Integrated Profiling for the Reflow Process

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Abstract

Recent advances in reflow technology have made it possible for cutting edge thermal profiling software to interface with modern furnace controllers. This paper will discuss the reasons thermal profiling has become critical, the process by which thermal profiling software was integrated with a furnace controller; the advantages of this new technology; and methods for using it to increase reflow yields.

The thermal profiling software/furnace controller interface's key feature is a simplified user interface which will allow minimally trained operators to setup solder reflow systems to process products within spec. This technology will be of interest to any SMT Process Engineer or SMT Manufacturer seeking to improve their solder reflow process and lower their operating expenses.

Introduction

In the new century individuals responsible for soldering processes will be faced by several significant challenges. The continuing outsourcing of a high percentage of SMT assembly to CMCs has created an extremely competitive contract assembly market that requires optimized process efficiency. A tightening labor market: professional, skilled, and unskilled, will also present new challenges to industry managers. Lead-free solders presents another challenge, and will require much more precise process windows, which in turn will require increased levels of thermal process performance.

Contract Manufacturing—The Quest for Efficiency

Approximately 40% of SMT assembly is currently outsourced, and the CMC (Contract Manufacturing Company) sector of the electronics assembly market is currently growing at a rate of better than 20% annually (See Fig. 1). The key to the growth of the CMC market has been increased production efficiency based on running assembly lines full time at maximum throughput. OEMs generally had lines dedicated to a single product, and these lines were run based on demand for product—when demand fell off, the line stopped running. Dedicated lines allowed production engineers the luxury of fine-tuning their processes, and once a line was dialed in for its dedicated product, all that was required was to monitor the line's performance. This was generally done by monitoring the quality of the product coming off the line and performing preventative maintenance at specified intervals. Dedicated lines allowed OEMs to assure the quality of their product, but the downside was that expensive capital equipment and human resources were often idled.

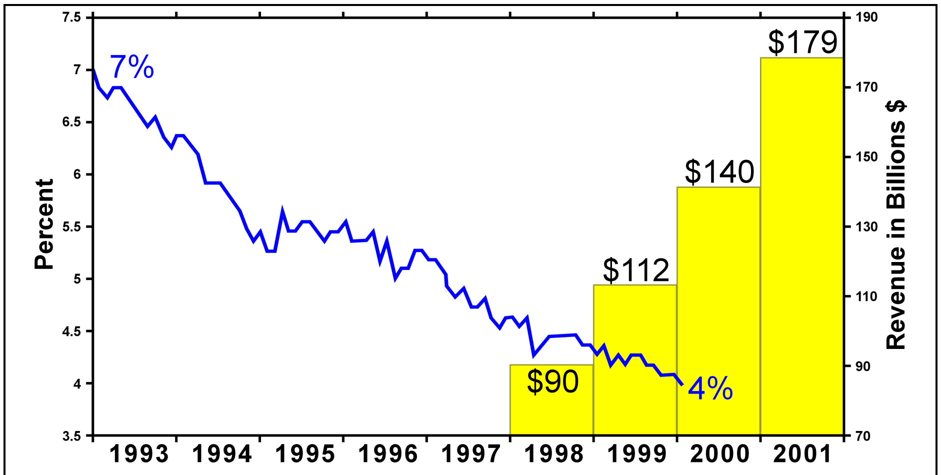

Figure 1: Growth of the CMC Sector

Contract Manufacturers have taken advantage of the inefficiencies of dedicated lines by developing highly flexible lines that run job lots of product. When one job is completed, the line is immediately shifted to the next job. Competition in the CMC industry is fierce and profit margins slim. A competitive edge is maintained by minimizing human resources, and this means that CMCs don't have the luxury of fine-tuning production. Processes must be set up quickly and efficiently in order to keep the lines running, and yet at the same time, quality must be assured. This makes line changeover time a critical factor in maximizing line efficiency.

