# Firing Thick Films in a Muffle-less Furnace with Real-time Process Monitoring

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## The Thick Film Process

In thick film production, few factors are more critical than establishing and maintaining an appropriate thermal profile for the firing of a product. The thick film process typically involves screen printing conductors, resistors, dielectrics, and glazes onto alumina, aluminum nitride or beryllia ceramic material. The printed material is then dried and fired at high temperature to bond it with the ceramic substrate. Firing temperatures range from 600C to 1000C, depending upon the type of material used. Multiple layers of material are printed, dried, and fired sequentially, beginning with the paste requiring highest processing temperature and ending with the paste requiring the lowest. The ability to precisely define, control, and monitor the thermal profile a product experiences as it travels through the furnace is paramount to the success of the process.

This paper will introduce tools for improving the thick film firing process and discuss how they may be used. It will conclude with a case study done at EMC Technology LLC, a Cherry Hill, New Jersey based company specializing in the production of thick film components for RF and microwave devices that are used in the telecommunications and aerospace industries.

## The Advanced Design Muffle-less Furnace

The advanced muffle-less furnace is designed specifically for thick film firing. The elimination of the metal muffle, its associated mass and thermal expansion allows the furnace to heat-up and cool rapidly. The furnace is capable of heating up from ambient to 900C in less than 10 minutes. Significant energy savings can be realized by shutting down the furnace during non-production periods such as nights and weekends. The cooling and heating characteristics of the low-mass process chamber allows rapid changeovers between thermal profiles. The flexibility of the muffle-less design is a valuable feature for both high volume and high-mix producers.

In 1980, the introduction of the first advanced muffle-less furnace marked a revolutionary shift from the traditional means of firing thick film in quartz or metal muffle furnaces. In 1996, the furnace was upgraded to meet the demand for tighter thermal profile process windows and to address cost of ownership (COO) issues such as energy efficiency and climate control costs. Improvements to the original muffle-less design include an improved insulation system, which increases energy efficiency by minimizing heat loss from the process chamber. The furnace enclosure is vented through a powered exhaust duct located at the top of the enclosure with make up air drawn from ventilation ports strategically located in the side panels. This system draws the heat lost from the furnace out of the production area, minimizing the cost of furnace operation in a climate-controlled environment.

The furnace's fully enclosed coil (FEC) heaters have been redesigned to provide optimal top/bottom heater power distribution. Balanced heater power distribution minimizes the thermal shock to the product while maintaining thermal uniformity, resulting in longer heater life and superior heat transfer uniformity. The heater power control configuration has been upgraded to provide independent, vertical, left-center-right (L/C/R) cross belt control, and an optimized temperature control algorithm enables the system to respond quickly to heavy loads while maintaining a tight thermal profile. The combination of improved heater design, control configuration, and software enhancements allow for cross belt uniformity within ±1C in the firing section on a 25 inch belt (see figure 1). While less modern furnaces often experienced variations in stability as high as ±20C, the advanced muffle-less furnace has passed rigorous stability tests, beating its own guarantee to maintain the firing section temperature within ±5C by holding to ±2C when tested at normal firing temperatures. Cross belt thermal uniformity and firing temperature stability are essential to produce high tolerance resistors with low thermal co-efficient of resistance (TCR) values. This minimizes the amount of laser trimming required to bring the resistor values within required specifications. The result is lower production costs, higher yields and throughput, and most importantly, superior product performance.

  

