Prototyping Techniques for Etched-Foil Heaters

MINCO

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Abstract

Etched-foil heaters provide excellent temperature control and uniformity in a broad range of applications. Their thin profile and foil elements contribute to fast warm-up, consistent heat distribution, and extended heater life. To achieve ideal performance, however, the heater must be properly configured to the thermal demands of the application. The complex physics of heat transfer makes it difficult to predict all aspects of system performance in the early design stages. Therefore, applications requiring tightly regulated temperature may require extensive prototype work. This white paper presents some tools and techniques to assist in thermal prototyping, which seeks to optimize the heater for desired:

- Initial warm-up and cycle recovery time
- Temperature uniformity or distribution
- Control accuracy

Factors influencing performance may include:

- Total heater wattage
- Heater and sensor positioning
- Profiled and multiple heater elements
- Insulation
- Controller type

Analytical Methods

Numerical analysis can eliminate part of the cost and lead time of repeated bench trials with actual equipment. Two analytical methods are:

Thermal Transfer Estimation Programs

Thermal estimation programs use simplified heat transfer equations to provide initial estimates of total wattage requirements. They consider warm-up and process heat requirements, plus losses due to convection, and radiation.

Thermal estimation programs can yield a good starting value for heater wattage but usually fall short of an exhaustive analysis. They necessarily oversimplify both the description of the heater/heat sink and the heat loss formulas. However, wattage estimation programs should often be your first design step as they are not time consuming and relatively inexpensive to get a benchmark for prototyping.

Finite Elements Analysis (FEA)

Computerized FEA more accurately simulates thermal systems. It subdivides the heater and hardware into discrete elements and calculates the thermal profile of each element. It can model both steady state and transient conditions, in two or three dimensions.

Advantages of FEA include:

- Simulation of temperature changes too rapid for ordinary sensors to handle, or determination of temperature in inaccessible locations.
- The ability to fine-tune the model by comparing predictions with observed data, and derive solutions with fewer hardware iterations.
- Experimental variations on a defined model.
- Assistance in laying out profiled heater patterns. Profiling is the addition of extra wattage in high-loss areas to equalize temperature. Higher wattage around the perimeter of a plate, for instance, will compensate for edge losses. One approach which employs FEA is to measure gradients produced by a non-profiled heater, then work backward from this data to develop a model for profiling (Figure 1).

FEA does have some limitations:

- Even the best model cannot account for all factors operating on and in the system.
- Depending on design complexity, FEA can be more expensive and time consuming than experimentation.
- FEA never fully replaces bench testing of heaters. You may still need to make more than one hardware iteration for ideal profiled patterns.

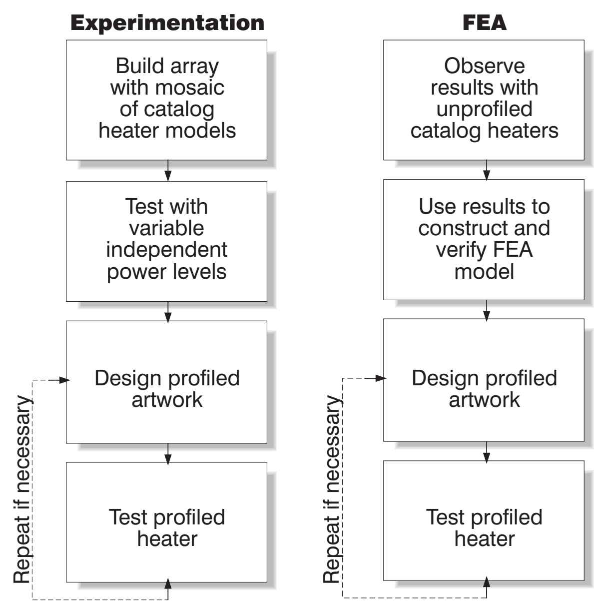

Figure 1: Alternative approaches to profiling heaters

Experimentation

The most accurate approach to heater design is the most direct: mount heaters to the heat sink, power them, and test operating parameters until the system behaves as desired.

A typical test setup will include:

- The heated device
- Heaters
- Temperature measurement instruments
- Power supply (AC or DC)
- Controller

Temperature monitoring

Experiments must produce data, and you will need some means to observe and/or record temperatures in your system. Thin, flexible RTDs, thermocouples, or thermistors are often cost effective sensors to detect temperatures.

But in many instances you must measure temperature gradients across whole surfaces, not single points. Infrared imaging answers this need. A thermal video system can vividly reveal temperature gradients in both static and dynamic situations (see page 7). It can resolve temperature differentials within a fraction of a degree and provides video output for taping of test results in addition to live display. Furthermore, the imager's isothermal maps can furnish solid empirical data to verify or improve FEA models.