Maximizing Human Resources

Further complicating the Contract Manufacturer's task is a booming economy that has produced historically unprecedented employment rates. Employee's frequently job-hop, and high employee turnover wreaks havoc with productivity in a technologically sophisticated industry. New employees require expensive training, and often it seems that as soon as they are up to speed, they move on to another job. High employee turnover also means a shrinking base of knowledge in CMC facilities. At OEMs, production problems are solved by experienced senior personnel with years of accumulated process knowledge. CMCs often don't have this knowledge base to draw on, especially in regards to specific assemblies. The problem is further exacerbated by the fact OEMs have a limited number of product processes to master, while CMCs are expected to successfully process up to several hundred products a year. This situation has left CMCs in a "Catch-22" situation: experienced personnel drive up production costs; inexperienced personnel can have a negative effect on productivity and product quality.

Another factor that has had a profound influence on the contract manufacturing industry has been the development of the "high-mix" business model. A high-mix assembly facility pursues contracts for small job lots, which have been shown to offer higher profit margins than low-mix, high volume assembly contracts. To take advantage of there higher profit margins, CMCs must have lines and equipment that are flexible enough to be reconfigured as often as several times a day.

For CMCs, tools to improve process efficiency have become essential. For the thermal portion of the electronics assembly process, tools are now available that can identify robust profiles that process multiple dissimilar products and increase throughput by finding optimal recipes. Simplified operator interfaces allow minimally trained operators to setup profiles, and for "high-mix" production, these tools can dramatically reduce line changeover times for the thermal process. Use of these tools will be a key difference between profitable CMCs and the others whose lines they acquire.

The Lead-free Challenge

It is almost certain that lead-free electronic assemblies will be mandatory by 2004 for companies exporting their products to Europe, and probably will be mandatory for the Japanese market as well. Currently available lead-free solders have a solidus/liquidous point about 20-50°C higher (depending on the alloy) than the leaded pastes currently in use. The primary challenge lead-free solders will present electronics assemblers with is higher process temperatures. The current thermal process window is a wide one, with the extreme lower limit of Sn63/Pb37 set at 183°C (a lower limit of 200-205°C is the most common setting), the eutectic temperature of this leaded solder, and the high limit at 235°C, which is the maximum temperature that some sensitive components can be exposed to. These high and low process limits provide a Delta of over 50°C—wide enough that a carefully monitored process can be expected to produce low defects and high yield with little fear of defects caused by process drift.

With lead-free assemblies, the process window will shrink dramatically. With the Bismuth alloys favored by Japanese assemblers (206-213°C liquidus), the window will shrink by half, to a Delta of 22-29°C. Using the more reliable Sn/Ag/Cu alloys (217°C liquidus), the window will be cut down by 65% to a Delta of 18°C. Given that few assemblers want to get within 5°C of their control limits, the true process window with Sn/Ag/Cu alloys will be approximately 8°C. This very narrow process window is the problem that will confront electronics assemblers making the shift to lead-free production, and the window is unlikely to open wider in the near future. (See Fig. 2).