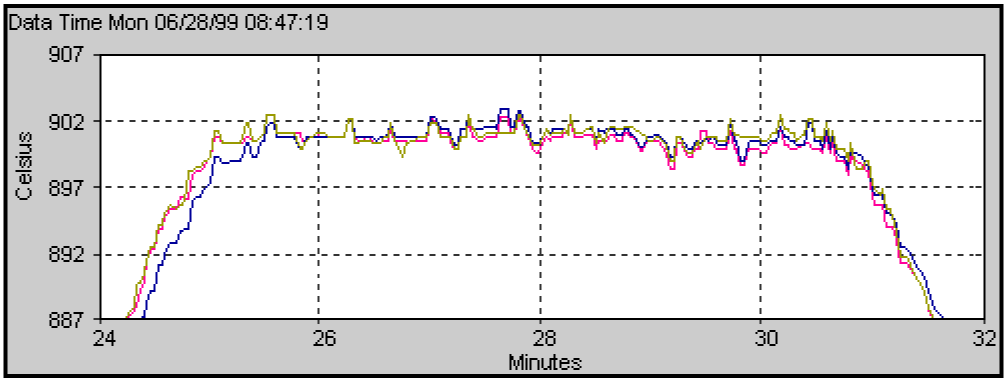

*Figure 1*

Another critical factor in the Thick Film firing process is effective process atmosphere distribution and burn out effluent removal. The organic materials in the dried thick film inks are burned out between 300-500C. It is essential that the furnace be able to provide a significant volume of uniformly distributed clean dry air (CDA) to the product during this stage of the process. The advanced muffle-less system utilizes a laser drilled quartz distribution tube with left/right flow control valves to provide uniformly distributed CDA in the burn out section of the furnace. The burn out effluent must then be effectively removed from the process chamber to prevent contamination of the firing section atmosphere. This is accomplished by two eductor powered exhaust plenums. These plenums, which extend across the entire width of the belt, have been designed utilizing a state of the art fluids analysis program to provide uniform and efficient draw of burn out effluents from the process chamber (see figure 2). Firing section atmosphere is introduced in the cooling muffle of the furnace through a multi-stage directional diffuser assembly and flows counter to the direction of belt travel (see figure 3). This counter flow prevents the migration of burn out effluents from the firing section of the process. If they aren't properly burned out and removed, these effluents will prevent the proper firing of the thick film materials, reducing yields as well as overall product reliability and performance.

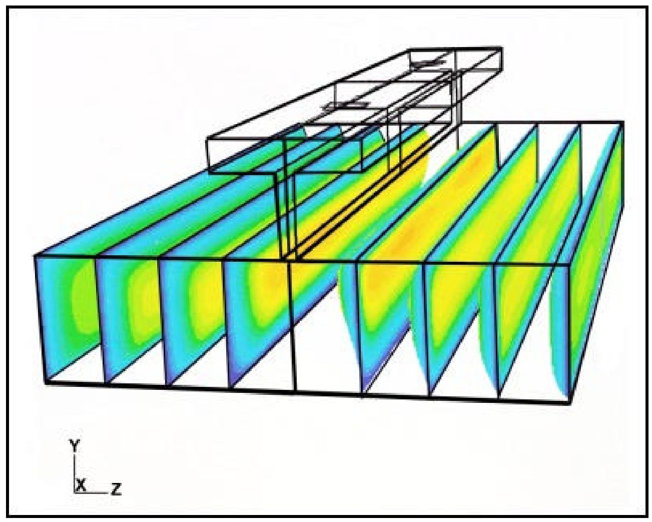

*Figure 2*

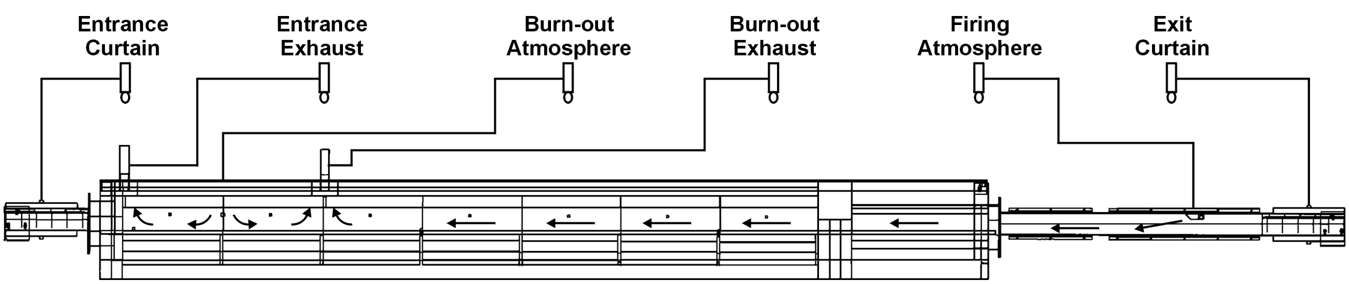

*Figure 3*

  

# Real-time Thermal Manager

One problem that plagues thick film manufacturers is production disruptions caused by constant thermal profiling. This problem is solved by the real-time thermal manager. There is no way to avoid running a trailing wire in the setup of a furnace, and to initially setup the thermal manager, but the real-time thermal profiler provides a simple and cost-effective way to significantly reduce the number of costly and time consuming confirmation profiles. The real-time thermal manager has thirty thermocouples that are permanently mounted in two probes (5/8" diameter stainless steel tubes, each containing fifteen internal thermocouples) at the conveyor level in the furnace. These sensors continuously monitor process temperatures along the full length of the conveyor, taking readings at rates of up to one per thermocouple every five seconds (see figure 4). Temperatures are continuously displayed as "Process Profiles" on a PC running a Windows based software package and data is permanently recorded on the hard disk. During production, any temperature drift and its location is instantly visible. Because the Thermal Manager is outside the oven control loop, it can reveal critical process temperature deviations that are often hidden from the oven control thermocouples (for example, in the case of EMC Technology, the high amount of drift in their original furnace would have been instantly identified).

