calculated for the board. The highest (worst) PWI becomes the PWI for the profile.

Test Procedures

Listed below is the step-by-step procedure we followed in testing the SlimKIC 2000 with Auto-Focus. Note that we followed this procedure 40 times (20 different boards and 2 different ovens):

1. Input the length, width, and weight of the product. Auto-Focus determines the best first oven recipe. If there were not enough boards in the database for Auto-Focus to determine a best first recipe, we simply used the recipe that the oven was already running.
2. Attach thermocouples to the board and run it through the oven using the SlimKIC 2000 to record the thermal profile.
3. The PWI (Process Window Index) for the thermal profile is automatically calculated and the Navigator software tool automatically searches for the oven recipe that will provide the lowest PWI. If the actual PWI is less than 60% the oven is considered setup for the board. If the actual PWI is greater than 60%, but the Navigator can improve it by at least 20 percentage points, then use the Navigator oven recipe and go back to step 2.

Notice in the above procedure that the testers do not need to make any “decisions” during the testing. The SlimKIC 2000 and Auto-Focus specify the setpoint temperatures and conveyor speed to use, and we follow a simple set of rules to determine when the profile has been optimized. This simplifies the training of the testers because they do not need any understanding of the relationship between the oven settings (setpoint temperature & conveyor speed) and the profile statistics (peak temperature, maximum rising slope, time above reflow, etc.).

BTU Paragon 150

We started testing in the BTU Paragon 150. This is the more modern oven we used for our testing, built in September 2000.

Since this is our first board, the database was empty and Auto-Focus could not give us a “first guess” recipe for the first profile. We simply used the recipe the oven happened to be running. It took three profiles for the SlimKIC 2000 find an in spec oven recipe for this board:

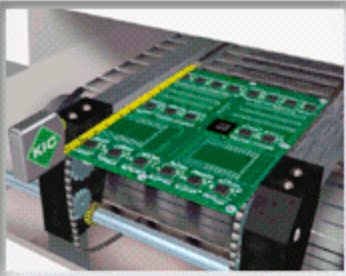
Board #	First Profile Predicted PWI	First Profile Actual PWI	Second Profile Predicted PWI	Second Profile Actual PWI	Third Profile Predicted PWI	Third Profile Actual PWI
1	None	231%	52%	102%	60%	67%

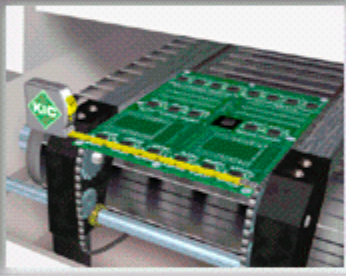
Results from the three profiles that were required to get the first board in spec


From the above table, notice that the PWI of the first profile was 231%. Since we have to be below 100% to be in spec, this oven recipe is well out of spec. The Navigator then suggested an oven recipe that should lower the PWI to 52%. We let the KIC 2000 software automatically copy this suggested recipe into the BTU oven control software. We waited until the oven stabilized on this new oven recipe and then we ran a second profile. The second profile had a PWI of 102%. This time the Navigator found an oven recipe with a predicted PWI of 60%. We used the suggested recipe and ran a third profile. The resulting PWI was 67%. At this point we quit, happy that the KIC 2000 software had found an oven recipe that would process this board in spec.


Measure length, width and weight of product:

Product Name: G1

 Enter Average Product Length (Inches)

 Enter Average Product Width (Inches)