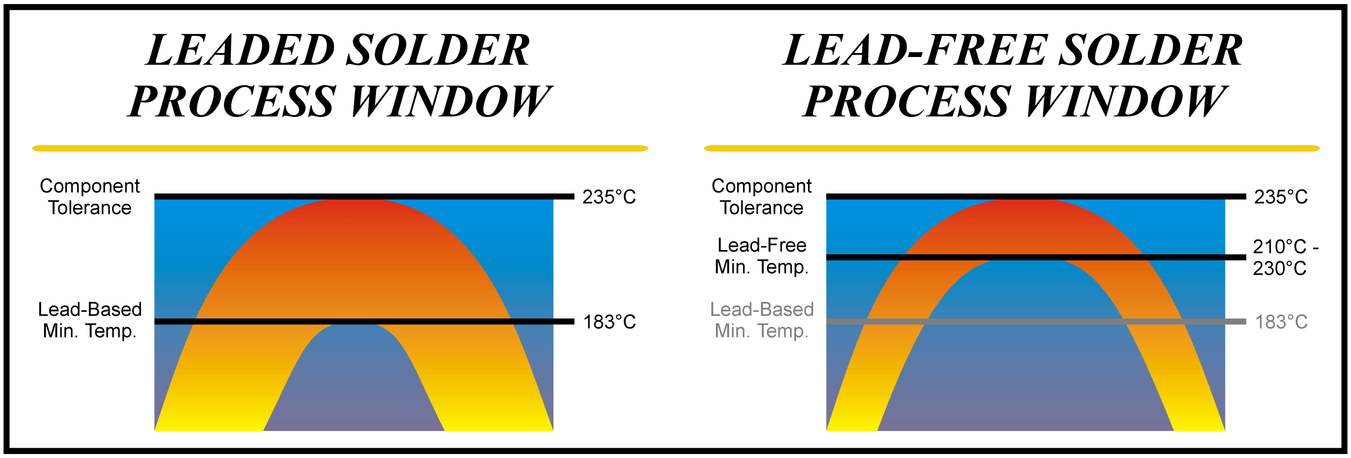

Figure 2: The Lead-free Process Window

It is widely acknowledged that the component sector is lagging behind assemblers, soldering materials, and soldering equipment in being prepared for the shift to lead-free assemblies. Component manufacturers are faced with a three part challenge: they must remove lead from their products; they must develop leads that are compatible with lead-free solders; and eventually they will need to develop components with higher temperature tolerances. The first two tasks must be completed in order to successfully assemble products which meet the European standards. This leaves the question as to whether component manufacturers will be able to raise their temperature tolerances in the short term. In the longer term, the question will be whether raising the process temperature limits of components will be economically justifiable or even necessary.

The problem of narrow process windows will be further exacerbated by the trend to more complicated assemblies with increased component density. Finding a profile that will reliably reflow these assemblies, especially larger ones which can experience large peak temperature Deltas across the board, has never been easy. Real world production issues like maintaining high throughput and minimizing oven changeover times between production runs also figure into the equation. The Lead-free Challenge will be to find and utilize technology that will allow electronics assemblers to define and maintain optimal thermal processes in the drastically reduced Lead-free process window. The increase in peak process temperatures, combined with the trend to components of decreasing size and robustness, means that precision tools will be required to find profiles that will safely process product at the higher temperatures required by lead-free solder.

Developing the Integrated Thermal Profiler

The sum effect of the trends and factors discussed above is that the thermal process, which some electronics assemblers have neglected in recent years, will again become the object of industry wide focus. The need for real-time continuous monitoring and documentation of processes will be greater that it has ever been before. Manufacturers will require both cutting-edge engineering technology and user-friendly operator interfaces. The key to successful thermal profiling in the Twenty-first Century will be combining the two.

In the fall of 1998, the solder reflow furnace industry leader approached the thermal profiling industry leader. The furnace manufacturer proposed a joint effort to automate the thermal profiling process. Several components had to be in place before this technology could be implemented. The key components were: highly reliable and repeatable reflow furnaces; an accurate and efficient profile prediction tool; a software interface to allow the thermal profiling software to communicate with the furnace controller; and a significantly simplified user interface.

A highly efficient, repeatable and reliable reflow furnace is the foundation on which this automated thermal profiling process is built. Advances in forced impingement convection and atmosphere control will allow Lead-Free users to reach the higher peak temperatures required while not exceeding the narrow process window. The use of efficient convection heat transfer and closed-loop blower speed control also increase the flexibility of the reflow furnace. In the past this has allowed users to process dissimilar products at common thermal setpoints while only varying conveyor speed. To reap the full benefits of the automated thermal profiling process furnace to furnace and run to run repeatability must be at acceptable levels. This allows for duplication of thermal setpoints from one line to another for a given process. Furthermore, run to run repeatability allows for the translation of thermal setpoints from one product to another similar product with little further optimization required. (See Fig 3).

Figure 3: Typical Forced Convection Reflow Furnace

Automated Profile Prediction

The first automated prediction tool was released in 1997. This breakthrough technology was capable of formulating over a hundred potential profile recipes per second, evaluating the recipes, and ranking them. This tool was capable of finding optimum oven setups that would yield a profile in the center of the process window, as well as the recipe with the highest possible conveyor speed to maximize throughput. Another capability included finding common recipes to process dissimilar products. With the automated prediction tool, users were able for the first time to know that they had found an optimal furnace recipe for a given product.

One issue with the original automated profiling tool was that it required an expert operator. With a ten zone furnace, there are literally billions of possible combinations of zone setpoints and conveyor speeds. To search all of these would take several days, so the operator was required know enough about thermal profiling to be able to tell the automated prediction tool which range of combinations of zone setpoint and conveyor speed to search in order to get a solution in a reasonable time. Furthermore, once an optimal furnace profile had been identified, it had to be manually transferred to the oven controller. This task could take a few minutes and there was always the possibility of transposition errors.