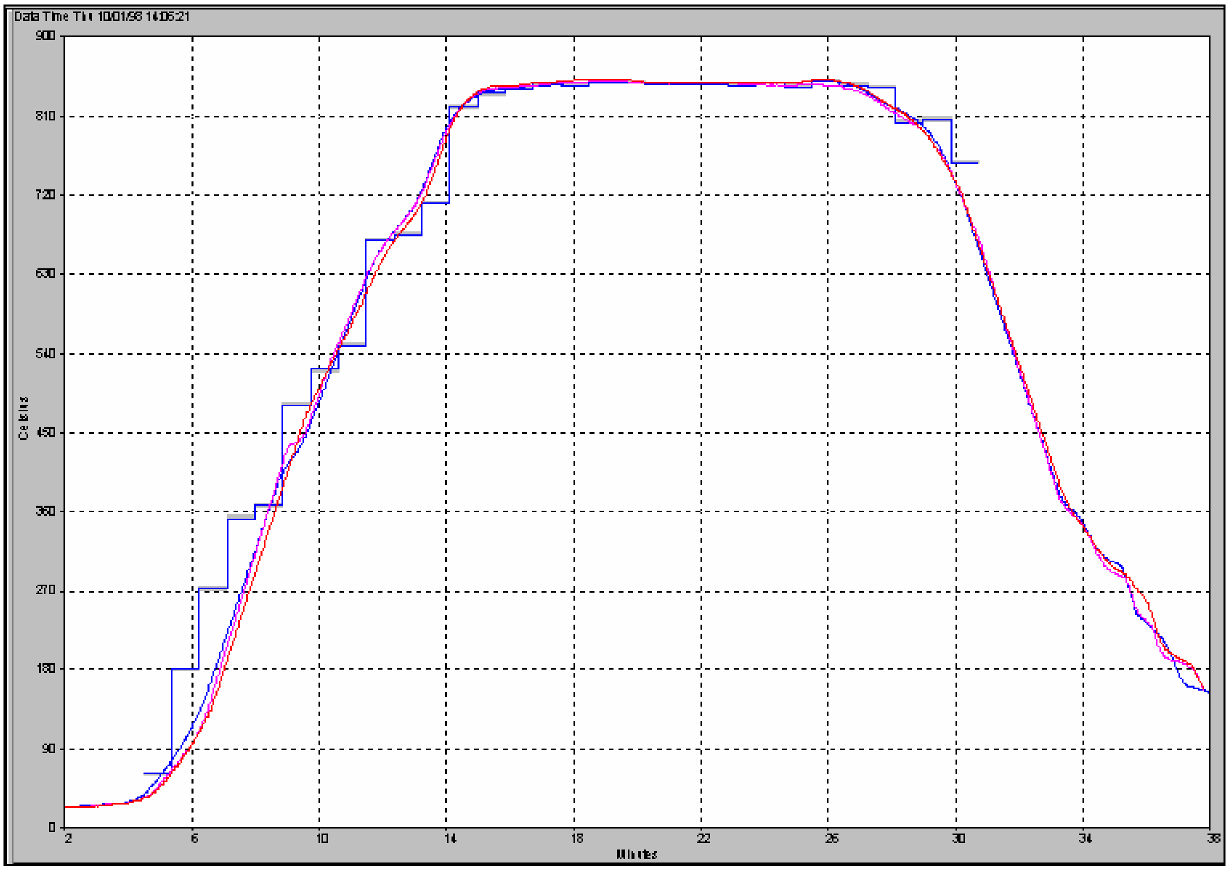


*Figure 4*

Additional features available with the thermal manager include Live Data Output; Auto-Predict; Product Sensors; and Barcode Reader Software. Live Data Output makes process data instantly available for export to a spreadsheet or SPC program. This option is especially valuable for achieving ISO 9000 certification. Live data can also be delivered via an intranet or the internet to offsite locations for remote process monitoring. The Auto-Predict option will calculate thousands of possible zone set point and belt speed combinations and then select the recipe that best fits process specifications, totally eliminating trial and error guesswork from furnace setup. Product sensors display the amount of product in the furnace, monitor belt speed, and provide a lost product alarm should product fail to exit the oven. Barcode reader software offers users total process trace ability, permanently recording the thermal profile of every product processed.