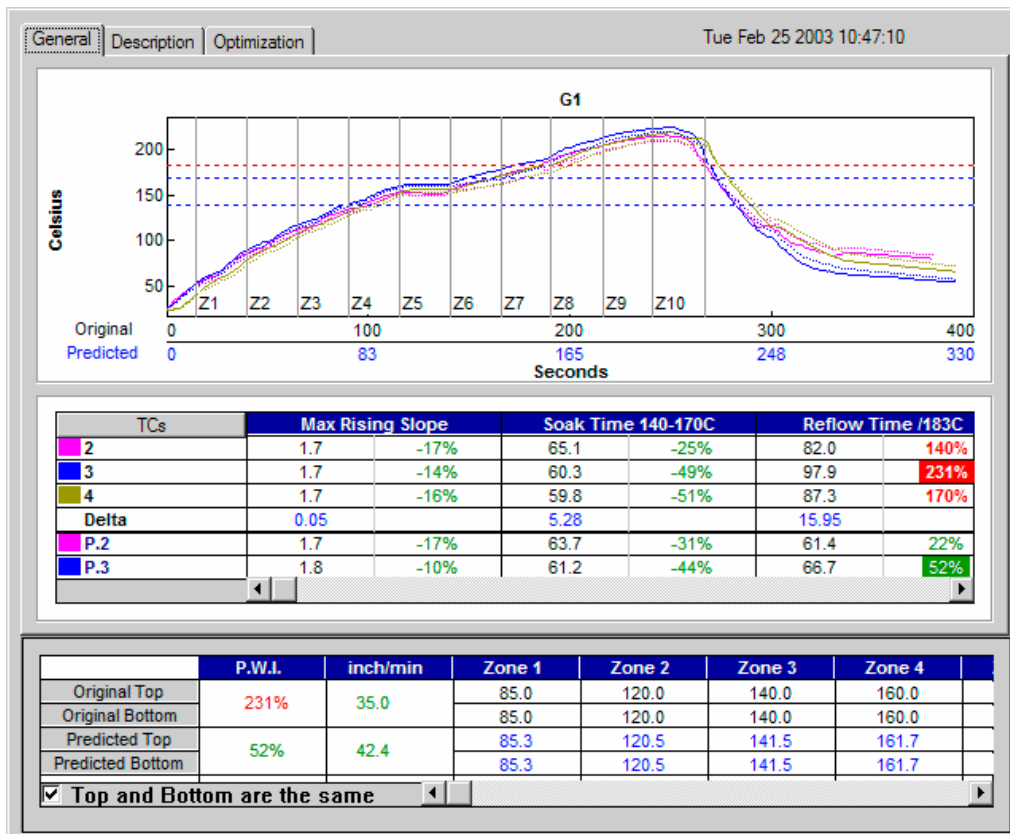
 Enter Product Weight (grams)



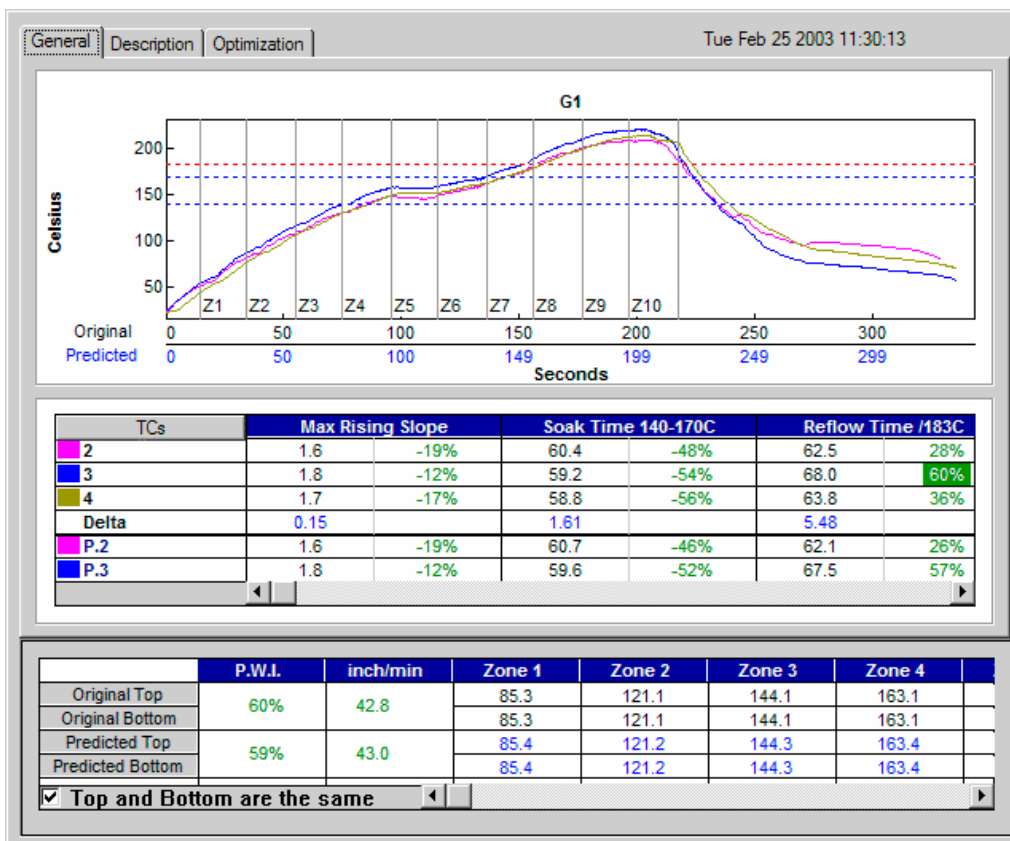
The Auto-Focus software option uses the length, width, and weight of the product to calculate a first oven recipe



On our first board, Auto-Focus did not suggest an oven recipe



This is the very first profile we ran. We simply used the oven recipe that the oven happened to be running. Notice that the PWI is 231%, well out of spec. The profile is spending too much time above the solder liquidous temperature of 183C. The spec is 40-75 seconds and the actual is 97.9 seconds.