The latest release of the automated profiling tool offers several significant improvements. The KIC Navigator is an integrated software package that includes an automated prediction tool that is exponentially more powerful and accurate than any tool currently on the market. The improved automated prediction tool is capable of automatically searching the entire range of possible recipes in less than a minute, so operators no longer need to set search parameters. The software package also includes a comprehensive database of solder paste specifications, including specs for the new lead-free solder pastes from all major manufacturers. The operator selects the solder paste being used from a drop down menu, enters any non-solder paste related process limits, runs a profile, starts the automated prediction tool, and in seconds has an optimal profile that is custom designed for both the oven and the product. A pass through profile is run to confirm that the oven settings are correct and then the oven is ready for production. Because the improved automated prediction tool has searched the entire range of possible oven setups, users are assured of finding the best possible profile.

The automated prediction tool is designed to center the profile in a process window defined by the solder paste specification and the user defined input process limits. This is done by ranking potential process profiles with a "Process Window Index" (PWI). The Process Window refers to how well a given profile "fits" the critical process statistics. A profile will process product without exceeding any of the critical process statistics is said to be inside the Process Window. Most profiling technology is capable of telling the user whether they are in or out of the Process Window (although it generally isn't capable of telling users how to get their profile into the process window.). The "Process Window Index" goes several steps beyond telling the user whether they are merely in or out of spec. The "Process Window Index" uses the input process limits to numerically rank profiles based on how well they fit the user defined process window. A "Process Window Index" of 100 or more indicates that the profile will not process product in spec. A "Process Window Index" of 99 indicates that the profile will process product within spec, but it is running at the very edge of the Process Window. A "Process Window Index" of less than 99 indicates that the profile is in spec and tells users what percentage of the process window they are using: for example, a PWI of 70 indicates a profile that is using 70% of the process spec. (See Figure 4) The PWI tells users exactly how much of their process window a given profile uses, and thus how robust that profile is. The lower the PWI, the better the profile. A PWI of 100 is risky because it indicates the process could easily drift out of control. Most users seek a PWI of below 80, and with the improved automated prediction tool, profiles with a Process Window Index between 50 and 60 are commonly achieved (if the furnace is sufficiently flexible and efficient).