Thermal imaging does require line-of-sight access to the heated area. Because heater mounting hardware and housings will affect heat loss, heaters must operate in the actual equipment for reliable observations. Where thermal imaging cannot "see" the heater, you may want to monitor temperature with an array of sensors connected to a multichannel recorder or data acquisition system.

Heaters

Many companies offer off-the-shelf stock heaters in a variety of sizes and insulation packages, including polyimide, silicone rubber, mica, optically-clear polyester, or PTFE.

If the size or shape of your heat sink precludes using a single standard heater, you can often construct a mosaic to cover the surface.

Grouped etched-foil heaters can also mimic profiled designs. You increase power to certain heaters until temperature stabilizes in the desired pattern. The resulting power settings tell you how to profile the watt density zones in a custom design.

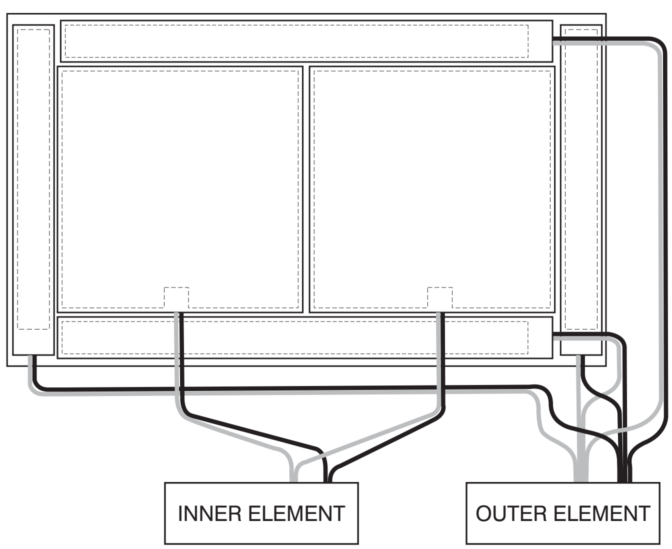

Figure 2: Test setup for heater profiling analysis

In the setup shown above (Figure 2), the first variable AC power supply (e.g. "Variac") drives the inner elements, while the second separately powers the outer elements. Adjusting the power to give uniform watt density produces the thermal profile on the following page (Figure 3). Notice the cooler edges.

Operating the outer heaters at a higher watt density (higher watts per unit area, not necessarily higher total wattage) cancels the edge losses for more uniform temperature (Figure 4):

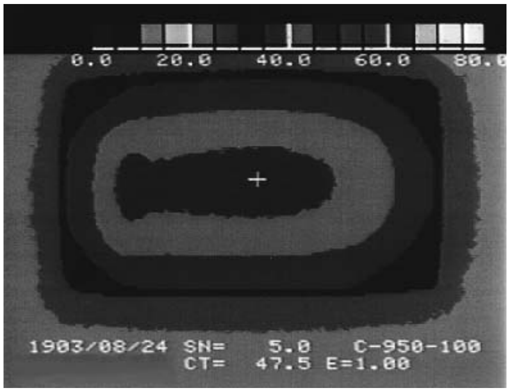

Figure 3: Temperature map, uniform wattage

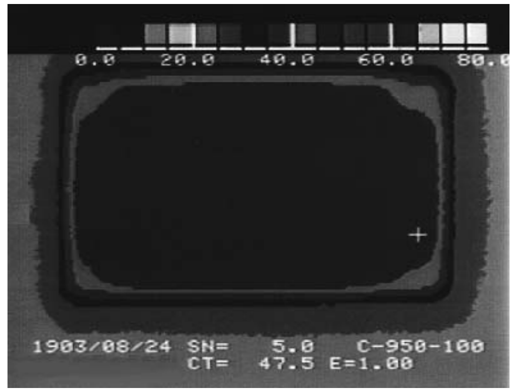

Figure 4: Temperature map, profiled wattage

Once the thermal system behaves as desired, record the power settings for each element. Etched element heater manufacturers can then reproduce the watt pattern in a custom single-element heater (narrower strands produce higher watt density) (Figure 5):

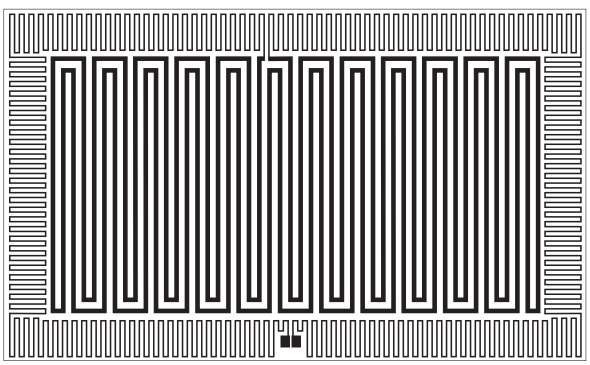

Figure 5: Heater profiled for higher wattage at edges

Note that you can change the wiring to place Variacs between controllers and heaters for simultaneous testing of wattage and control methods provided that the controller furnishes AC power, not DC, to the heater. Power resistors or rheostats in series with the heater can be used to scale DC (or AC) voltage.