This is the third profile run on Board #1. Notice that the PWI is now well in spec.

Confirm

ProductName: G3

Process Window: System Default

Application: Solder Reflow

Oven Name: BTU

Product Dimensions

Length: 8.25 (Inches)

Width: 11.25 (Inches)

Weight: 190.00 (grams)

Above are the dimensions for the third board

Auto-Focus ✕

Auto-Focus Successful!

The PWI is likely to be below 72%.

Use the Auto-Focus Oven Recipe?

On the third board Auto-Focus found an in-spec oven recipe

Product Name: G3

Confirm First Guess Recipe

Oven: Number of Zones:

Top and Bottom Setpoints are the same

Zone	1	2	3	4	5	6
Top	86	123	153	173	180	172
Bottom	86	123	153	173	180	172
Celsius	◀ ▶					

Conveyor Speed: inches/minute

Auto-Focus gives the user a chance to approve the oven recipe before the setpoints and conveyor speed are loaded into the oven control software

Once the oven was setup for the first board, we continued in the same manner setting it up for boards 2-10. Here are the results for the first 10 boards in the BTU oven:

BTU Paragon 150						
Board #	First Profile Predicted PWI	First Profile Actual PWI	Second Profile Predicted PWI	Second Profile Actual PWI	Third Profile Predicted PWI	Third Profile Actual PWI
1	None	231%	52%	102%	60%	67%
2	None	99%	17%	23%		
3	72%	62%	35%			
4	None	102%	41%	43%		
5	100%	83%	11%	20%		
6	134%	62%	29%	47%		
7	109%	65%	33%	42%		
8	90%	78%				
9	85%	100%	25%	28%		
10	83%	80%	36%	48%		

Results for the first ten boards on our BTU oven

Auto-Focus gave us a first oven recipe on the third board and on all the boards from the fifth through the tenth. Notice that on all but one board, the actual PWI for the first profile was less than Auto-Focus predicted it would be. We were very impressed that, after the first board, we never had to run more than two profiles to get the board in spec.

We can summarize the results for the first 10 boards as follows:

Board #	First Profile Predicted PWI	First Profile Actual PWI	Final Profile Actual PWI	Number of Profiles Required
1	None	231%	67%	3
2	None	99%	23%	2
3	72%	72%	62%	1
4	None	102%	43%	2
5	100%	83%	20%	2
6	134%	62%	47%	2
7	109%	65%	42%	2
8	90%	78%	78%	1
9	85%	100%	28%	2
10	83%	80%	48%	2
Average	96%	97%	46%	1.9

Observations:

- The average predicted PWI for the Auto-Focus “first guess” oven recipes was 96%.
- The average first profile PWI was 97%.
- The average final PWI was 46%.
- Using the KIC 2000 with Auto-Focus, it took an average of 1.9 profiles to find an in-spec oven recipe for each of these 10 boards.

The following table is a record of the progress of setting up the BTU oven for boards 11-20:

BTU Paragon 150				
Board #	First Profile Predicted PWI	First Profile Actual PWI	Final Profile Actual PWI	Number of Profiles Required
11	84%	49%	49%	1
12	84%	62%	62%	1
13	87%	74%	37%	2
14	67%	72%	59%	2
15	105%	66%	21%	2
16	82%	65%	65%	1
17	70%	51%	42%	2
18	112%	91%	76%	2
19	82%	73%	40%	2
20	72%	50%	50%	1
Average	84%	65%	50%	1.6

From the test results on boards 11-20, there were three impressive discoveries:

- Every single board was in spec on the first pass.
- It only took an average of 1.6 profiles to get the boards below the PWI goal.
- For every board, the PWI of the first profile was below what Auto-Focus predicted it would be.

After running these 20 boards, our Quality Assurance group feels confident that if the Auto-Focus “Expected PWI” is below 90%, we can safely run the board through our BTU Paragon 150 solder reflow oven without running a confirmation profile.