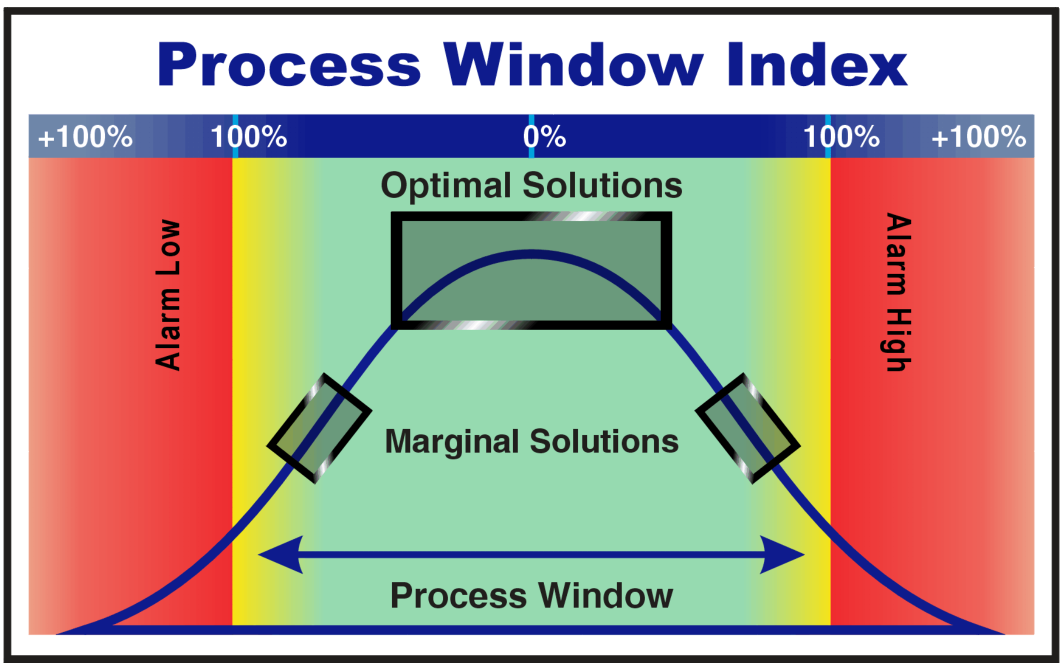

Figure 4: Process Window Index

An example of how the improved automated prediction tool works would be the sensitive components mentioned in the section on lead-free solders above—if the assembly can't see temperatures above 235°C, but must see peak temperatures above 225°C to reflow properly, the automated prediction tool will find the optimal profile and center it between the high and low process limits, giving users the most robust profile their oven is capable of achieving. The integrated software package also automatically exchanges zone setpoints and conveyor speed between the profiling software and the oven controller, eliminating any potential for data entry errors.

Self-Profiling Solder Reflow Furnace

Even more revolutionary than the improved automated prediction tool is the KIC Pilot, which is an automated self-profiling software that interfaces directly with the furnace controller. The improved automated prediction tool will find the optimal profile for a given product, but requires an experienced operator or engineer to do so. The self-profiling furnace is the next evolutionary step in thermal profiling, in that it does not require an expert or even experienced operator to profile the furnace. This software features a dramatically simplified user interface which will allow a minimally trained operator to set up a profile by merely selecting a pre-profiled product from a menu. The software will automatically change the furnace setpoints and conveyor speed, and then let the operator know when the furnace is ready to run production. (See Fig. 5).

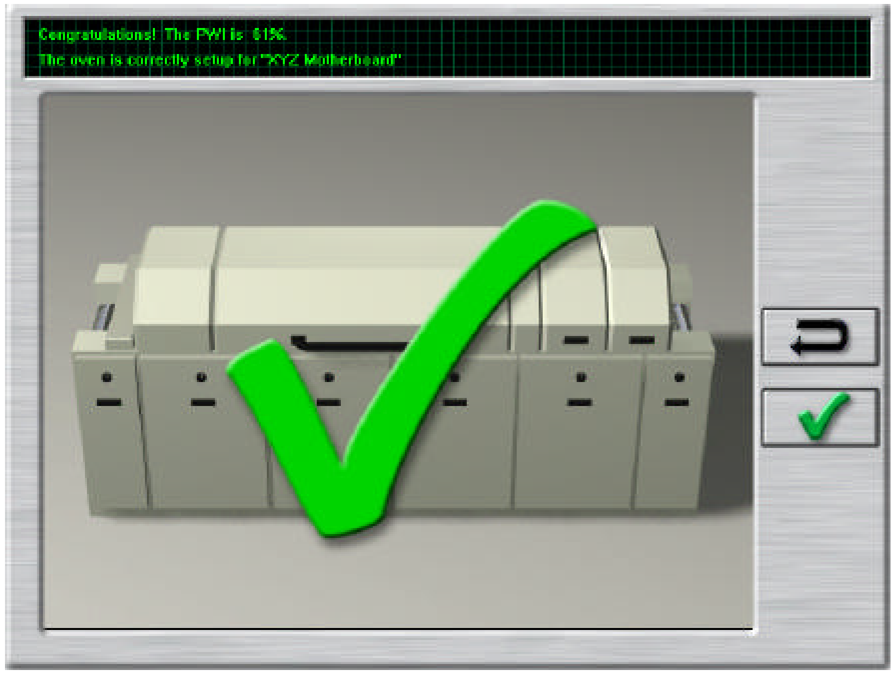

Figure 5: Self-Profiling Furnace—Furnace OK Screen

If a new product needs to be profiled, this software will allow a minimally trained operator to setup the solder reflow furnace. The operator will not have to understand thermal profiling, or terms such as "peak temperature", "time above reflow", "max slope" etc., or even how to input a zone setpoint temperature or conveyor speed. A series of animations will show the operator exactly how to complete the profiling process (See Figure 6). The only things the operator will need to know how to do are attach thermocouples to a PCB, run the PCB through the furnace, and catch it at the other end. The only decisions the operator makes are which product to run, where to place the thermocouples on the product, and which preset process window to apply to the profile. This revolutionary product utilizes the improved automated prediction software discussed above and will deliver the best profile the oven is capable of. Conventional thermal profiling software will be running in the background and be available for an "engineer" so they can input process window limits and view the profiles that have been run by the operator.