Odd-shaped heat sinks may require custom heaters for profile testing. Although this approach incurs the setup cost of a custom heater, the overall price tag may be less than consulting fees for FEA.

The custom heater below has a guard element running along both the inner and outer edges in addition to the central heating element. Each element operates from its own power supply (Figure 6):

As with the simple rectangular heater, the finished design will have a single profiled element (Figure 7).

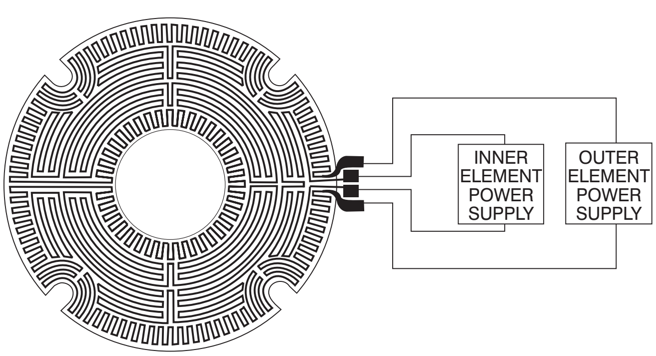

Figure 6: Custom dual-element heater for profile testing

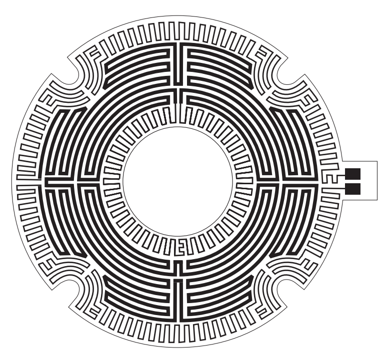

Figure 7: Resulting profiled design

Controller

A comparison of control methods, both mechanical and electronic, is too broad a topic for this white paper. There are many different controller options available on the market, each with unique options for different applications. The best way pick one is to assess your control needs for your specific application, and contact a control manufacturer and inquire about available products.

Thermography Services

Some companies offer thermal imaging as a paid consulting service to help you optimize heater designs. You can send your heat sink and associated hardware for testing, or the consulting service can bring the imager to your plant if necessary. Results can be output on videotape or as color printouts (Figure 8).

Thermal imagers operate by detecting infrared radiation at wavelengths from 2 to 5.6 micrometers. They convert the radiation to patterns of color corresponding to temperature.

Understanding the concept of "emissivity" is essential for accurate thermal imaging. Maximum infrared radiation is emitted from an ideal material called a blackbody. All other materials emit less radiation at the same temperature. A material's emissivity is the ratio of its thermal radiation to that of a blackbody. As a rule of thumb, electrical insulators (like plastics and paint) have high emissivity values, around 0.9. Metals range from 0.05 to 0.4 for shiny surfaces, 0.3 to 0.9 for anodized or oxidized surfaces.

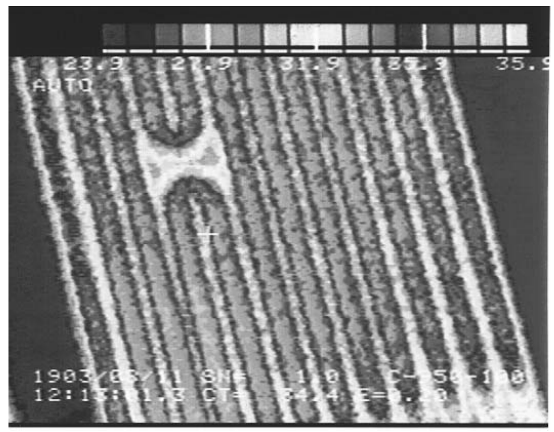

Figure 8: Thermogram of heater element strand

Practical implications of emissivity are:

- Absolute temperature measurement requires emissivity correction. The thermal imager allows such correction if you know the emissivity of the measured surface or the actual temperature of a reference point.
- Measurement of relative temperatures across a single material requires no emissivity correction.
- Shiny surfaces will reflect the thermal radiation of surrounding objects. (It may be necessary to coat the shiny surface with flat black paint to eliminate the reflectance and increase the emissivity.)
- Some optically transparent materials (e.g. window glass) are actually opaque to infrared radiation.

Summary

The broad range of uses for etched-foil heaters makes prototyping a unique experience for almost every application. As this white paper explained, tools exist to make the prototyping process accurate, reliable and in many cases cost-efficient. Thermal estimation programs and Finite Element Analysis (FEA) are practicable methods when prototyping. However, experimentation with heaters, sensors and controllers is the most accurate way to determine the nominal watt density and profile for your application. Thermography is also a useful tool when a custom profiled etched-foil heater is needed.

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