Vitronics Unitherm II SMR 1200N

The BTU oven is less than three years old and still fairly representative of the state-of-the-art in solder reflow oven technology. On the other hand, the Vitronics oven we are testing in is almost 8 years old and spent 6 years with a major contract assembler where double-shifts were common. We wanted to determine if Auto-Focus would be as successful on an older oven as it was on a much more modern oven.

We ran the same test in the Vitronics oven that we ran in the BTU, using the same boards and running them in the same order. Here are the results for the first 10 boards:

Vitronics Unitherm SMR 1200N				
Board #	First Profile Predicted PWI	First Profile Actual PWI	Final Profile Actual PWI	Number of Profiles Required
1	None	137%	76%	2
2	None	137%	34%	2
3	70%	77%	36%	2
4	None	94%	59%	2
5	101%	83%	8%	2
6	126%	43%	43%	1
7	117%	75%	32%	2
8	82%	107%	73%	4
9	102%	73%	54%	2
10	77%	57%	57%	1
Average	96%	88%	47%	2.0

The Average PWI for the first profile of each board is actually lower on the Vitronics than it was on the BTU, but this is mostly due to the first BTU profile for which Auto-Focus could not suggest an oven recipe. If this is removed, the results were about the same as they were for the BTU.

The results for boards 11-20 are as follows:

Vitronics Unitherm SMR 1200N				
Board #	First Profile Predicted PWI	First Profile Actual PWI	Final Profile Actual PWI	Number of Profiles Required
11	83%	55%	55%	1
12	88%	87%	49%	2
13	83%	32%	32%	1
14	61%	103%	53%	2
15	95%	15%	15%	1
16	74%	52%	52%	1
17	73%	49%	49%	1
18	123%	70%	45%	2
19	74%	56%	56%	1
20	57%	61%	61%	1
Average	81%	58%	47%	1.3

The averages were all slightly better on the Vitronics than they were on the BTU. However, there was one board that was out of spec on the first pass (Board 14=103%) on the Vitronics. All the boards were in spec on the first pass on the BTU. All in all, the results between the two ovens were fairly similar and to me show that Auto-Focus is working as advertised.

Conclusion

We are now able to answer the questions posed at the beginning of this paper:

- On average, how many profiles does it take to find a good oven recipe for a new product?

We setup an oven a total of 40 times and it took, on average, 1.7 profiles per oven setup. If we only look at the second 10 boards for each oven, the average was 1.45 profiles per oven setup.

- How many boards must I profile before Auto-Focus has enough information to give me a useful first pass oven recipe?

This will depend greatly on the range of boards to be profiled. Even if you profile 100 “heavy” boards, Auto-Focus will not specify an oven recipe for the first “light” board. However, in our tests with a fairly diverse set of boards, Auto-Focus was suggesting recipes after the first few boards and after the first 10 boards, the profiles were almost always in spec.

- Is Auto-Focus reliable enough to confidently setup the oven for a new product without running a profile?

In both ovens we ran a total of 20 boards. If we look at the second 10 boards in each oven we see that 19 out of 20 had a PWI less than 92% and only one board had a PWI over 100% and that was barely out of spec at 103%. It is our finding that with modern and well maintained solder reflow ovens and a typical leaded solder paste, the SlimKIC 2000 with Auto-Focus is a tool that can indeed setup an oven properly by simply measuring and weighing the board. And if the database of previously profiled boards is complete, the resulting oven recipe will not need to be verified by running a product thermal profile.

KIC has spent over two years developing this revolutionary tool and we have already won major industry awards for parts of this platform. We hope you will consider the SlimKIC 2000 with Auto-Focus as a way to improve your process setups and improve your quality.

Appendix

The SlimKIC 2000 “Oven Setup System” vs. Conventional “Thermal Profilers”

The Q/A department at KIC has the opportunity to test other brands of profilers to see how they compare. The biggest difference is that many other companies make “thermal profilers”, but the SlimKIC 2000™ is the only true “oven setup system”.

Setting up an oven with a conventional “thermal profiler” involves the following steps:

1. Using your skill and experience, determine a “first guess” oven recipe that is likely to process the board in spec.
2. Attach thermocouples to the product and record the thermal profile as the product passes through the oven.
3. View a display of the graph of the thermal profile and key profile statistics such as peak temperature and time above reflow. From this information, manually determine if the process is well enough in spec to start production.
4. If the process is not in spec, use your skill and experience to manually determine changes to the oven setpoints and conveyor speed that are likely to put the process in spec and go back to step 2.