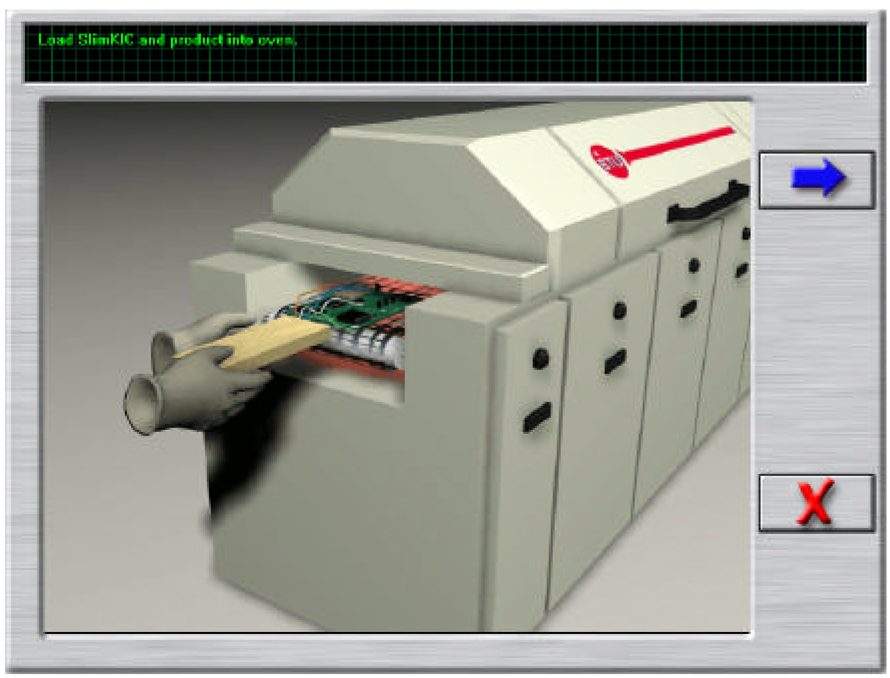

Figure 6: Self-Profiling Oven--Animated "Start Profile" Screen

The key to understanding the revolutionary capabilities of the self-profiling furnace is simple. Up until now, the operator has been responsible for controlling the furnace. Now, the furnace has the intelligence to tell the operator how to set it up, and will not allow the operator to run product if the profile is out of spec. In effect, the self profiling furnace's intelligent system controls the operator.

Conclusions

For many years the "Holly Grail" for the thermal process has been the "self-profiling oven." The conventional method of thermal management for the reflow process has been to use a pass through profiler to set up the oven and monitor its performance. In recent years, advanced profilers have allowed users to optimize their processes, but users are still required to make changes to the oven's setpoints manually.

Now an interface has been developed that allows profiling software to "talk" to the furnace controller. With these challenges surmounted, the self-profiling furnace has been developed. One key to this revolutionary product is a thermal management software/furnace controller interface, which also features a dramatically simplified user interface. The other key is the ability to define a profile's "Process Window Index" which ensures that a profile is the best possible one for a given product. The combination of the simplified operator interface, the profiler/furnace controller interface, and the "Process Window Index" allows a minimally trained operator to setup the solder reflow oven better than the most expert operator could previously, and to do it in just a few minutes. This state of the art profiling technology offers CMCs and OEMs alike a multitude of benefits:

- Advanced thermal profiling software features tools that can improve process efficiency by finding robust profiles that process multiple dissimilar products and allow increased throughput by finding optimal recipes.
- The improved automated prediction tool will make it possible to develop optimized profiles to meet the higher peak temperatures required by lead-free solders without damaging sensitive components.
- A tightly controlled thermal process can significantly reduce solder joint defects and the expensive rework associated with them.
- The self-profiling furnace allows users to changeover the line to a new product in minutes.
- The self-profiling furnace will not allow an operator to run product if the profile is not within spec.
- Use of a state of the art thermal profiling systems has become an industry wide indicator of dedication to quality and is used by many leading CMCs to assure their customers that production meets the highest quality standards.

With the self-profiling furnace, electronics assemblers will be able to meet the challenges of the new millennium by increasing efficiency, maximizing human resources, and achieving unprecedented levels of reflow process reliability.

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