The real-time thermal manager also streamlines the setup of new processes. The Prediction Tool, included in the thermal manager software package, shows how changes to furnace set points or belt speeds will affect an existing profile. An Auto-Predict Tool, available as an option to the Thermal Manager, automatically sorts through thousands of potential furnace recipes and finds the optimal furnace recipe. The Auto-Predict option is capable of ranking potential recipes in terms of total degrees changed in oven setpoints or maximum belt speed. With critical thermal process specifications entered, the automated prediction tool can rank recipes on the basis of how much of the process window they use.

## Low Yields, Low Throughput

EMC Technology LLC manufactures a wide variety of thick film products including terminations, attenuators, baluns, and hybrid couplers utilizing platinum, gold, silvers, and various resistive and dielectric materials. Primary lines are thick film attenuators for base stations and satellites; other lines include big flange, little flange, discreet resistors, and capacitors. The problem EMC Technology faced was a thermal process with high defect rates and low throughput. The unacceptable defect rates were traced to an outdated furnace with limited thermal control. The original furnace at EMC Technology was an older model with only four controlled heating zones. The limited number of controlled zones made it very difficult to control the heating and cooling rates of the firing profile. As a result, the product experienced significant thermal shock resulting in poor yields due to substrate cracking.

Low throughput was due to three factors:

- Insufficient furnace capacity
- A large number of product profiles requiring frequent oven recipe changeovers
- The need to run a confirmation profile every time the oven recipe was changed

The length and width of the process chamber, as with any continuous furnace, inherently limited the original furnace's throughput capacity. It was however the lack of thermal control and flexibility that ultimately eroded throughput to unacceptable levels. Special profiles were required for the various size and thicknesses of the ceramic substrates in order to minimize substrate cracking and maintain acceptable firing results. EMC Technology's in-house preventative maintenance procedures required a profile once a month and any time the furnace experienced a profile change. Because of the high number of oven changeovers and resulting confirmation profiles, the furnace was commonly down for 25% of the day shift.

This requirement to change profiles made the firing furnace the point of constraint for the whole plant and raised significant throughput issues.

The trailing wire profiles also revealed the furnace was unable to provide and maintain a stable and repeatable profile. Fluctuations in actual thermal profiles were confirmed by changes in product performance and yield. Considering the time lost to daily profile changes and poor production yields due to substrate cracking, the cost of ownership of this furnace was very high.

## The Solution

The solution to EMC Technology's throughput and yield problems required two elements: an advanced muffle-less furnace and a real-time thermal manager. As a result of acquiring the BTU Fastfire muffle-less furnace with a KIC Prophet System, EMC Technology has reduced the number of profiles used in production from 22 to 2 and increased throughput by 75%. Ceramic breakage has been reduced to less than 1%. In the two years since the furnace was purchased, the manufacturer has experienced over 13,000 hours of trouble free production operation, and operators are smiling now that they don't have to profile the furnace several times a day.

EMC Technology found the real-time thermal manager's profile prediction tool to be accurate within ±10C, an error of only 1% on a 950C profile. Using the prediction tool, a new product profile could be found and verified to be good after two trailing wire profiles — a significant timesavings over the old trial and error method of profiling. EMC Technology reduced the number of product profiles required dramatically by using the prediction tool to identify defect-free generic profiles that would process multiple products. The combination of the stable and repeatable furnace and the prediction tool allowed EMC Technology to quickly reduce 7 glazing profiles to 1 and 15 firing profiles to 1.

The thermal manager is also used as a preventative maintenance tool. Because the thermal manager is capable of instantly detecting any change in process temperature, operators can service the furnace when it needs to be serviced rather than relying on a rigid and inefficient schedule. Many of EMC Technology's customers specify that the furnace be verified monthly, and verification is easily documented by the thermal manager's event browser, which automatically creates a permanent record of every profile.

EMC Technology installed an advanced muffle-less furnace to increase throughput, as well as to obtain a stable and repeatable thick film firing process. They installed a continuous real-time thermal manager on their new furnace to increase throughput by avoiding repeated profiling and gain the capability to verify their process instantly at any time. Both of these goals were realized. In fact, EMC Technology is so pleased with their BTU Fastfire Furnace and KIC Prophet System that they use them as a sales tool. The Prophet System instantly verifies the stability and repeatability of the Fastfire furnace to prospective customers and gives EMC Technology the opportunity to show off the robustness of their process.