Setting up an oven with the SlimKIC 2000 “oven setup system” involves the following steps:

1. Measure the length, width, and weight of the product and enter this information into the SlimKIC 2000 software. Auto-Focus will specify an oven recipe to use on the first profile along with the expected Process Window Index (PWI).
2. Attach thermocouples to a product and record the thermal profile as the product passes through the oven.
3. The PWI will automatically be calculated showing whether or not the process is in spec and by how much.
4. If the PWI is below the requirement, the process is setup. If the PWI is above the requirement and the Navigator option of the KIC 2000 software cannot lower the PWI, then there is no oven recipe capable of processing this product in spec. If the Navigator has specified an oven recipe that will lower the PWI, then load this recipe into the oven and go back to step 2.

The key advantages of the SlimKIC 2000 over the conventional oven setup method are as follows:

1. The final determination of whether or not the process is in spec is completely defined by a formula that does not require anyone’s *opinion*. If the PWI is below 100%, the process is in spec. The lower the PWI, the more in spec the process. Getting consistent results across all products, ovens, and factories is automatic.
2. The operator does not have to understand the relationship between oven setpoint temperature and conveyor speed, nor does the operator need to understand “rise time”, “soak time”, or “time above liquidous”. Yet, using the SlimKIC 2000, the operator can find as good or better an oven recipe than the most experienced expert.
3. With the SlimKIC 2000 and Auto-Focus, the operator is required to make only two decisions:
 - a. Which process window to use (they choose from a list provided by the engineer).
 - b. Where to attach the thermocouples to the board.

The SlimKIC 2000 then walks them through the oven setup process. In the end either they have found an “in spec” oven recipe, or the SlimKIC 2000 has determined that there is no oven recipe that will process this particular product inside the selected process window.

Note: If the SlimKIC 2000 is communicating directly with the oven, the operator will require far less training on the oven control software, and the chance of error introduced because the operator copied an incorrect value from the profiling software to the oven control software is completely eliminated.

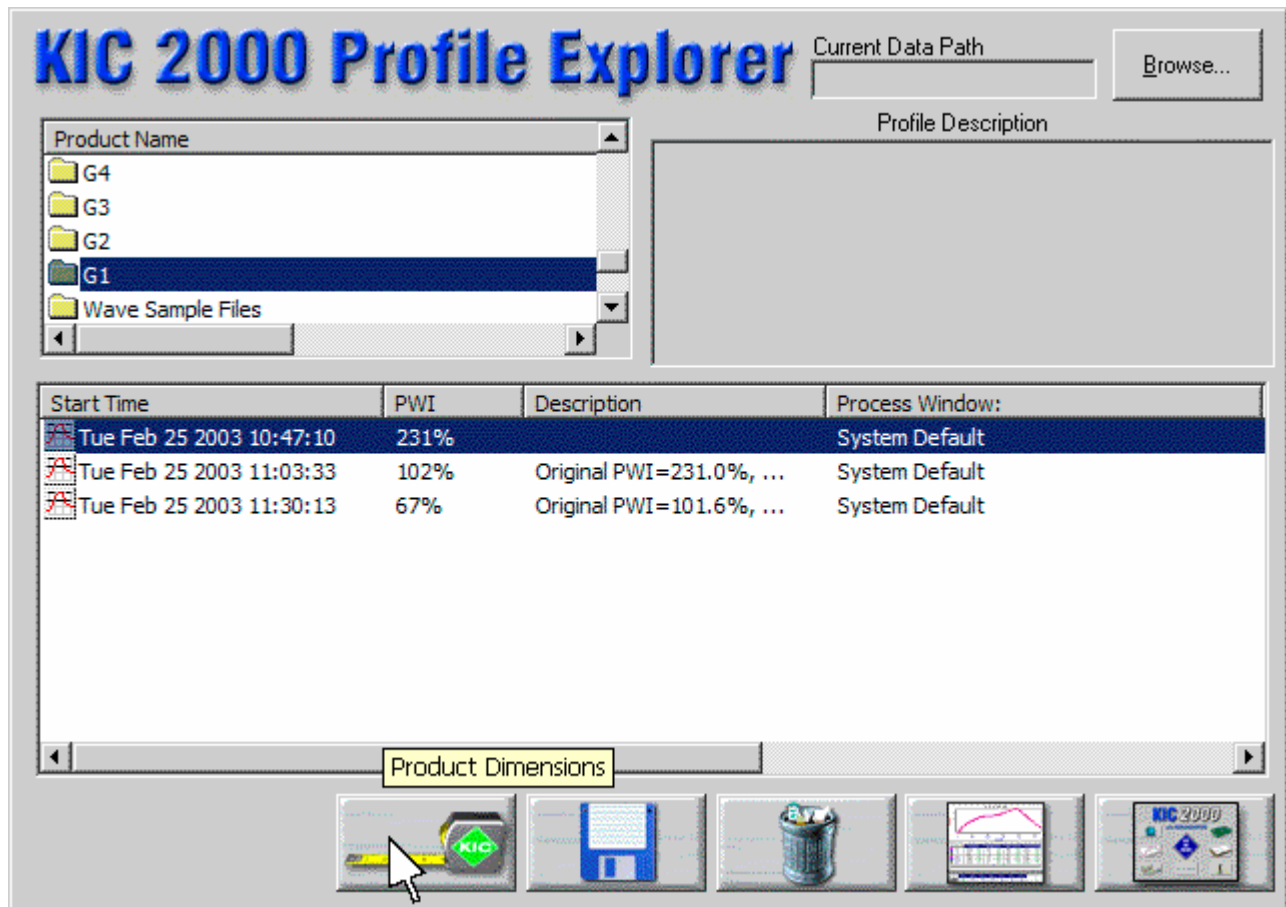
Tips

In running the tests for this report and in working with customers that call with problems, we have come up with a list of tips to help avoid the most common profiling errors. The results of this report would not be nearly as impressive if we did not follow these rules. It is important to note that Tips 1-4 apply to any profiling work performed and is not limited to KIC products:

1. **Thermocouple attachment** is extremely critical. Loose TCs will not give repeatable results from profile to profile and the predicted profiles will not be accurate. We attached all our thermocouples with a special aluminum tape¹ that provides an extremely reliable and repeatable thermal connection. The aluminum tape will typically last at least 5 profiles before needing to be replaced.
2. **Thermocouple placement** is also extremely critical. TCs must cover the entire range of temperatures on the board. Otherwise, the resulting PWI will not be the true PWI for the board and reflow related rework may still occur on what appears to be an in-spec process. Also, these profiles will distort the database and reduce the accuracy of Auto-Focus. When in doubt, add another TC.
3. **Oven stability** is extremely critical. The Oven control thermocouples must be within 2C of the setpoint temperature. If you run a profile before the oven is stable, then the Navigator will not predict accurately. Modern reflow ovens will typically control to within 1C. If this is not happening, you likely have something wrong with the oven.
4. **The board must be cool** before starting the next profile. We are careful to let all the thermocouples on the board get to within about 3C of the air TC temperature before starting the next profile. Starting a profile with a hot board will reduce the accuracy of the profile predictions.
5. The **Oven Name** should be consistent because Auto-Focus only uses boards in the database that have the same oven name as the new board. If the KIC 2000 software is communicating with the Oven Control software, then this is simply a matter of giving your oven a name when you first install the KIC software, and never changing this name. In this case the oven name is set in Global Preferences. However, if the KIC 2000 software is not communicating with the oven controller, it is very important that you always use the same oven name for each oven you profile. In this mode, the oven names are in a drop down list to help reduce the confusion.
6. The **product length, width, and weight** must be entered correctly or the accuracy of Auto-Focus will be reduced.
7. Auto-Focus and Navigator **Conveyor Speed Constraints**. Both the Auto-Focus and Navigator allow you to define the maximum and minimum conveyor speed. We found on the Vitronics oven that the Navigator would give us somewhat lower PWI's if we set the maximum conveyor speed to 45 inches/minute. This did not make any difference on the BTU.

Taking Advantage of Your Existing Profiles

If you already own an earlier version of the SlimKIC 2000, you can add the length, width, and weight information to your profiles using the “Product Dimension” button on the Profile Explorer.



Auto-Focus will immediately take advantage of all such updated profiles to give you your next first recipe

References

1. Cameron Sinohui, "[A Comparison of Methods for Attaching TCs to PCBs for Thermal Profiling](#)", Presented at Nepcon West 1999
2. Jim Hall and Phil Zarrow, "[PWI: Process Optimization Made Simple](#)", Circuits Assembly Magazine, February 2002

Additional materials and resources on PWI can be found at: www.kicthermal.com/pwi

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